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Review Article

Salmonella Biofilm on Food Contact Surfaces and the Efficacy of Chemical Disinfectants: A Systematic Review

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ABSTRACT

Foodborne illness has always been a major public health concern, usually caused by cross-contamination during food preparation. *Salmonella* is one of the most reported pathogens, which can attach to and survive on food contact surfaces by forming a biofilm. Biofilm formation enhances the persistence of food pathogens and protects them from external threats, and increases their resistance to chemical disinfectants. This systematic review aims to obtain an overview of the *Salmonella* biofilm formation on food contact surfaces and the efficacy of chemical disinfectants based on the latest scientific data. Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines were used to carry out the study. From the review, plastic (91%), stainless steel (64%), and sodium hypochlorite (86%) were most commonly tested. Most chemical disinfectants used in the reported studies were sodium hypochlorite (NaOCl, 100–500 mg/L), hydrogen peroxide (H_2O_2, 0.56%), and benzalkonium chloride (BAC, 100–400 µg/ml). The result showed that *Salmonella* contamination was more common on hydrophobic food contact surfaces like wood and concrete than on hydrophilic surfaces like glass. In addition, the previous studies also revealed that biofilm formation on stainless steel, plastic, and silicone rubber surfaces was not significantly different. Plus, most chemical disinfectants showed inefficacy in eliminating *Salmonella* biofilm at regular concentrations (<0.05%). It shows that frequent cleaning is important to avoid biofilm formation and ensure the maximum efficacy of the sanitisers.

Keywords: Biofilm, disinfectant, efficacy, food contact surface, *Salmonella*

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INTRODUCTION

Foodborne illness or food poisoning is any disease caused by consuming contaminated food or food containing toxins. Foodborne illness is a serious global public health issue. According to the World Health Organization (WHO, 2020), around 600 million people are affected by foodborne illness, and 420,000 deaths are reported yearly. One of the most prevalent bacteria that can cause foodborne disease is *Salmonella* spp. They are rod-shaped, Gram-negative, and non-spore-forming foodborne pathogens (Abeysundara et al., 2018). Food contaminated with *Salmonella* can pose health issues and lead to diarrhoeal diseases. Contaminated eggs and poultry also cause most *Salmonella*-related foodborne outbreaks, and many cases related to fresh produce like tomatoes and leafy vegetables were also reported (Anderson et al., 2011; Painter et al., 2013). *Salmonella* is ubiquitous bacteria that can survive in a dry environment for several weeks and months in water. The cell diameter can range from 0.7 to 1.5 µm and 2 to 5 µm in length (Fàbregaa & Vila, 2013). *Salmonella* grows between 5°C to 45°C, with an optimum growth temperature of 35°C to 37°C.

Salmonella is classified into 2 major serovars: Typhoidal and Non-Typhoidal *Salmonella* (NTS). *Salmonella enterica* serotype Enteritidis (*S.* Enteritidis) and *Salmonella enterica* serotype Typhimurium (*S.* Typhimurium) are the two major NTS that cause salmonellosis. *Salmonella* Enteritidis and *S.* Typhimurium are also classified as broad-host-range serovars that seldom trigger systemic infection; however, they can inhabit the alimentary tract of a wide range of animals (Graziani et al., 2017). Salmonellosis can cause infection in most people, but certain groups are more vulnerable, like youngsters, the elderly, and those with chronic diseases and weakened immune systems. Thoroughly cooking the food can effectively destroy most cells, and freezing may cause damage to *Salmonella*, but it does not guarantee destruction to these microbes as it can survive prolonged storage under freezing conditions (Jay et al., 2003). *Salmonella* cross-contamination can happen during the whole food supply chain: harvesting, processing, transportation, storage, and distribution. Therefore, proper food handling measures are important in every stage of the food supply chain. The cleanliness of food contact surfaces is vital, especially during food preparation. It is where the application of disinfectants and sanitisers is crucial.

Disinfection of food contact surfaces is crucial in maintaining the safety and quality of food products and reducing contamination by foodborne pathogens (Zhang et al., 2021). Most commonly, the disinfectants would have active ingredients such as chlorine, quaternary ammonium compounds, peroxides, peracids, acid anionics, and alcohol that have an antimicrobial effect (Fraser et al., 2021). The general protocol for using chemical disinfectants is to clean the surface, rinse with potable water, apply the disinfectant, rinse again using potable water, and finally apply a food-grade sanitiser. However, the effectiveness of sanitisers and disinfectants may be affected by multiple factors such as temperature, the presence of organic matter, its concentration, and the type of surfaces (Møretrø et al., 2009).

Salmonella biofilm can also affect the efficacy of disinfectants. Once *Salmonella* biofilm is formed, its survival ability and persistence will be enhanced and made very difficult to kill by normal sanitation compared to planktonic cells (Giaouris et al., 2012).

Biofilm is responsible for most food poisoning outbreaks related to food contact surfaces (Chen & Wang, 2020; Shao et al., 2020). Unlike planktonic cells, it is hard to eliminate biofilm as it has higher persistence to sanitiser and disinfectant. In addition, *Salmonella* spp. has been linked as the causative agent for foodborne illness in many cases in recent years (Akinola et al., 2020), and the formation of biofilm on food contact surfaces certainly contributes to cross-contamination and increases the risk of a foodborne outbreak (Lee et al., 2020). Therefore, many studies were conducted to identify the characteristics of biofilm and the effectiveness of disinfectants on it. Therefore, this research aims to obtain an overview of the *Salmonella* biofilm formation on food contact surfaces and the efficacy of chemical disinfectants based on the latest scientific data systematically extracted from authoritative publications databases.

METHODS

Data Sources and Search Strategy

The preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guideline was used for the study. The literature search was conducted on ScienceDirect, PubMed, and Scopus using specific search terms (Table 1). Keywords used were *Salmonella*, biofilm, disinfectants, and food contact surface.

Table 1
The search string used for the systematic review process

Databases	Keywords used
ScienceDirect	Title, abstract, keywords: ("*Salmonella*") AND ("biofilm") AND ("food contact surface*") AND ("disinfect*" OR "clean*") AND ("resist*" OR "surviv*" OR "inactiv*")
Scopus	OR "infectioncontrol" OR "cross infection") AND ("resist*" OR "surviv*" OR "inactiv*"))
PubMed	(*Salmonella*) AND (biofilm) AND (food contact surface*) AND (disinfect* OR clean* OR decontamina* OR sanitiz*) AND (resist* OR surviv* OR inactiv*)

Inclusion and Exclusion Criteria

Studies were included if they focused on *Salmonella* biofilm on food contact surfaces; the prevalence of *Salmonella* biofilm can be calculated; are written in English; focusing on the *Salmonella* biofilm sensitivity to chemical disinfectants; and were published between 2010 to 2021.

Studies were excluded if the articles were unrelated to *Salmonella* contamination; samples were collected from other resources instead of food contact surfaces; specific pathogenic bacteria and the sample sources were not reported; focusing on physical disinfectants; and published in non-English language journals.

Data Extraction

In this review, the data extraction focused on relevant descriptive and quantitative variables from the selected manuscripts. The variables include the *Salmonella* strains, food contact surface types, total samples collected, disinfectant types and concentrations, and the bacterial count of the *Salmonella* strains. The extracted data analysis was conducted by reading the full articles and then narrowing them with specific search terms. Only relevant information was synthesised and summarised in the result of this study.

RESULTS AND DISCUSSION

General Finding and Results of Search

The online database search on ScienceDirect, Scopus, and PubMed was completed in September 2021, limiting studies from 2010 to 2021. After a proper screening process, only 11 articles were included in the review (Figure 1).

Among 11 articles included in the literature review, only 1 article did not mention the specific serotype of *Salmonella,* while the numbers of articles focused on *S.* Enteriditis, *S.* Agona, *S.* Typhimurium, and *S. Hadar* were 6, 2, 5, and 1, respectively. Four out of

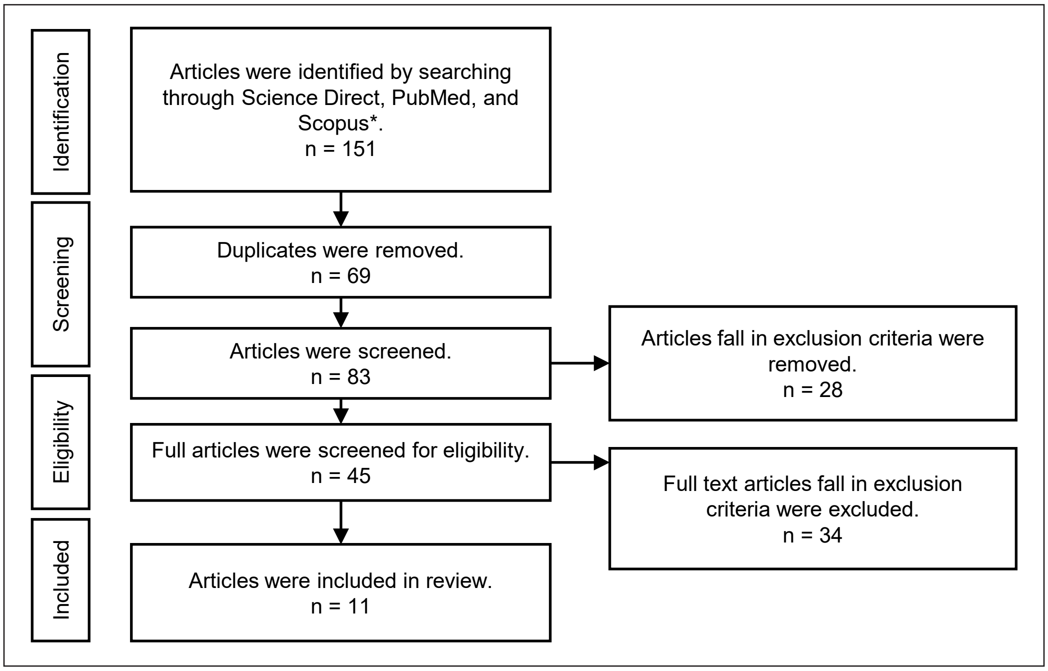

Figure 1. PRISMA flowchart—Selection process of eligible articles
Note. *One additional article was retrieved from Wiley Online Library

11 articles focus mainly on *Salmonella* biofilm formation on food contact surfaces, 2 articles focus on chemical disinfectant efficacy on *Salmonella* biofilms only, and 5 articles focus on *Salmonella* biofilm formation and chemical disinfectant efficacy on *Salmonella* biofilms.

A total of 9 types of surfaces were tested in the studies. Plastic is the most studied food surface area (10/11), followed by stainless steel (7/11), glass (4/11), silicon rubber (2/11), concrete (2/11), and tile (2/11) (Table 2). Several types of plastic were used as the surface for the biofilm formation: polycarbonate, polystyrene, polyvinyl chloride, polyethene, and polypropylene. Most authors did not specify the constituents of surface materials used in their study. Only Corcoran et al. (2013a; 2013b) mention borosilicate glass and glazed tile.

Table 2
Food contact surfaces and types of chemical disinfectants extracted from the articles

Types of surfaces	Article numbers
1. Plastic	10/11
2. Stainless steel	7/11
3. Glass	4/11
4. Silicone rubber	2/11
5. Concrete	2/11
6. Tiles	2/11
7. Wood	1/11
8. Granite	1/11
9. Formica laminate	1/11
Types of chemical disinfectants	
1. Sodium hypochlorite (NaOCl)	6/7
2. Benzalkonium chloride (BAC)	2/7
3. Chlorine oxide (Cl_2)	2/7
4. Sodium hydroxide (NaOH)	1/7
5. Triclosan	1/7
6. Peracetic acid	1/7
7. Ammonium quaternary compound (QUAT)	1/7
8. Chlorine (Cl_2)	1/7

As for the articles that evaluate the efficacy of chemical disinfectants, sodium hypochlorite (NaOCl) was most commonly used (6/7), followed by benzalkonium chloride (BAC) (2/7) and hydrogen peroxide (H_2O_2) (2/7) (Table 2). In addition, Singla et al. (2014) studied the effective concentrations of ozonated water and organic acids against the growth of bacterial pathogens.

Biofilm Formation on Food Contact Surfaces

The outcome of *Salmonella* biofilm adherence on food contact surfaces is presented in Table 3. Corcoran et al. (2013b) reported that all tested strains of *S.* Agona, *S*. Typhimurium, and *S.* Enteriditis formed denser biofilm on tile and concrete (hydrophobic) and formed less dense biofilm on steel (hydrophilic). In general, *S.* Agona biofilms are denser than *S.* Enteriditis on all five surfaces (glass, stainless steel, polycarbonate, concrete, and tile). *S.* Typhimurium also formed a denser biofilm than *S.* Enteriditis. However, the comparison of *S.* Typhimurium and *S.* Agona biofilm shows a less consistent pattern and overall insignificant differences.

Moreover, Dantas et al. (2018) found that the glass surface is better at preventing *Salmonella* biofilm formation ($P<0.05$) as compared to wood and plastic. After being

Table 3
The selected outcome of Salmonella *biofilm adhesion on food contact surfaces*

Test Organism	**Surface**	**Study**	**Adhesion time (hour)**	**Bacterial count (log CFU/cm²)**
***Salmonella* spp. (without specifying serovars)**	Stainless steel	Ashrafudoulla et al. (2021)	24	6.17±0.04
	Silicon rubber	Ashrafudoulla et al. (2021)	24	6.30±0.08
	Plastic	Ashrafudoulla et al. (2021)	24	6.28±0.05
***S.* Enteriditis**	Stainless steel	Corcoran et al. (2013b)	24	4.73–5.71
		Corcoran et al. (2013a)	48	4.73
		Corcoran et al. (2013a)	168	6.87
		Silva et al. (2010)	12	5.26
	Plastic	Corcoran et al. (2013b)	24	5.20–5.72
		Corcoran et al. (2013a)	48	5.20
		Corcoran et al. (2013a)	168	6.80
	Glass	Corcoran et al. (2013b)	24	4.85–5.61
		Corcoran et al. (2013a)	48	4.85
		Corcoran et al. (2013a)	168	6.73
	Concrete	Corcoran et al. (2013b)	24	6.43–6.74
		Corcoran et al. (2013a)	48	6.43
		Corcoran et al. (2013a)	168	7.65
	tile	Corcoran et al. (2013b)	24	7.02
		Corcoran et al. (2013a)	48	7.02
		Corcoran et al. (2013a)	168	8.04
	Granite	Silva et al. (2010)	12	6.00
***S.* Agona**	Stainless steel	Corcoran et al. (2013b)	24	5.38–6.12
		Corcoran et al. (2013a)	48	5.80–6.12
		Corcoran et al. (2013a)	168	5.29–6.92
	Plastic	Corcoran et al. (2013b)	24	6.03–6.81
		Corcoran et al. (2013a)	48	5.59–6.33
		Corcoran et al. (2013a)	168	5.46–6.67
	Glass	Corcoran et al. (2013b)	24	5.41–6.16
		Corcoran et al. (2013a)	48	5.41–5.81
		Corcoran et al. (2013a)	168	5.91–7.26
	Concrete	Corcoran et al. (2013b)	24	6.08–7.47
		Corcoran et al. (2013a)	48	6.75–7.08
		Corcoran et al. (2013a)	168	7.08–7.59
	tile	Corcoran et al. (2013b)	24	6.94–7.59
		Corcoran et al. (2013a)	48	6.94–7.56
		Corcoran et al. (2013a)	168	7.52–7.87
***S.* Typhimurium**	Stainless steel	Corcoran et al. (2013b)	24	5.46–6.28
		Corcoran et al. (2013a)	48	5.71–6.28
		Corcoran et al. (2013a)	168	6.00–6.59
		Bayoumi et al. (2012)	72	1.63–1.96

Table 3 *(continue)*

Test Organism	Surface	Study	Adhesion time (hour)	Bacterial count (log CFU/cm^2)
	Plastic	Corcoran et al. (2013b)	24	5.92–6.10
		Corcoran et al. (2013a)	48	6.10–6.53
		Corcoran et al. (2013a)	168	6.25–6.30
		Singla et al. (2014)	72	4.20±0.07–6.20±0.05
		Bayoumi et al. (2012)	72	1.74–2.03
	Glass	Corcoran et al. (2013b)	24	5.15–5.41
		Corcoran et al. (2013a)	48	5.15–5.41
		Corcoran et al. (2013a)	168	5.97–6.30
	Concrete	Corcoran et al. (2013b)	24	6.70–7.00
		Corcoran et al. (2013a)	48	6.78–7.00
		Corcoran et al. (2013a)	168	6.93–7.47
	tile	Corcoran et al. (2013b)	24	7.01–7.23
		Corcoran et al. (2013a)	48	7.17–7.23
		Corcoran et al. (2013a)	168	7.62–7.73

washed with disinfectant and hot water, the highest percentage of recovery was seen on wood (60%) and plastic (40%), whereas glass (10%) showed the lowest percentage of recovery of *S.* Enteritidis. The result also suggested that the cleaning procedure did not remove the *Salmonella* biofilm completely. Similarly, Djebbi-Simmons et al. (2019) reported that *S.* Typhimurium survived better on plastic and Formica laminate (hydrophobic surface) than on stainless steel (hydrophilic surface) at drying time of 24 h at medium and high (4 log CFU/cm^2 and 6 log CFU/cm^2, respectively) microbial loads. Furthermore, Silva et al. (2010) noted that the number of *S.* Enteritidis adhered to granite (hydrophobic) was greater than stainless steel (hydrophilic) ($P<0.05$), which were 6.00 and 5.26 log CFU/cm^{2,} respectively. Besides, in between the two types of plastic tested, Singla et al. (2014) recovered more counts of *S.* Typhimurium biofilm from PVC (ranged from 4.5±0.07 to 6.2±0.05 log CFU/g) than from polyethene bag (ranged from 4.2±0.07 to 5.8±0.08 log CFU/g).

In studies by Corcoran et al. (2013a), even though limitation existed as there was incomplete removal of 168h biofilm from coupons by sonication, 168 h biofilm were overall denser than 48 h biofilm on all surfaces (glass, stainless steel, polycarbonate, concrete, and tile) for all *S.* Agona, *S.* Typhimurium, and *S.* Enteritidis tested. Moreover, tile recorded the highest number of pathogens recovered (7.56 and 8.04 log CFU/cm^2 for 48 h and 168 h, respectively). In comparison, stainless steel recorded the least (4.73 and 5.29 log CFU/cm^2 for 48 h and 168 h, respectively) among 5 tested surfaces. Besides, the *S.* Enteritidis strain also formed denser biofilm on 4 (stainless steel, plastics, glass, and concrete) out of

5 surface areas (stainless steel, plastics, glass, concrete, and tile) tested as compared to *S.* Agona and *S.* Typhimurium strains.

In contrast, Rodríguez-Melcón et al. (2018) observed higher *S.* Hadar biofilm formation on a hydrophilic surface (glass) than on a hydrophobic surface (polystyrene) with regards to the biovolume and percentage of coverage. However, other tested microorganisms like *Listeria monocytogenes*, methicillin-resistant *Staphylococcus aureus,* and vancomycin-resistant *Enterococcus faecium* showed no difference in biofilm formation on both surfaces. Further analysis revealed that the percentage of surface coverage, biovolume, and thickness of the *S.* Hadar increased when the incubation time increased.

On the other hand, Ashrafudoulla et al. (2021) reported there is no significant difference among the *S.* Enteriditis biofilm formation on plastic, stainless steel, and silicon rubber ($P>0.05$) at 24 h adhesion times, ranging from 6.17±0.04 log CFU/cm^2 (stainless steel) to 6.30±0.08 log CFU/cm^2 (silicon rubber). In another study, Bayoumi et al. (2012) tested the adherence of *S.* Typhimurium isolated from raw milk and dairy product to stainless steel and polypropylene and found that the type of surface used does not significantly influence the adherence of the pathogen. Although all strains tested were able to adhere to both surfaces, no significant difference was observed between tested surfaces for *S.* Typhimurium (polypropylene and stainless steel). This study also found that the *S.* Typhimurium strain had the highest recovered count (7.34 log CFU/cm^2 on polypropylene and 7.27 log CFU/cm^2 on stainless steel) as compared to *Staphylococcus aureus* and *Cronobacter sakazakii* after 72 h incubation (*S. aureus* and *C. sakazakii* were 5.7 and 5.48 log CFU/cm^2, respectively on polypropylene and 5.23 and 5.44 log CFU/cm^2, respectively on stainless steel).

Biofilm formation often depends on three factors: bacteria cells, type of surfaces, and environmental factors. This review highlights the role of food contact surfaces in *Salmonella* biofilm formation and adherence and the effect of chemical disinfectants on the *Salmonella* biofilm. Surface roughness, texture, porosity, and wettability often affect the hydrophobicity of a surface. Generally, a surface will be classified as hydrophobic if its droplet contact angle is higher than 90 degrees; however, hydrophilic surfaces have less than 90 degrees of droplet contact angle measurement (Chieng et al., 2019). Six out of nine articles agreed that hydrophobic surfaces are more susceptible to biofilm formation (Silva et al., 2010; Corcoran et al., 2013a; 2013b; Singla et al., 2014; Dantas et al., 2018; Djebbi-Simmons et al., 2019); however, the opposite was observed in Rodríguez-Melcón et al. (2018) while Bayoumi et al. (2012) and Ashrafudoulla et al. (2021) found no significant difference in biofilm formation on hydrophobic and hydrophilic surfaces.

The result showed there is a trend that biofilms are more likely to form on hydrophobic surfaces than on hydrophilic surfaces, which is under numerous studies (Cerca et al., 2005; Di Ciccio et al., 2015; Delaviz et al., 2015). It is because most bacterial cell wall proteins adhere easily to a hydrophobic surface, which results in a strong binding force, thus, allowing the formation of more abundant and profuse biofilms (De-la-Pinta et al., 2019). Nevertheless, the variability of the results may be due to several reasons, including high variability in testing procedure, types of tested *Salmonella* strains, and physiochemical properties of the microbes. Besides, most studies did not report information regarding the degree of surface hydrophobicity, which significantly impacts biofilm adherence. A general name such as plastic was used in some studies despite there being at least 7 types of plastic available, and each has its distinct characteristics (Dantas et al., 2018; Djebbi-Simmons et al., 2019; Byun et al., 2021).

Chemical Disinfectants' Efficacy

Selected chemical disinfection efficacy against *Salmonella* biofilm on food contact surfaces is summarised in Table 4. Bayoumi et al. (2012) noted that applying 250 mg/L of NaOCl for 30 s disinfected all *S.* Typhimurium planktonic cells on stainless steel and polypropylene. Although the same amount of NaOH cannot completely remove *S.* Typhimurium biofilm on both surfaces, it showed more than 6 log CFU/cm^2 reduction, which was significant ($P<0.05$).

Byun et al. (2021) studied the efficacy of chlorine-based disinfectants against *S.* Enteriditis biofilm formed on stainless steel, silicone rubber, and plastic and found that the average population of *S.* Enteriditis biofilm decreased significantly ($P<0.05$) on all tested surfaces as the disinfectant concentration increased from 10 to 100 µg/mL and reaction time increased from 1 to 5 min. On stainless steel, a minimum 3.77 log CFU/cm^2 reduction was shown by NaOCl and not detected by ClO_2. On plastic, a minimum 3.50 log CFU/cm^2 reduction was shown by NaOCl and 5.49 log CFU/cm^2 by ClO_2. Silicon rubber showed the least minimum reduction among tested surfaces: 3.21 log CFU/cm^2 by NaOCl and 5.20 log CFU/cm^2 by ClO_2. The results indicated that ClO_2 is more effective than NaOCl at removing *S.* Enteriditis biofilm from stainless steel, followed by plastic and silicon rubber.

Corcoran et al. (2013a) reported a reduction in cell counts increased as exposure time (up to 90 minutes) to disinfectant increased for 48h biofilm. Nevertheless, NaOCl (500 mg/L) and BAC (0.02%) were not effective in eliminating 48h *Salmonella* biofilm as only sodium hydroxide (1 M) demonstrates complete elimination. No disinfectants fully eradicate 168h biofilm or achieve a ≥4 log reduction.

Silva et al. (2010) observed greater efficacy ($P<0.05$) of NaOCl (100 mg/L of total available chlorine, pH=10) and peracetic acid (60 mg/L, pH=3) than the QUAT (200 mg/L, pH=9). In addition, no significant difference in disinfectant efficacy against *S.* Enteriditis that adhered to granite and stainless-steel surfaces was observed.

The study by Djebbi-Simmons (2019) showed that H_2O_2 (0.88%, 10 min) was able to eradicate *S.* Typhimurium biofilm on all tested surfaces completely, whereas NaOCl (0.0095%, 2 min) achieved 31–32% and 34–35% disinfection efficacy against long-term

Table 4
Selected chemical disinfection efficacy against Salmonella *biofilm on food contact surfaces*

Test Organism	Surface	Study	Disinfectant	Concentration	Exposure time	*LRV (log CFU/cm^2)
***S.* Enteriditis**	Stainless steel	Byun et al. (2021)	NaOCl	10–100 mg/L	1–5min	0.96–4.91
		Byun et al (2021)	ClO_2	10–100 mg/L	1–5min	1.38– >6.00
	Plastic	Byun et al (2021)	NaOCl	10–100 mg/L	1–5min	0.97–4.20
		Byun et al (2021)	ClO_2	10–100 mg/L	1–5min	1.14– >6.00
		Rodrigues et al (2011)	NaOCl	6.3–12.5 µg/ml	-	>6.00
		Rodrigues et al (2011)	BAC	100.0-400.0 µg/ml	-	>6.00
		Rodrigues et al (2011)	H_2O_2	5.6-90.0 mg/ml	-	>6.00
		Rodrigues et al (2011)	Triclosan	>4000 µg /ml	-	<6.00
	Concrete	Corcoran et al (2013a)	NaOCl	500 mg/L	10–90min	0.35–0.79
		Corcoran et al (2013a)	NaOH	1 M	10–90min	0.79–0.84
		Corcoran et al (2013a)	BAC	0.02%	10–90min	0.10–0.19
***S.* Agona**	Concrete	Corcoran et al (2013a)	NaOCl	500 mg/L	10–90min	0.13–0.97
		Corcoran et al (2013a)	NaOH	1 M	10–90min	1.66–7.66
		Corcoran et al (2013a)	BAC	0.02%	10–90min	0.03–0.97
***S.* Typhimurium**	Stainless steel	Bayoumi et al. (2012)	NaOCl	250 mg/L	30s	>6.00
		Djebbi-Simmons	NaOCl	0.0095%	2min	0.68–3.85
		Djebbi-Simmons	H_2O_2	0.88%	10min	>6.00
	Plastic	Bayoumi et al. (2012)	NaOCl	250 mg/L	30s	>6.00
		Djebbi-Simmons	NaOCl	0.0095%	2min	0.73–3.79
		Djebbi-Simmons	H_2O_2	0.88%	10min	>6.00
		Singla et al (2014)	Malic acid	4.1–4.3%	-	>6.00
		Singla et al (2014)	Acetic acid	4.7–4.9%	-	>6.00
		Singla et al (2014)	Citric acid	4.1–4.3%	-	>6.00
		Singla et al (2014)	Lactic acid	5.2–5.3%	-	>6.00
		Singla et al. (2014)	Ozonated water	2.0–2.2 ppm	-	>6.00
	Concrete	Corcoran et al (2013a)	NaOCl	500 mg/L	10–90min	0.15–1.11
		Corcoran et al (2013a)	NaOH	1 M	10–90min	1.50–7.63
		Corcoran et al (2013a)	BAC	0.02%	10–90min	0.06–0.83
	Formica laminate	Djebbi-Simmons	NaOCl	0.0095%	2min	0.63–2.74
		Djebbi-Simmons	H_2O_2	0.88%	10min	>6.00

Note. *Log reduction value

stationery (14 days) cell at 2 and 24 h, on plastic and stainless-steel surfaces respectively, but only 26% on Formica laminate surface when the initial microbial load was high. The log-phase cell (6 h) showed the least resistance to NaOCl disinfection among the 3 growth-phase cells.

In a study by Rodrigues et al. (2011) comparing the minimum biofilm eradication concentration (MBEC) of 4 disinfectants, NaOCl showed the lowest MBEC for all *S.* Enteriditis strains tested, ranging from 6.3 to 12.5 µg/ml, followed by BAC (100 to 400 µg/ml) and H_2O_2 (5.6-90 mg/ml). On the other hand, disinfection by triclosan showed lower susceptibility since it failed to eliminate any *S.* Enteriditis biofilm even at the maximum concentration (4,000 µg/ml).

Another study by Singla et al. (2014) was conducted to determine the efficacy of disinfectants in reducing biofilm on food contact surfaces such as PVC pipes, polyethene bags, plastic surfaces, and fresh produce. The research discovered that 2 ppm of ozonated water was most effective in inhibiting *S.* Typhimurium biofilm growth, and 2% organic acid is needed to inhibit *S.* Typhimurium biofilm growth. Results also showed that the sensitivity of the tested strain against disinfectant decreased biofilm formation. Interestingly, the study discovered that with a combination of 2% malic acid and 2 ppm of ozonated water, biofilm formation was significantly reduced ($p<0.05$) after 20 h and 40 h exposure.

As for the efficacy of chemical disinfectants, NaOCl has been widely applied in disinfection for its low cost, ease of use, and effectiveness (CDC, 2014). In the present review, despite showing higher efficacy among tested chemical disinfectants, four out of six studies found that NaOCl was less effective in eradicating *Salmonella* biofilm (Silva et al., 2010; Bayoumi et al., 2012; Corcoran et al., 2013a; Djebbi-Simmons et al., 2019). The concentration of NaOCl used ranged from 100 mg/L to 500 mg/L. Although significant reductions were observed, none of the NaOCl used in these studies could fully eliminate *Salmonella* biofilm, even at high concentrations. These results also suggested that NaOCl is less effective in removing *Salmonella* biofilm at regulatory concentration. However, using a high concentration of chlorine-based disinfectant may produce by-products that are potentially harmful to public health, such as chloroform which is probable carcinogenic (CDC, 2014). Plus, sodium hypochlorite is reported to cause inflammation and skin irritation (Chia et al., 2016).

On the other hand, Rodrigues et al. (2011) and Byun et al. (2021) reported that NaOCl was effective against *Salmonella* biofilm. Rodrigues et al. (2011) found that the MBEC of tested NaOCl were lower than recommended concentration, and BAC. In contrast with Djebbi-Simmons et al. (2019), NaOCl in this study also proved to have higher efficacy than H_2O_2. Again, the inconsistency may be due to the high variation of the testing procedure, types of tested *Salmonella* strains, and physiochemical properties of the microbes. Exposure time may act as a factor that affects the efficacy of disinfectants; as shown in the studies by Corcoran et al. (2013a), disinfectant efficacy increases as the contact time increases (up to 90 min). However, it is less applicable in the real-life setting as high costs may be induced and result in inconvenience.

Moreover, Singla et al. (2014) were the only article that studied the disinfectant efficacy of ozonated water on *Salmonella* biofilm and acid. Hence, insufficient data were available to compare disinfectant efficacies between ozonated water and acid and other disinfectants.

Plastic and stainless steel are often used in surface disinfectant efficacy research due to their wide application in household kitchen and food premises, and chemical disinfectant, especially chlorine-based, is readily available and have been used for over a century. Therefore, it is unsurprising that most studies in this review focus on plastic, stainless steel, and chlorine-based disinfectant. However, the efficacy of similar disinfectants is inconsistent in *Salmonella* biofilm-forming ability on similar food contact surfaces. As a result, it is difficult to formulate a statistically valid conclusion regarding the research objective. Nevertheless, the chemical disinfectant included in this review showed less effectiveness in regular concentration. High concentration may enhance the effectiveness, but harmful by-products could be formed; thus, it is not recommended. In short, most food industries use NaOCl as a chemical disinfectant because it is cheap and is proven to reduce the planktonic bacterial number to a safe level. However, due to this disinfectant's low efficacy in eliminating biofilm, consistent cleaning is highly critical.

CONCLUSION

In conclusion, despite the variability that existed in reported *Salmonella* biofilm susceptibility on various food contact surfaces and the efficacy of chemical disinfectants, the result showed a trend that hydrophobic food contact surfaces such as wood and concrete are more susceptible to *Salmonella* contamination. Plus, *Salmonella* Enteritidis and *Salmonella* Typhimurium are used in most studies as they are the common outbreak serovars and can contaminate the surface easily. Furthermore, the result also suggested that regular concentrations of chemical disinfectants, like NaOCl, are less effective in *Salmonella* biofilm eradication. High concentration is not encouraged as it may form by-products that affect public health, such as chloroform. It shows that the cleanliness of the food contact surfaces is important, and cleaning should be done regularly to avoid the formation of biofilm.

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