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Review

Prevalence, Antibiotic Resistance, and Control of Pathogenic *Shewanella* in Seafoods ☆

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ABSTRACT

Some *Shewanella* spp. have been classified as emerging pathogens and are a concern for food safety. Species such as *Shewanella algae* and *Shewanella putrefaciens* are known to cause soft tissue necrosis and invasive infections from marine exposure. Seafood consumption has been linked to *Shewanella* illnesses, raising concerns about public health risks. Seafood consumption has been on the rise in recent years due to its reported benefits and overall positive health and nutritional perception of consumers. However, an emerging seafood pathogen, *Shewanella* spp., threatens the safety of these products. This review synthesizes existing data on: (i) the prevalence of potentially pathogenic *Shewanella* spp. in oysters and seawater from locations around the world, (ii) the antibiotic resistance profiles of isolates from diverse geographic regions, and (iii) processing treatments to reduce *Shewanella* in seafoods. Findings suggest that *Shewanella* spp. are widespread in seafood and marine environments. Studies have also shown that over time *Shewanella* spp. have become more resistant to β-lactam antibiotics such as penicillin, ampicillin, and vancomycin. This growing antibiotic resistance is largely attributed to the overuse and misuse of antibiotics in aquaculture and agriculture, contributing to the emergence of multiple-antibiotic-resistant (MAR) bacteria in seafood. The presence of MAR bacteria limits treatment options in the event of infection by *Shewanella* and other pathogenic bacteria underscoring the need for better control measures in seafood production to ensure public health safety.

Shewanella is a genus of Gram-negative, facultatively anaerobic, rod-shaped bacteria of varying shapes and sizes with significant environmental versatility and pathogenic potential. Over the past few decades, certain *Shewanella* species have emerged as human pathogens, raising concerns, especially in relation to seafood consumption and handling. These aquatic microorganisms are globally distributed and often found in marine and freshwater environments (Heidi & Gralnick, 2007). According to the NCBI database, over 100 species are assigned to the genus; however, uncertainty remains about how many are truly pathogenic to humans. Of those species, five have been documented as being associated with human infection: *S. algae*, *S. putrefaciens*, *S. xiamenesis* (Zong, 2011), *S. haliotis*, and *S. upenei* (Zhang et al., 2018). Notably, *Shewanella* has been readily found in raw oysters, freshwater fish, shellfish, and infection sites (i.e., cuts and abrasions) making *Shewanella* an emerging concern for food safety (Cape May County Department of Health, 2020; Myung et al., 2009).

This review focuses on the prevalence of *Shewanella* spp. in seafood and its surrounding environments. Specifically, we examined the clinical manifestations of infections caused by *S. algae* and *S. putrefaciens,* including skin and soft tissue infections, sepsis, and other invasive diseases (Holt et al., 1997; Huang et al., 2018; Troy et al., 2015; Yu et al., 2022). Illnesses have been documented from the consumption of raw clams (Heller et al., 1990), lightly cooked shark meat (Wang et al. 2004), and raw fish (Liu et al., 2019; Myung et al., 2009; Otsuka et al., 2007; Shimizu & Matsumura, 2009). *Shewanella algae* is most commonly associated with illness, particularly soft tissue infections, bone and joint infections, ear infections, lower respiratory tract infections, and occasionally gastroenteritis (Holt et al., 1997; Huang et al., 2018; Troy et al., 2015). It is a flesh-eating bacterium that attacks people who are often immunocompromised with renal failure, malignancies, and diabetes mellitus (Kitaoka et al., 2019; Lee et al., 2016; Takata et al., 2017; To et al., 2010). Another species, *S. putrefaciens*, has also been associated with pathogenicity in humans but is fre-

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quently recovered from nonhuman sources such as marine waters, freshwater, oil, gas, soil, fish, dairy, poultry, and beef products (Khashe and Janda, 1998; Vogel et al., 1997). In addition to clinical concerns, *S. putrefaciens* presents a unique challenge to the food industry due to its ability to form biofilms on food processing equipment, further complicating sanitation efforts to ensure the safety of seafood production (Bagge et al., 2001; Gram et al., 1999).

Infections linked to seafood consumption are believed to occur primarily through infection, in which viable *Shewanella* organisms colonize or invade host tissues following ingestion. There is currently no substantial evidence supporting that *Shewanella* spp. cause intoxication (illness from preformed toxins) or toxicoinfection (illness from in vivo toxin production after ingestion), as no specific toxins have been clearly identified in association with gastrointestinal illness (Ng et al., 2022; Yu et al., 2022). Instead, human illness appears to result from the direct pathogenicity of the organism itself, particularly in immunocompromised individuals or those with underlying health conditions (Yu et al., 2022).

Shewanella spp. can be isolated from a wide range of aquatic temperate environments around the globe causing it to be an emerging human pathogen of concern. Key virulence determinants include the ability to form robust biofilms, which protect bacterial communities from host immune defenses and antimicrobial agents, facilitating persistent colonization on biotic and abiotic surfaces (Abdulmaged et al., 2024). Many pathogenic *Shewanella* strains produce extracellular enzymes such as proteases, lipases, and hemolysins, which degrade host tissues and enable bacterial invasion (Paździor, 2016; Reda et al., 2024; Vignier et al., 2013). Siderophore-mediated iron acquisition systems are also important, allowing *Shewanella* to thrive in iron-limited environments such as the human body (Paździor, 2016). Additionally, some strains possess secretion systems (notably Type II and Type VI) that deliver effector proteins into host cells to modulate immune responses and promoting infection (Paździor, 2016; Reda et al., 2024). Motility, mediated by flagella, enhances colonization and dissemination, while resistance to oxidative stress further supports survival within host tissues.

The pathogenic potential of *Shewanella* is both species and strain-dependent. *Shewanella algae* and *S. putrefaciens* are most frequently implicated in human infections, including wound infections, bacteremia, and soft tissue infections, with *S. algae* generally considered more virulent due to its higher hemolytic activity and greater resistance to environmental stresses (Fernandes et al., 2023; Müller et al., 2023). In contrast, other species such as *S. baltica* and *S. oneidensis* are more commonly associated with environmental or spoilage roles and are rarely linked to clinical disease. Nonpathogenic strains typically lack key virulence factors, such as potent hemolysins or efficient biofilm-forming capabilities, and are less able to cause invasive disease. The distinction between pathogenic and nonpathogenic *Shewanella* strains is thus determined by the presence, expression, and regulation of these virulence determinants, as well as their adaptability to host environments.

In addition to their virulence traits, *Shewanella* spp. have undergone notable taxonomic revisions over time. *Shewanella putrefaciens* was originally classified as *Pseudomonas putrefaciens, Alteromonas putrefaciens,* and *Achromobactin putrefaciens* (Derby & Hammer, 1931). *Shewanella algae* were first described as *Shewanella alga* by Simidu et al. in 1990 and later renamed *S. algae* (Nozue et al., 1992). Today, *S. algae* are more frequently isolated from clinical samples than *S. putrefaciens*. These species can be differentiated based on their phenotypic characteristics; *S. algae* typically form mucoid, beta-hemolytic colonies at 37 °C and can grow at elevated NaCl concentrations and temperatures, while *S. putrefaciens* is usually nonhemolytic or alpha-hemolytic and may require up to 72 h to display delayed hemolysis (Holt et al., 2005; Khashe and Janda, 1998; Ong et al., 2014). Hemolytic activity may serve as a useful indicator of virulence, particularly for clinical isolates of *S. algae* (Myung et al., 2009).

The presence of *Shewanella* spp. in clinical cases, particularly *S. algae* and *S. putrefaciens* has been widely reported (Holt et al., 2005). However, there is very limited information available on the prevalence and antibiotic resistance of this bacterium in seafood. The purpose of this review was to focus on the information available on pathogenic *Shewanella* spp. in seafood by highlighting geographical prevalence, antibiotic resistance, and current and future food safety mitigation strategies.

Geographical prevalence of *Shewanella*

Recent studies have provided more insight into the prevalence and geographic distribution of *Shewanella* infections. A comprehensive review published in 2022 analyzed 273 cases of *Shewanella* infection from 125 studies worldwide, finding that exposure to marine environments was reported in 43.59% of cases, with recreational activities, occupational exposure, and seafood ingestion identified as key risk factors (Yu et al., 2022). Similarly, Ng et al. (2022) described 128 cases of *Shewanella* infection in Hong Kong, further highlighting the clinical relevance and diverse presentations of these infections. Epidemiological studies from regions such as Australia and China have also documented the incidence, risk factors, and outcomes associated with *Shewanella* spp. infections (Laupland et al., 2022; Liu et al., 2019). Places with hot summer weather have the highest number of reported cases including Southern Europe, Southeast Asia, and Southern Africa (Yu et al., 2022). Seasonal prevalence can be considered species specific. For example, *S. algae* and *S. putrefaciens* are more commonly isolated during warmer seasons (Li et al., 2024; Torri et al., 2018), while species like *S. baltica* may not follow a clear seasonal trend (Vogel et al., 1997; Ziemke et al., 1998). Overall, *S. algae* shows the most notable seasonal pattern in temperate climates, although local environmental conditions and seafood harvesting practices also play a role (Paździor, 2016; Reda et al., 2024). Frequent environmental and clinical isolation of *Shewanella* spp. is directly related to food safety, as our food is often grown and produced in these environments. For instance, seafood, such as oysters, is particularly susceptible to harboring bacteria due to their role in water filtration. This highlights the potential risk to consumers, as the bacteria can be transferred through consumption. Understanding both clinical and environmental detection is crucial in ensuring the safety of food and protecting public health. The forthcoming sections will focus on pathogenic strains of *Shewanella* collected from clinical and environmental sources from Australia, Denmark, China, Iran, and the USA – areas of high seafood consumption.

Africa. A study by Reda et al. (2024) on the infection dynamics of *Shewanella* spp. in Nile tilapia under varied water temperatures (22 °C, 28 °C, and 31 °C) took place in Egypt. They found that *Shewanella* spp. infections in Nile tilapia can cause significant physiological and tissue damage, particularly under suboptimal temperature conditions (Reda et al., 2024). Such infections may compromise fish health, leading to increased susceptibility to secondary pathogens and higher overall microbial loads in aquaculture environments. This is a food safety concern because tilapia is widely consumed globally, and bacterial contamination including *Shewanella* spp. has been identified as a risk factor in both wild and farmed fish. Poor fish health and increased pathogen load can elevate the risk of transmitting foodborne bacteria to consumers, especially if products are inadequately cooked or mishandled.

Australia. McAuliffe et al. (2015) focused on *Vibrio, Aeromonas, Chromabacterium violaceum,* and *Shewanella* spp. isolated from patients presenting to hospitals in Australia's Northern Territory (Table 1). This study measured the relative freque`ncy, characteristics, and antimicrobial susceptibility patterns of these species. Among these four groups, *Shewanella* spp. were the third most frequently isolated, accounting for 13% (61 out of 468) of the total isolates (McAuliffe et al., 2015; Table 1).

Table 1
Summary of geographical prevalence of *Shewanella* species

Country	Samples site	Isolated from	% of Samples Positive[a]	Species	Reference
Australia			13%		McAuliffe et al. (2015)
	Royal Darwin Hospital	Skin soft tissue		*S. putrefaciens*	
	Katherine Hospital	Blood		*S. algae*	
	Gove Hospital	Feces		*S. baltica*	
		Intraabdominal			
		Respiratory			
		Eye			
			76%		Laupland et al. (2022)
	Queensland; 16 hospital and healthcare service regions	Blood cultures		*S. algae*	
				S. putrefaciens	
				17 were not identified to the species level.	
Caribbean Island			16 cases		Vignier et al. (2013)
	Martinique	Blood		21 *Shewanella* spp. not identified to the species level.	
		Pus			
		Joint Fluid			
		Leg surgical site			
		Bronchial aspiration			
		Gastric liquid			
China			128 patients		
	Pamela Youde Nethersole Eastern Hospital (PYNEH)	Intraabdominal specimens		*S. algae*	Ng et al. (2022)
		Skin and soft tissue specimens		*S. putrefaciens*	
		Blood			
		Sputum			
Denmark			61%		
	Danish Coast	Seawater		*S. algae*	Gram et al. (1999)
				S. putrefaciens	
			521 patients		Hounmanou et al. (2023)
	Danish Microbiology Database	Blood		*S. algae*	
		Wound swabs		*S. putrefaciens*	
		Deep soft tissue		Unclassified *Shewanella* spp.	
		Ear			
		Trachea			
		Urine			
		Feces			
India			12.50%		Dutta et al. (2020)
	Retail markets in and around Kolkata, West Bengal	Fresh Shrimp		*S. algae*	
Iran					Taherzadeh et al. (2014)
	Persian Gulf	Neonatal swab		*S. algae*	
Italy			83%		Labella et al. (2013)
	Adriatic Sea	Water from fish farms		*S. algae*	
United States			12%		Richards et al. (2008)
	Delaware Bay	Oyster		*S. putrefaciens*	
				S. algae	
		Seawater		*S. baltica*	
				S. algae	
				S. putrefaciens	
			66.22%		Johnson et al. (2025)
	Chesapeake Bay	Seawater		*S. algae*	
	Horn Point	Oyster		*S. xiamenensis*	
	Honga River			*S. putrefaciens*	
	Tangier Sound			*S. khirikhana*	
	Maryland Coastal Bay			*S. marisflavi*	
	Sinepuxent Bay			11 other *Shewanella* spp.	

[a] The percentages in this column differ, in part, because different isolation methods were used.

Laupland et al. (2022) conducted a comprehensive population-based surveillance study in Queensland, Australia from 2000 to 2019 and provided valuable insights into the incidence and geographical distribution of bloodstream infections (BSIs) caused by *Shewanella* spp. Reporting an incidence of 1 case per million Queensland residents annually, the study confirmed the rarity of these infections while offering novel epidemiological data (Table 1). The distribution of BSIs caused by *Shewanella* spp. in Queensland showed some regional variation. The tropical coastal Torres and Cape area emerged as a hotspot for these infections, reporting the highest rates in the state (Laupland et al., 2022). This pattern aligns with the known preference of *Shewanella* species for warm, marine environments. In stark contrast, no cases were observed in the western outback regions of Queensland, characterized by their arid climate (Laupland et al., 2022). The Greater Brisbane area, despite its larger population, reported low rates of BSIs from *Shewanella* spp. (Laupland et al., 2022). This distribution suggests a strong correlation between environmental factors, particularly climate and proximity to coastal waters, and the incidence of *Shewanella* infections.

Caribbean Island. In the Caribbean, particularly in Martinique, *Shewanella* infections have been reported with notable frequency, often linked to warm marine environments and recreational water exposure. Vignier et al. (2013) documented 16 cases in Martinique and conducted a comprehensive review of 239 additional cases from the literature. The study found that *Shewanella* spp. are part of the marine microflora in warm climates and are increasingly recognized as opportunistic human pathogens. Infections most presented as soft tissue infections, ear infections, or abdominal and biliary tract infections (Vignier et al., 2013). A skin or mucosal portal of entry was identified in 53% of cases, and 44% of patients reported marine exposure. Notably, 79% of patients had underlying health conditions, and bacteremia occurred in 28% of cases. While most patients (87%) recovered, chronic ear infections and a mortality rate of 13% were observed (Vignier et al., 2013).

China. While seawater exposure is a known risk factor for *Shewanella* infections, recent studies suggest that seafood consumption may play a more significant role than previously thought. Ng et al. (2022) conducted a comprehensive study in Hong Kong and found that out of 128 patients with *Shewanella* infections, only 6 had documented seawater contact (Table 1). This finding suggests that direct seawater exposure may not be the primary route of transmission in urban settings. The authors proposed that contaminated seafood from local waters, especially when consumed raw or undercooked, could be a significant route of transmission (Ng et al., 2022). This hypothesis is supported by the high seafood consumption rates in Hong Kong and the favorable climate for *Shewanella* growth in coastal waters (Ng et al., 2022). The study also noted that *Shewanella* infections were more common in summer months, aligning with increased seafood consumption and higher water temperatures (Ng et al., 2022). This comprehensive study from Hong Kong challenges the traditional understanding of *Shewanella* infection transmission routes.

Denmark. Gram et al. (1999) studied the occurrence of *S. algae* and the effects of seawater temperature and culture conditions on its survival in Danish coastal waters. They found that both *S. algae and S. putrefaciens* could be easily and readily isolated in 61% of the samples tested (Table 1). Previously, researchers stated that *S. algae* levels often correlate with water temperature and become undetectable during the cold winter and spring months. However, in contrast, *S. putrefaciens* was still detectable during the winter (Gram et al., 1999). This same study also reported that *S. algae* formed a multilayered biofilm on stainless steel surfaces within a few days. This finding is significant because stainless steel is widely used in the food processing industry, highlighting the potential for contamination and persistence in food production environments. Additionally, the ability of *S. algae* to form biofilms suggests that it may be more resistant to adverse conditions than previously realized (Gram et al., 1999).

Hounmanou et al. (2023) conducted a comprehensive nationwide study in Denmark from 2010 to 2018 and reported 521 cases of *Shewanella* infections, noting a clear correlation between infection rates and seawater temperatures (Table 1). Years with higher coastal water temperatures saw a marked increase in *Shewanella* cases, supporting earlier observations about the temperature-dependent nature of these infections. The geographic distribution of cases showed a higher prevalence in areas with brackish waters (low salinity) and higher water temperatures, particularly along Denmark's coastlines. This pattern suggests that the combination of warmer temperatures and low salinity creates favorable conditions for *Shewanella* growth. The most common clinical manifestations were ear infections (595 cases) and wound infections (424 cases), with *S. algae* being predominant in ear infections. These findings underscore the growing public health concern associated with climate change and rising sea temperatures, emphasizing the need for increased awareness, preventive measures, and potentially mandatory notification policies for these emerging infections (Hounmanou et al., 2023).

India. Dutta et al. (2020) examined the prevalence of *S. algae* in shrimp samples collected from various domestic retail markets in West Bengal, India (Table 1). The researchers found *S. algae* in 8% of the shrimp samples tested (Dutta et al., 2020). Although not particularly high, this prevalence rate is noteworthy, as shrimp is a popular and affordable seafood in India and globally. The study highlighted that *S. algae* isolates were beta-hemolytic, indicating potential virulence (Dutta et al., 2020). The authors emphasized that the presence of *S. algae* in shrimp warrants increased surveillance of this pathogen in clinical samples, especially given the rising occurrence of human infections caused by *S. algae* (Dutta et al., 2020).

Iran. South Iran is known for having a hot and desert-like climate, routinely topping 43 °C (Schwartzstein, 2019), which could be considered too hot for the growth of many *Shewanella* species. Temperatures in southern Iran range from warm to extremely hot for most of the year, with minimal seasonal variation and virtually no cold winter, especially in the coastal and desert regions (Weather Atlas, n.d.). In July, daily average temperatures in southern Iran often exceed 38 ° C, with some areas near the Persian Gulf experiencing extreme heat indices surpassing 50 °C (Di Liberto, 2015; Weather Atlas, n.d.). However, by August, temperatures slightly decrease, averaging around 32 ° C, though the humidity levels can make it feel significantly hotter (Weather Atlas, n.d.). As a mesophilic bacterium, *S. algae* has adapted to a vast number of temperatures (4 °C, 25 °C, 37 °C, and 42 °C), and it is the temperature that plays an important role in determining the pathogenicity of *S. algae* because at 25 °C and 37 °C, this species hemolyzes red blood cells (Tseng et al., 2018).

Taherzadeh et al. (2014) found that a man with a history of swimming in the Persian Gulf had a wound infection caused by *S. algae* (Table 1). From the researcher's understanding, this was the first case of wound infection clearly caused by *S. algae* reported in Iran. This demonstrates the need for further studies to be conducted within the Persian Gulf, and other bodies of water surrounding Iran. The author also stated that in this region, there has only been one other case of wound infection, which was reported in Turkey, and it was shown to be *S. putrefaciens* (Taherzadeh et al., 2014). However, this was identified using an API system, which is an unreliable identification system, as *S. putrefaciens* is the only species listed in the API database. Since the temperature of South Iran matches the favorable survival temperatures of *S. algae,* it is recommended that further studies be conducted to better assess the incidence and levels of *S. algae* and other potentially pathogenic species in the Persian Gulf.

South Korea. Myung et al. (2009) documented a case in South Korea where a patient with liver cirrhosis developed primary *S. algae* bacteremia after ingesting raw seafood. The patient, a 61-year-old man with alcohol-induced liver cirrhosis, developed fever and chills shortly after consuming raw seafood (Myung et al., 2009). Blood cultures revealed *S. algae*, which was confirmed by 16S rRNA sequencing

(Myung et al., 2009). These findings highlight the opportunistic nature of *Shewanella* infections, particularly in individuals with compromised health including those with underlying conditions such as liver, kidney, or other systemic vulnerabilities.

United States. Liu et al. (2019) reported the first case of *S. haliotis* infection in the United States, which was linked to raw salmon consumption. The patient, an 87-year-old man, developed appendicitis after eating raw salmon 10 days earlier. *Shewanella haliotis* was isolated from the patient's appendix and identified through 16S rRNA gene sequencing (Liu et al., 2019). This case is noteworthy as it represents the first human infection by *S. haliotis* reported in the United States and only the second reported case worldwide. The patient's age and the consumption of raw salmon highlight the potential risk of *Shewanella* infections from consuming raw seafood, particularly in elderly or immunocompromised individuals (Liu et al., 2019).

Richards et al. (2008) found an abundance of presumptive *Shewanella* in oysters and seawater samples during a 2-year *Vibrio* study conducted in the Delaware Bay (Table 1). A total of 1,421 bacterial isolates from seawater and shellfish were screened as potential *Shewanella* by biochemical analysis and hemolysis on blood agar plates. Twelve percent (170) of the isolates were identified as presumptive *S. putrefaciens* using the API 20E identification system which lacked discrimination for the various species of *Shewanella*. PCR and 16S rRNA sequencing of selected isolates identified limited hits for *S. putrefaciens* or *S. algae* from the original 1,421 bacterial isolates. Beta hemolysis was observed for isolates identified by 16S rRNA sequencing as *S. algae* and *S. baltica* (Richards et al., 2008). Typically, it has been reported that *S. baltica* will not grow at 37 °C, but three strains from the Delaware Bay grew readily at 37 °C which suggests that this species has adapted either to warmer climates or that some other bacterium shares the same 16S rRNA gene sequence as *S. baltica*. Another study showed that *S. baltica* can grow at 0 °C, 15 °C, 20 °C, and 37 °C; however, the growth rate was slower at 37 °C (Vogel et al., 2005).

Johnson et al. (2025) recovered a diverse array of *Shewanella* isolates from oysters and seawater samples collected between 2019 and 2021 during a study in the Chesapeake and Maryland Coastal Bays (Table 1). A total of 1,344 bacterial isolates were initially screened for presumptive *Shewanella* using biochemical methods (oxidase test) and hemolysis on blood agar plates (Johnson et al., 2025). Molecular identification through 16S rRNA sequencing confirmed 16 different *Shewanella* spp., with 3 species that can be human pathogens (*S. algae, S. xiamenensis,* and *S. putrefaciens*). *Shewanella khirikhana* (49%) and *S. marisflavi* (19%) were the most prevalent species identified. Beta hemolysis was observed in 45% of the isolates, with *S. algae* and *S. khirikhana* displaying a high portion of beta hemolysin, while alpha hemolysis was observed in 54% of the isolates, with *S. marisflavi* displaying a high portion of alpha hemolysin, suggesting potential pathogenicity. Interestingly, *S. khirikhana* had not been previously reported in this region, marking a novel finding for the Mid-Atlantic coastal areas. Seasonal patterns revealed peak abundances of *Shewanella* in oysters during the spring (April to June) and in seawater during the summer (May to August). The study also identified correlations between *Shewanella* abundance and environmental parameters, including a positive association with temperature and a negative association with dissolved oxygen (Johnson et al., 2025), emphasizing the role of environmental conditions in shaping the distribution and potential risks associated with these bacteria.

Bauer et al. (2019) provided unique insights into the impact of *S. algae* infections on healthy individuals under extreme conditions through a case study involving Naval Special Warfare (NSW) trainees in California. Six cases of *S. algae* infection were reported in young, healthy Naval Special Warfare trainees in San Diego, California, from 2014 to 2016. These infections occurred during consecutive El Niño seasons which are characterized by warmer water temperatures. The infections exclusively affected male NSW trainees undergoing Basic Underwater Demolition/SEAL (BUD/S) training. These individuals were subjected to extreme physiological stress, particularly during a challenging 5-day exercise known as "Hell Week". The infections occurred in the coastal waters of the Pacific Ocean in Coronado, California. Notably, these waters are typically colder, with average ocean temperatures between 15.5 °C and 20 °C; however, where the training took place, authors noted temperatures approximately 2 °C above average. This increase in temperature may have created more favorable conditions for *S. algae* growth and infection (Bauer et al., 2019).

Edwards & Figueroa (2024) reported six cases of *Shewanella* bacteremia in hospitals in New Orleans, underscoring the organism's presence in the Gulf Coast region. Among these, *S. algae* was isolated in four cases, *S. putrefaciens* in one, while the remaining case did not specify the species. Unlike earlier reports from California, where *Shewanella* infections affected healthy individuals exposed to extreme environmental conditions, the Louisiana cases predominantly involved patients with underlying conditions. Five patients had chronic lower extremity wounds or skin and soft tissue infections, and two had cirrhosis of the liver. Additional risk factors included diabetes, hypertension, kidney disease, trauma, and, in one case, environmental water exposure associated with a bullous necrotizing skin infection (Edwards & Figueroa, 2024).

Antibiotic resistance profiles of *Shewanella* spp.

Considerable antibiotic resistance information is available for some pathogens, like *Vibrio* and *Aeromonas* species in seafood, but antibiotic resistance in *Shewanella* spp. has little documentation. The low documentation may be due to the state health departments not being required to report *Shewanella* infections to the Centers for Disease Control and Prevention (CDC) because it is not officially listed as a reportable pathogen. According to the CDC, nearly 3 million individuals in the United States become infected with a bacterium that is resistant to antibiotics, causing more than 35,000 deaths per year (CDC, 2020). In the European Union, over 25,000 deaths per year occur in individuals who have been infected with a bacterium that is resistant to antibiotics (CDC, 2019). As a result of the excessive use of antibiotics in humans, agriculture, and aquaculture systems, many bacterial genera have emerged as antibiotic-resistant during the past few decades (Cabello, 2006).

Shewanella spp., like many Gram-negative bacteria, employs several mechanisms to resist antimicrobial agents. These mechanisms include efflux pumps, enzymatic degradation, biofilm formation, metabolic bypass, target site modification, and resistance to heavy metals (Sher et al., 2025). *Shewanella* spp. possess efflux pumps, which are integral membrane proteins that actively pump out a wide variety of antimicrobial agents, thus reducing their intracellular concentration and rendering them less effective. Some *Shewanella* strains produce enzymes, such as β-lactamases, that degrade antibiotics like β-lactams, rendering them ineffective in inhibiting bacterial growth (Sher et al., 2025; Kim et al., 2006). Other mechanisms include target site alteration, metabolic pathway bypass, and reduced membrane permeability via porin modification (Sher et al., 2025).

In their comprehensive review, Sher et al. (2025) and Kim et al. (2006) highlighted that *Shewanella* spp., particularly *S. algae* and *S. putrefaciens*, are emerging as significant clinical and environmental pathogens with resistance to multiple antibiotic classes. Their study detailed resistance to β-lactams (e.g., penicillins, cephalosporins, carbapenems), aminoglycosides, quinolones, sulfonamides, and tetracyclines. They also noted that the presence of resistance genes (e.g., *blaOXA, blaTEM, qnr, aac(3)-Ilb, emrE*) and mobile genetic elements, like plasmids and integrons, enables *Shewanella* to spread resistance through horizontal gene transfer. Clinically, strains show growing resistance to imipenem and colistin, posing serious challenges for treatment, especially in immunocompromised patients (Kim et al., 2006). Their environmental distribution in aquatic ecosystems further highlights the potential of *Shewanella* spp. as a reservoir for antibiotic resistance genes that may be transferred to other human pathogens.

In Australia, *Shewanella* infections have been reported in both hospital-acquired and community-acquired cases. McAuliffe et al. (2015) identified *S. algae* from skin and soft tissue infections at Royal Darwin Hospital, reporting low-level ciprofloxacin resistance (0–4%) and 100% susceptibility to amikacin (Table 2). Similarly, *S. putrefaciens* isolates from blood samples in Katherine Hospital were found to be 95% susceptible to ceftazidime, with low-level resistance to co-trimoxazole (0–3%) (Table 2). A Queensland-wide study covering 16 hospitals and healthcare service regions reported notable carbapenem resistance in *S. algae,* with 6% of isolates resistant to meropenem (Laupland et al., 2022; Table 2). Meanwhile, *S. putrefaciens* isolates exhibited low-level ceftazidime resistance (1%) but remained susceptible to ciprofloxacin and gentamicin (Table 2).

Kang et al. (2024) analyzed 26 *Shewanella* isolates from fecal samples in Beijing and found high levels of resistance to polymyxin E (76.92%), followed by cefotaxime (57.69%) and ampicillin (50%) (Table 2). Intermediate resistance was observed for ampicillin-sulbactam (34.62%), nalidixic acid (15.38%), and ciprofloxacin (11.54%), while all isolates were 100% susceptible to ceftazidime/avibactam, tigecycline, meropenem, chloramphenicol, streptomycin, ertapenem, azithromycin, and amikacin (Kang et al., 2024; Table 2). Additionally, 38.46% of isolates were classified as multidrug-resistant (MDR), indicating potential public health risks. Resistance patterns varied by species, with *S. chilikensis* exhibiting 50% ampicillin resistance and *S. indica* showing 57.69% cefotaxime resistance (Kang et al., 2024). At Pamela Youde Nethersole Eastern Hospital (PYNEH), *S. algae* isolates from intraabdominal specimens displayed 23.4% resistance to imipenem, though they remained susceptible to ceftazidime (98.7%) (Ng et al., 2022; Table 2). Other hospital-acquired infections involving *S. putrefaciens* showed 97.4% susceptibility to gentamicin, while bloodstream isolates retained 93.5% susceptibility to cefoperazone-sulbactam (Table 2). Additionally, *Shewanella* isolates from marine exposure cases demonstrated 88.3% resistance to piperacillin and 90% resistance to ciprofloxacin (Ng et al., 2022; Table 2).

Beyond clinical settings, rural agricultural studies have identified antibiotic-resistant *Shewanella* strains in livestock environments, particularly in dairy farms in China (Li et al., 2022). Isolates from shed environments were found to be resistant to meropenem and colistin (Table 2), two antibiotics classified as last-resort treatments for multidrug-resistant Gram-negative infections. The cooccurrence of resistance to both meropenem and colistin in agricultural environments raises concerns about antibiotic selection pressure in livestock settings, where antibiotic use may be contributing to the emergence of drug-resistant bacteria. In milling environments, *S. putrefaciens* isolates displayed resistance to ceftiofur and tigecycline, along with amoxicillin, enrofloxacin, chloramphenicol, and tetracycline (Li et al., 2022; Table 2). The presence of tigecycline resistance is notable because tigecycline is a broad-spectrum glycylcycline antibiotic often used against MDR pathogens in human medicine. The resistance to ceftiofur, a third-generation cephalosporin commonly used in veterinary medicine, suggests potential cross-resistance between human and animal bacterial populations.

Taherzadeh et al. (2014) reported that *S. algae* isolates from wound infections in the Persian Gulf exhibited high resistance to multiple β-lactam antibiotics, raising concerns about the efficacy of antibiotic treatment in marine-related infections. These isolates were resistant to amoxicillin, vancomycin, doxycycline, cephalexin, and tetracycline (Table 2), suggesting the presence of β-lactamase production and efflux pump-mediated resistance mechanisms (Alcalde et al., 2021). Resistance to cotrimoxazole, a combination of sulfamethoxazole and trimethoprim, could limit treatment options for infections. Despite the broad resistance profile, *S. algae* isolates remained susceptible to several antibiotics, including ceftazidime, ciprofloxacin, amikacin, gentamicin, ceftriaxone, and nitrofurantoin (Taherzadeh et al., 2014; Table 2). The preserved susceptibility to aminoglycosides and third-generation cephalosporins indicates that these drugs may still be effective for treating *Shewanella* infections in the region. However, the presence of nalidixic acid resistance (Table 2) suggests that early-generation quinolones may no longer be effective against these isolates.

Kang & So (2016) investigated *S. putrefaciens* isolates from shellfish in the West Sea and revealed high resistance to cephalothin, gentamicin, erythromycin, vancomycin, ampicillin, rifampicin, and streptomycin (Table 2). Some isolates also exhibited intermediate resistance to tetracycline, trimethoprim/sulfamethoxazole, and chloramphenicol (Table 2). Furthermore, certain *Shewanella* strains demonstrated low-level resistance to heavy metals, highlighting the complex interplay between environmental contamination and antibiotic resistance (Kang & So, 2016). The study concluded that ongoing antibiotic exposure in aquaculture contributes to the emergence of MDR bacteria in seafood environments, raising food safety concerns.

While conventional antibiotics such as β-lactams, aminoglycosides, and fluoroquinolones have historically been employed to control *Shewanella* spp. and other Gram-negative bacteria in seafood, the emergence of multidrug-resistant strains has significantly reduced their effectiveness (Müller et al., 2023; Li et al., 2024). In addition to antibiotics, various synthetic chemicals, including food-grade preservatives like organic acids, nitrites, and chlorine-based disinfectants, as well as sanitizers such as quaternary ammonium compounds and peracetic acid, are routinely used in seafood processing environments to inhibit bacterial growth to support product safety (Salama & Chennaoui, 2024). However, the widespread and prolonged use of these synthetic agents has contributed to the development of resistance mechanisms in *Shewanella* spp., such as efflux pumps, enzymatic degradation, and robust biofilm formation, thereby limiting the long-term efficacy of these interventions. These challenges, combined with consumer demand for safer and more natural food preservation strategies, have driven research toward the use of natural plant extracts and essential oils as alternative or complementary approaches for controlling *Shewanella* and other seafood-borne pathogens.

Control of *Shewanella* spp. in seafood

Over the years, *Shewanella* have been increasingly recognized as emerging human pathogens due to a rise in reported *Shewanella*-associated infections despite earlier studies indicating their potential to cause disease in humans (Holt et al., 1997; Sharma & Usha, 2010; Wright et al., 2018). All the studies discussed in the antibiotic resistance profiles of *Shewanella* spp. section above mentioned how tetracycline was the recommended antibiotic for treating *Shewanella* spp. Unfortunately, due to the continuous use of this antibiotic, *Shewanella* spp. eventually developed resistance to tetracycline. Concerns have been raised about possible antibiotic treatment failure and should be investigated due to the MAR profiles displayed by some strains of *S. putrefaciens.* In addition to antibiotic therapies and thermal treatments, nonthermal technologies such as high-pressure processing, pulsed electric fields, and ultraviolet (UV) treatment have been explored for microbial inactivation; however, their efficacy against *Shewanella* spp. specifically has limited published studies.

Thermal treatments to control *Shewanella*. Thermal treatment is one of the oldest and safest methods for eliminating pathogens in food as high temperature effectively inactivates some bacteria. A range of control strategies have been evaluated to reduce or eliminate pathogenic *Shewanella* spp. in seafood. Traditional thermal treatments remain widely used. For example, Esua et al. (2021) demonstrated that immersing seafood samples in water baths at 50 °C, 55 °C, and 60 °C for 15 min resulted in progressively greater bacterial reductions, with higher temperatures and longer exposure times yielding the most significant effects. However, heat treatments may negatively impact the

Table 2
Summary of geographical antibiotic resistance profiles of *Shewanella* species[a]

Country	Samples		Species	Resistant	Intermediate	Susceptible	References
	Site	Type					
Australia	Royal Darwin Hospital	Skin soft tissue	*S. algae*		Ciprofloxacin (0–4%)	Amikacin (100%)	McAuliffe et al. (2015)
	Katherine Hospital	Blood	*S. putrefaciens*		Contrimoxazole (0–3%)	Ceftazidime (95%)	
	Gove Hospital	Feces Intraabdominal Respiratory Eye				Cefepime (100%) Gentamicin (100%) Meropenem (100%) Piperacillin-tazobactam (89%) Contrimoxazole (100%) Tobramycin (95%)	
	Queensland; 16 hospital and healthcare service regions	Blood culture	*S. algae*	Meropenem (6%)		Gentamicin	Laupland et al. (2022)
			S. putrefaciens 17 were not identified at the species level.	Ceftazidime (1%)		Ciprofloxacin	
China	2 clinics in Shunyi district, Beijing	Fecal samples	*S. algae*	Polymyxin E (76.92% resistant)		Ceftazidime/avibactam	Kang et al. (2024)
			S. indica	Cefotaxime (57.69% resistant)		Ceftazidime-avibactam	
			S. chilikensis	Ampicillin (50% resistant) Ampicillin-Sulbactam (34.62%)		Tigecycline Meropenem	
				nalidixic acid (15.38% resistant)		Chloramphenicol	
				Ciprofloxacin (11.54% resistant)		Streptomycin	
				Selectrin (3.846% resistant)		Ertapenem	
				Tetracycline (3.846% resistant)		Azithromycin	
				multidrug resistance was 38.46%		Amikacin	
	Dairy farm in China	Shed environment Milling environment	*Shewanella* spp. *S. putrefaciens*	Meropenem Ceftiofur Amoxicillin Chloramphenicol Tetracycline	Colistin Tigecycline Enrofloxacin		Li et al. (2022)
	Pamela Youde Nethersole Eastern Hospital (PYNEH)	Intraabdominal specimens	*S. algae*	Impenim (23.4% resistant)		Ceftazidime (98.7%)	Ng et al. (2022)
		Skin and soft tissue specimens	*S. putrefaciens*			Gentamicin (97.4%)	
		Blood Sputum Marine exposure				Cefoperazone-sulbactam (93.5%) Ciprofloxacin (90%) Pipercillin (88.3%)	
Iran	Persian Gulf	Wound discharge	*S. algae*	Amoxicillin (30 μg)		Ceftazidime (30 μg)	Taherzadeh et al. (2014)
				Vancomycin (30 μg) Doxycyclin (30 μg) Cephalexin (30 μg) Ampicillin (10 μg) Tetracycline (30 μg) Cephalothin (30 μg) Ceftizoxime (30 μg)		Ciprofloxacin (5 μg) Naidixic acid (30 μg) Nitrophorantion (300 μg) Amikacin (30 μg) Ceftiaxone (30 μg) Gentamicin (10 μg) Co-trimoxazole (1.25 μg & 23.75 μg)	

(continued on next page)

Table 2 (*continued*)

Country	Samples: Site	Samples: Type	Species	Resistant	Intermediate	Susceptible	References
South Korea	West Sea	Shellfish	*S. putrefaciens*	Cephalothin (30 µg) Vancomycin (30 µg) Ampicillin (10 µg) Streptomycin (10 µg)	Cefotaxime (30 µg) Kanamycin (30 µg) Erythromycin (15 µg) Rifampicin (5 µg)	Chloramphenicol (30 µg) Trimethoprim/sulfamethoxazole (1.25 µg & 23.75 µg) Tetracycline (30 µg) Ciprofloxacin (5 µg Cefepime (30 µg) Cefotetan (30 µg)	(Kang & So, 2016)[c]

Antimicrobial susceptibility categories: Susceptible – Isolates likely to respond to standard antibiotic treatment. Intermediate – Isolates with moderate susceptibility – may require higher doses or site-specific concentration for effectiveness. Resistant – Isolates unlikely to respond to treatment at normal dosages.

[a] Not all cited papers used percentage to measure antibiotic resistance. The article for Australia's data used percent susceptibility. Papers that cited data from Iran, Italy, and South Korea used the concentration of each antibiotic tested.

[c] The article does not mention intermediate resistance, but they mentioned a mixed response from *S. putrefaciens* from these antibiotics.

sensory qualities of seafood. To address these limitations, novel technologies have been explored. Jiang et al. (2024) investigated thermosonication, a technique combining ultrasound with heat, as an alternative to traditional cooking and pasteurization. Their findings indicate that thermosonication can achieve effective inactivation of *Shewanella* spp. while better preserving product quality due to its controllability and reduced thermal load. These findings collectively reinforce that cooking and heat-based treatments are effective in disinfecting *Shewanella*, with higher temperatures and longer cooking times generally leading to greater bacterial reduction. However, the effectiveness may vary depending on the *Shewanella* species and the heating method employed.

High-pressure processing (HPP) to control *Shewanella*. High-pressure processing (HPP) is a valuable nonthermal technique for reducing microbial loads and extending the shelf life of seafood products while preserving taste, texture, and nutritional value (Alba et al., 2019; Kawano et al., 2004; Mircea-Valentin et al., 2016). HPP works by applying high levels of isostatic pressures (typically 100–600 megapascals [MPa]), which disrupts cellular structures, damages bacterial membranes, and inactivates key enzymes, leading to microbial inactivation (Kontominas et al., 2021). The application of HPP varies in effectiveness depending on factors such as bacterial species, pressure levels, and exposure duration. Studies have shown that while HPP significantly reduces bacterial loads in seafood, complete inactivation may not always be achieved, particularly in pressure-resistant strains.

Although no studies have specifically assessed the effectiveness of HPP on inactivating *S. algae* and *S. putrefaciens*, research has been conducted on *S. violacea* and *S. oneidensis*. Kawano et al. (2004) investigated the stability of RNA polymerase under high pressure, finding that *S. violacea* RNA polymerase remains stable at pressures that significantly inhibit *E. coli* transcription. Similarly, Hazael et al. (2014) found that *S. oneidensis* exhibited high survival rates under HPP conditions, with only a slight decrease in viability at 250 MPa, and viable CFUs were still present at 500 MPa. Their study further demonstrated that higher pressures and temperatures significantly reduced bacterial survival; however, some survivors displayed adaptive resistance upon reexposure to high-pressure conditions. This finding suggests that combining HPP with other hurdles or preservation strategies may be necessary for robust control of *Shewanella* spp. in seafood products.

More recent research by Malas et al. (2024) further highlights the resilience of *S. oneidensis*, demonstrating that this species can survive pressures of 158 MPa for 15 min for up to 2 h with minimal prior pressure adaptation. Notably, *S. oneidensis* actively fine-tunes its gene expression under high-pressure conditions by upregulating genes involved in DNA repair (to fix pressure-induced DNA damage), stress response (to protect proteins from denaturation), and membrane reconfiguration (to maintain cell membrane integrity). This suggests that some *Shewanella* species may be naturally equipped with mechanisms to withstand pressure-based food preservation techniques. These findings highlight that while HPP can significantly reduce *Shewanella* populations in seafood, certain strains may persist despite high-pressure treatment.

Kontominas et al. (2021) also explored the effectiveness of HPP as part of a broader strategy for seafood preservation. Their study found that HPP extended the shelf life of seafood by 10–15 days when combined with other preservation methods, such as modified atmosphere packaging and natural antimicrobial agents. Importantly, *S. putrefaciens*, a known seafood spoilage organism, was found to be susceptible to HPP under certain conditions, though its resistance varied with strain type and processing parameters (Kontominas et al., 2021). Given the resilience of certain *Shewanella* strains to HPP, researchers emphasize the need for multihurdle approaches to enhance bacterial reduction and prevent regrowth. Synergistic strategies that can improve the efficacy of HPP include antimicrobial treatments, modified atmosphere packaging (MAP), and combination processing techniques. Natural antimicrobials, such as bacteriocins (e.g., lacticin), plant-derived compounds (e.g., thyme oil), and organic acids (lactic and citric acids), have been shown to enhance bacterial inactivation in seafood. The use of CO_2-enriched atmospheres has been effective in further inhibiting spoilage bacteria, including *Shewanella* spp. Pairing HPP with ozonation, irradiation, or pulse light technology has been explored to improve microbial control in seafood products (Kontominas et al., 2021).

HPP remains a promising method for reducing *Shewanella* contamination in seafood, but its effectiveness varies depending on bacterial species and pressure conditions. The ability of certain *Shewanella* species, such as *S. oneidensis,* to survive high-pressure conditions underscores the need for complementary control measures (Malas et al., 2024). Future research should focus on optimizing pressure conditions, identifying strain-specific vulnerabilities, and integrating HPP into multihurdle food safety approaches to enhance seafood safety and shelf life.

Nonthermal processing technologies to control *Shewanella*. Beyond HPP, additional nonthermal technologies have emerged as promising interventions for controlling *Shewanella* spp. in seafood while preserving product quality. Cold plasma, particularly atmospheric cold plasma (ACP), has shown potent antimicrobial effects against *S. putrefaciens*. A study by Hu et al., 2023 utilized a cyclical ACP treatment on shrimp achieved a 3.41 log CFU/mL reduction in viable cell counts and an 85.30% decrease in cell viability. This treatment also disrupted biofilm formation and caused extensive damage to bacterial cell membranes and DNA (Hu et al., 2023). A related technology, plasma-activated seawater (PASW), demonstrated even greater antimicrobial activity. PASW utilizes reactive oxygen and nitrogen species along with halogen compounds to enhance membrane disruption and bacterial inactivation, suggesting strong potential for seafood decontamination (Ke et al., 2024).

Ozonation has been applied in both gaseous and aqueous forms to reduce microbial loads in seafood. Although direct studies on *Shewanella* spp. are limited, ozone has been effective against similar Gram-negative bacteria, indicating potential for broader application (López Hernández et al., 2018). Its use is particularly suited for surface decontamination and is often integrated with refrigeration or packaging strategies to enhance microbial control (Park et al., 2020). Pulsed electric fields (PEFs), typically used in liquid food processing, have also been explored in seafood systems. While studies specifically targeting *Shewanella* spp. are sparse, PEF has demonstrated efficacy in reducing other spoilage and pathogenic bacteria in fish slurries and brines. The method works by applying short bursts of high-voltage electricity that permeabilize microbial cell membranes, making it a candidate for further development in seafood preservation (He et al., 2016).

Probiotic potential to control *Shewanella*. Members of the *Shewanella* genus have been investigated for their probiotic potential, particularly in aquaculture settings. Some *Shewanella* strains, including *S. putrefaciens* Pdp11, exhibit several characteristics that make them suitable candidates for use as probiotics (Ringø et al., 2022). These strains are resistant to bile salts, possess adhesion and colonization proteins specific to the gastrointestinal tract, and can inhibit the adhesion of pathogenic microorganisms, making them promising candidates for enhancing fish health (Ringø et al., 2022).

In aquaculture, *Shewanella* species have been shown to improve growth performance, modulate gut microbiota, and enhance immune responses in fish. For example, supplementation with *S. putrefaciens* Pdp11 has led to improved growth and immune responses in species such as gilthead seabream and Senegalese sole. In addition, studies have demonstrated the ability of *Shewanella* to aid in wound healing by modulating antioxidant activity and inflammatory responses (Ringø et al., 2022). Furthermore, the administration of *Shewanella xiamenensis* has been associated with enhanced resistance to bacterial pathogens, such as *Aeromonas hydrophila*, through improved immune system activity and modulation of gut microbiota (Ringø et al., 2022).

Despite the promising probiotic potential of certain *Shewanella* strains, safety remains a concern, particularly with pathogenic strains. Some *S. putrefaciens* strains carry plasmids associated with virulence factors that are absent in probiotic strains like Pdp11. These plasmids may harbor antibiotic resistance genes, raising safety concerns about their use in both aquaculture and human health contexts (Domínguez-Maqueda et al., 2022). Therefore, while certain *Shewanella* strains offer promising probiotic benefits, their application should be carefully considered, with further research needed to assess the long-term safety and efficacy of these bacteria.

Plant bioactive constituents to control *Shewanella*. The increasing prevalence of antibiotic-resistant *Shewanella* strains and other seafood-related Gram-negative bacteria has highlighted the limitations of relying solely on synthetic antibiotics and chemical preservatives for microbial control. Synthetic chemicals, including conventional antibiotics, disinfectants, and food-grade preservatives, have been effective historically; however, their extensive use has contributed to the emergence of multidrug-resistant bacteria, posing significant challenges to food safety and public health (Li et al., 2024; Müller et al., 2023). Moreover, synthetic chemicals often raise concerns related to environmental impact, chemical residues in food products, and potential adverse effects on human health. For instance, chlorine-based sanitizers and nitrites, while effective, may produce harmful by-products or alter the sensory qualities of seafood (Salama & Chennaoui, 2024). Consumer demand is increasingly shifting towards “clean label” foods, free from synthetic additives, which has driven research interest in natural, plant-based antimicrobial agents.

Plant-derived compounds such as essential oils, phenolics, and flavonoids offer promising alternatives due to their broad-spectrum antimicrobial activity, biodegradability, and generally recognized as safe (GRAS) status. These natural extracts often act through multiple mechanisms, including disruption of bacterial membranes, inhibition of biofilm formation, and interference with quorum sensing, which reduces the likelihood of resistance development (Gu et al., 2024; Lan et al., 2024). In this subsection, plant bioactives refer not only to crude extracts but also to essential oils and their primary antimicrobial constituents, such as phenolics, terpenoids, and flavonoids, which have shown promise against *Shewanella* spp. While most studies to date have focused on in vitro antimicrobial activity of plant extracts and essential oils against *Shewanella* spp., there are limited in situ investigations evaluating their effectiveness in real seafood matrices. For example, Murhekar et al. (2017) suggested that Kakadu plum extracts could delay spoilage and extend the shelf life of prawns, but large-scale or commercial in situ trials remain scarce. Further research is needed to validate these promising results under practical seafood processing and storage conditions.

Gu et al. (2024) investigated the antibacterial mechanism of ultrasound combined with thymol, a major constituent of thyme essential oil, against *S. putrefaciens*. Their results showed that this combined treatment significantly disrupted cell membrane integrity, increased membrane permeability, and led to leakage of intracellular contents, ultimately resulting in effective inhibition of both planktonic cells and biofilm formation. Similarly, Lan et al. (2024) evaluated the antibacterial activity of ginger essential oil against *S. putrefaciens*. They found that ginger essential oil not only disrupted the bacterial cell structure and caused loss of membrane integrity but also significantly inhibited biofilm formation and reduced the viability of cells within established biofilms. Both studies highlight that plant bioactive compounds, particularly essential oils and their primary constituents, exert their effects through multiple mechanisms, including membrane disruption and biofilm inhibition, making them promising candidates for enhancing seafood safety and shelf life.

Murhekar et al. (2017) evaluated leaf and fruit extracts and found that they displayed potent growth-inhibitory properties against all *Shewanella* spp. tested. These plant extracts contained antimicrobial compounds and high antioxidant content to block the oxidation of fish macromolecules as well as act as an inhibitory reagent for microbial growth, thus acting as a preservative. An Australian fruit known as *Terminalia ferdinandiana,* also known as a Kakadu plum, has compounds that have potent growth inhibitory activity against several pathogenic bacteria (Murhekar et al., 2017). The antimicrobial activity of Kakadu plum extract is primarily attributed to its high content of phenolic acids (such as garlic and ellagic acids), flavonoids, hydrolysable tannins, and vitamin C. These bioactive compounds disrupt bacterial membranes and inhibit essential microbial enzymes, leading to the growth inhibition of *Shewanella* spp. (Netzel et al., 2007; Sahib et al., 2020). Although studies on the antibacterial properties of Kakadu plum leaf extracts were not investigated on a large scale, the available research suggests that the extracts have the potential to delay spoilage and considerably increase the shelf life of commercially harvested prawns. Although *S. baltica* and *S. frigidimarina* were completely unaffected by high doses of ampicillin, both showed high susceptibility to the Kakadu plum extracts. This study showed that the methanolic, aqueous, and ethyl acetate-containing Kakadu plum fruit extracts and all the leaf extracts tested inhibited the growth of *S. putrefaciens* (Murhekar et al., 2017).

A study by Jamieson et al. (2014) used *Syzygium austral* (brush cherry) and *Syzygium luehmannii* (riberry) to inhibit the growth of *Shewanella* spp. in fish. Researchers used the fruit and leaf extracts for testing and found both extracts to be good inhibitors of the majority of *Shewanella* spp. Tests were performed for extract toxicity, as well as antioxidant content. To determine the ability of these extracts to inhibit the growth of *Shewanella* spp., a combination of the disc diffusion method and the minimum inhibitory concentration (MIC) method was used. Results showed that about 92% of *S. putrefaciens* growth was inhibited by the extracts. The *S. leuhmannii* extract gave a weaker inhibition of *S. putrefaciens* growth than the *S. austral* extract. Like the studies on *S. putrefaciens*, researchers discovered that *S. baltica* also showed a higher susceptibility to the *Syzgium* extracts than to the ethyl acetate extracts (Jamieson et al., 2014). These results are very good considering that much fresh fish spoilage is the result of oxidation (Jamieson et al., 2014) and because *S. austral* and *S. luehmannii* extracts have extremely high antioxidant capacities (Jamieson et al., 2014; Pazos et al., 2004). These extracts can decrease lipid oxidation which in return inhibits oxidative rancidity (Jamieson et al., 2014; Pazos et al., 2004). It was concluded that these extracts would be effective against all psychotrophic and mesophilic *Shewanella* spp., therefore, the use of extracts should be considered for the preservation of both fresh and cold storage fish (Jamieson et al., 2014).

More recent studies have identified additional plant-based extracts that exhibit strong antimicrobial properties against *Shewanella* spp. Bambara groundnut (*Vigna subterranean*) seed coat extract has been shown to effectively inhibit *S. putrefaciens* and *S. algae* due to its rich content of polyphenols, flavonoids, and tannins (Palamae et al., 2024). The red seed coat (RSC) extract exhibited a minimum inhibitory concentration (MIC) of 4 mg/mL for *S. putrefaciens* and 8 mg/mL for *S. algae*, demonstrating a stronger effect compared to the white seed coat extract (Palamae et al., 2024).

Furthermore, time-kill kinetic studies indicated that a 2MIC and 4MIC treatment led to complete bacterial inhibition within 6–8 h (Palamae et al., 2024). Scanning electron micrographs confirmed that bacterial cells exposed to the extract displayed membrane disruption and loss of structural integrity (Palamae et al., 2024). Additionally, confocal laser scanning microscopy (CLSM) revealed that the RSC extract significantly inhibited biofilm formation in *S. algae*, with an 80% reduction at 2MIC concentration. The antimicrobial activity of plant extracts is largely attributed to the disruption of bacterial cell membranes, leading to protein leakage and bacterial cell lysis (Palamae et al., 2024). Inhibition of quorum sensing, which prevents biofilm formation and reduces bacterial virulence, plays a crucial role in limiting the pathogenic potential of bacteria by disrupting cell-to-cell communication and reducing the expression of virulence factors (Palamae et al., 2024). Reduction of oxidative stress protects seafood from spoilage by helping maintain the freshness and quality of seafood products by preventing lipid oxidation and microbial degradation, ultimately extending shelf life and improving food safety (Kontominas et al., 2021).

The use of plant extracts for controlling *Shewanella* spp. in seafood is a promising alternative to synthetic preservatives. Recent research on Bambara groundnut seed coat extracts demonstrated their strong antimicrobial and antibiofilm activity making it a potential candidate for seafood preservation. Further studies should focus on optimizing extraction methods, evaluating commercial-scale applications, and exploring synergistic combinations with other food safety technologies.

Conclusion

Pathogenic *Shewanella* species are found in freshwater, estuarine environments, and in fish and shellfish, thus posing a risk to human health. This review showed that *Shewanella* species are susceptible to third- and fourth-generation cephalosporins such as ceftazidime and cefepime; β-lactam/β-lactamase inhibitor combinations such as piperacillin-tazobactam, aminoglycosides (including gentamicin and amikacin), and fluoroquinolones such as ciprofloxacin and levofloxacin. These antibiotics are considered effective options for treating shewanellosis when guided by susceptibility testing (Laupland et al., 2022; Sher et al., 2025; Vignier et al., 2013). Limited studies on the antibiotic resistance of *Shewanella* showed that isolates recovered from clinical and environmental samples exhibit high resistance to β-lactam antibiotics such as penicillin, ampicillin, and vancomycin (Murhekar et al., 2017). Continued research is warranted to test the effectiveness of first-line drugs against *Shewanella* spp. Most shewanellosis cases have been associated with *S. algae* and *S. putrefaciens* which can be spread by the foodborne route. National incidence reporting of shewanellosis cases has not been established in the U.S. or elsewhere. Notifiable disease reporting should be developed with epidemiological traceback to ascertain the sources of illness. Such reporting would permit, for the first time, comprehensive data on (i) the number of cases occurring annually, (ii) trends in the number of cases over time, and (iii) and cause of illness. Causes of illness could include seafood or other food consumption; recreational activities (like swimming, fishing, boating); working in the marine or other environments; trauma (cuts and abrasions, water in the ears, etc.). Increasing seawater temperatures and the ability of *S. algae* to readily grow at elevated temperatures make it a prime candidate for environmental enrichment as well as higher levels of seafood contamination and human illness. In addition to temperature effects on *Shewanella* growth and persistence, research is also needed to determine what other environmental factors (salinity, dissolved oxygen, pH, etc.) contribute to the proliferation of *Shewanella* within the environment. These factors could lead to increasing levels of human illness, particularly in immunocompromised individuals. Many nonpathogenic species of *Shewanella* are fish spoilage organisms and deserve further evaluation to ascertain their effects on seafood quality and shelf-life. Additional research is needed to better understand the pathogenicity, genetic diversity, environmental triggers, seasonal prevalence, and antibiotic resistance of *Shewanella* spp. and strains recovered from seafoods and their surrounding environments. Since *Shewanella* spp. are beginning to show a higher resistance to antibiotics and to multiple antibiotics that are typically used for treating human and animal diseases, nonantibiotic strategies, especially natural antimicrobial alternatives, are needed to control infections in aquaculture and humans. Further research is needed to determine the susceptibility of *Shewanella* to various food processing technologies, particularly for those foods served raw or only lightly cooked. Finally, there are many *Shewanella* spp. whose roles are uncertain in human and animal disease. More rapid detection and identification methods are needed to sort pathogenic species and strains from the many environmental strains. Only with a concerted effort can the challenges of *Shewanella* be understood and mitigated.

CRediT authorship contribution statement

Tahirah Johnson: Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation. **Gary P. Richards:** Writing – review & editing, Writing – original draft, Visualization, Validation, Methodology, Investigation, Data curation, Conceptualization. **Salina Parveen:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, 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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