Incidence, Transmission Mechanisms and Pathologic Implications of Bacterial Zoonotic Diseases of Fish

49

Sana Alam[1], Gulnaz Afzal[1], Abu Baker Siddique[2], Riaz Hussain[3,*], Muhammad Rizwan[1,4], Sajid Raza Khan[5], Rehana Iqbal[6], Yasir Mahmood[1], Ghulam Ali Raza[1], Nimra Aslam[1] and Ghulam Mustafa[1]

ABSTRACT

Fish harbor a variety of bacterial pathogens, some of which can cause disease in humans. Zoonotic bacteria that may be present in asymptomatic fish hosts pose a public health risk when transmitted to humans through handling or consuming infected fish. Mycobacteriosis, caused by species in the *Mycobacterium marinum* group, is perhaps the most notorious zoonotic infection associated with fish and can produce serious skin infections in humans. Streptococcosis and staphylococcosis also occur with some frequency in fish and can result in human cases of septicemia, endocarditis or pneumonia if injured skin comes into contact with infected fish tissues and bacteria access wounds. Additionally, some Vibrio and Clostridium species found among fish may cause wound infections or gastrointestinal illness in humans, usually subsequent to exposure through handling or ingesting raw seafood. Clinical signs of bacterial zoonosis are variable and diagnosis in human cases can prove complicated by the vast diversity of potential pathogens involved. Preventative measures center on educating aquarists and fish handlers to avoid direct contact with ulcerated areas, lesions or feces from diseased fish. For consumer safety, good aquaculture practices that reduce bacterial loads in farmed fish stock are recommended. Moreover, thoroughly cooking fish to an internal temperature over 140°F destroys pathogens that may be present. Additional research priorities include better characterization of bacterial diversity among wild and farmed fish, investigating genetic and immunological aspects of disease resistance, developing improved diagnostics through genomic analysis, assessing efficacy of existing antibacterial treatments in clearing pathogens prior to human consumption and formulating integrated control strategies to mitigate risks. This book chapter examines the incidence, transmission mechanisms and pathologic implications of common bacterial zoonosis originating from fish hosts.

Keywords: Fish, Zoonotic diseases, Incidence, Transmission mechanisms, Pathologic implications, Bacterial zoonosis

CITATION

Alam S, Afzal G, Siddique AB, Hussain R, Rizwan M, Khan SR, Iqbal R, Mahmood Y, Raza GA, Aslam N and Mustafa G, 2023. Incidence, transmission mechanisms and pathologic implications of bacterial zoonotic diseases of fish. In: Altaf S, Khan A and Abbas RZ (eds), Zoonosis, Unique Scientific Publishers, Faisalabad, Pakistan, Vol 4: 625-645. https://doi.org/10.47278/book.zoon/2023.184

CHAPTER HISTORY Received: 12-Feb-2023 Revised: 25-July-2023 Accepted: 15-Aug-2023

[1]Department of Zoology, The Islamia University of Bahawalpur, Bahawalpur, Pakistan
[2]Department of Microbiology, Government College University, Faisalabad, Pakistan
[3]Department of Pathology, Faculty of Veterinary and Animal Sciences, The Islamia University of Bahawalpur, 63100, Pakistan
[4]King Saud University Riyadh, Saudi Arabia
[5]Department of Zoology, Govt Graduate College Kot Sultan Layyah, Higher Education Department Punjab Pakistan
[6] Institute of Pure and Applied Biology, Zoology Division, Bhauddin Zakariya University, Multan, Pakistan
***Corresponding author:** dr.riaz.hussain@iub.edu.pk

1. INTRODUCTION

The interplay between humans, animals and the environment has long been recognized as a significant factor in the emergence and spread of infectious diseases. Among zoonotic diseases, those transmitted from fish to humans hold a unique place due to the increasing popularity of fish as a vital food source worldwide (Ziarati et al. 2022). This chapter provides a comprehensive review of bacterial zoonotic diseases in fish, exploring the risks, transmission mechanisms, and control measures associated with these infections. By understanding the complexity of these diseases, we can devise effective strategies to safeguard public health and ensure the sustainability of the fishing industry.
The consumption of fish as a primary protein source has surged in recent decades, driven by the recognition of its nutritional value and health benefits. However, this growing demand has also given rise to concerns about the transmission of zoonotic diseases from fish to humans (Farzadnia and Naeemipour 2020). Bacterial pathogens are of particular concern due to their ability to cause severe illnesses and pose significant economic risks to the fishing industry. In this chapter, we will explore the most common bacterial zoonotic diseases associated with fish, their modes of transmission, and the preventive measures to mitigate the risks (Irshath et al. 2023). The most common bacterial zoonotic diseases of fish are presented in Table 1.

1. LISTERIOSIS

Listeria monocytogenes is another significant bacterial pathogen that can be transmitted to humans through contaminated fish. The mechanism of action of listeria is shown in Fig. 1. This bacterium is widely distributed in the environment and can survive under various conditions. Listeriosis, the disease caused by *L. monocytogenes*, is particularly dangerous for pregnant women, elderly individuals, and those with weakened immune systems (Lassen et al. 2016). Symptoms range from mild flu-like signs to severe invasive infections like meningitis and septicemia. Proper fish processing, hygiene, and refrigeration are vital in preventing L. monocytogenes contamination.
Listeria monocytogenes has the ability to invade several cell types, including macrophages. After getting confined inside phagosomes and being absorbed by macrophages, Listeria monocytogenes secrete virulence factors, such as listeriolysin O (LLO) that damage the phagosomal membrane and invade the cytoplasm. Due to this invasion, it will survive (Köster et al. 2014).
A complex immune response that includes both the innate and adaptive immune systems is necessary to achieve the best protection possible against infections. By regulating the production of proinflammatory cytokines, type I interferons (IFNs), and antimicrobial effectors, the innate immune system plays a critical role in starting and coordinating host defenses (Iwasaki and Medzhitov 2010). Pattern recognition receptors (PRRs) act as molecular defenders that continuously scan the cytoplasm and

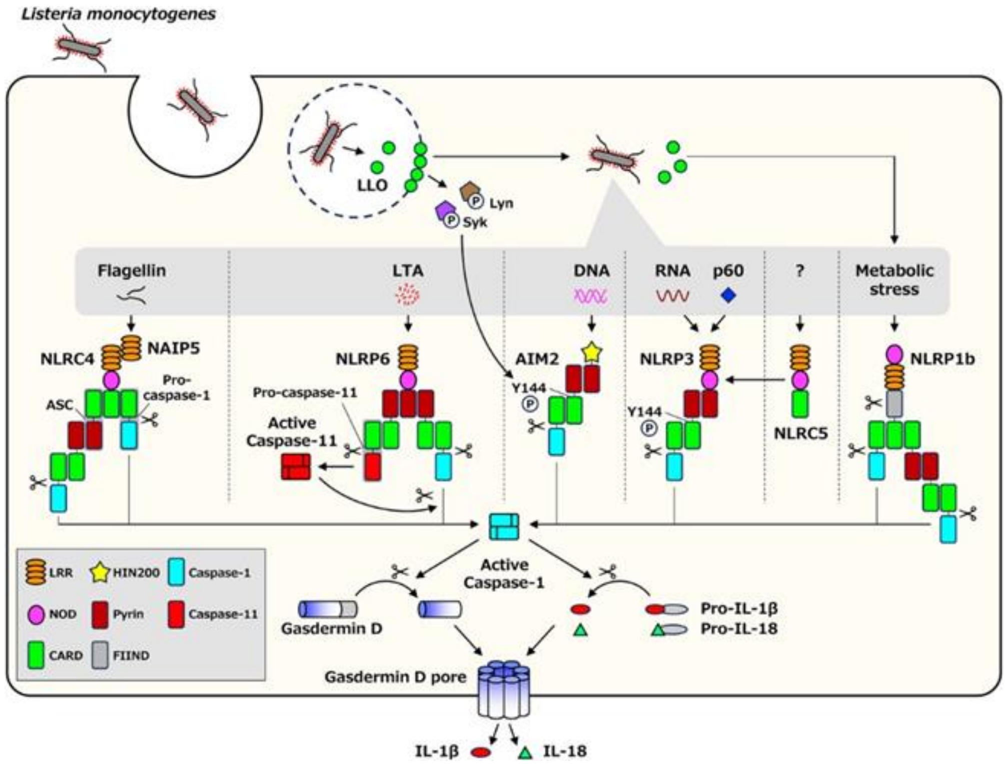

Fig. 1: The mechanism of action of Listeria (Matsuda et al. 2023).

Table 1: Bacterial zoonotic diseases of fish

S.No.	Name of Disease	Bacterial agent	Fish species effected	Human health impact
1	Listeriosis	*Listeria monocytogenes*	Various fish species	gastrointestinal symptoms and flu-like illness, poses more severe risk to pregnant women and newborns
2	Salmonellosis	*Salmonella spp.*	Smoked fish	Diarrhea, fever and abdominal cramps
3	Streptococcosis	*Streptococcus spp*.	Farmed fish	Skin infections
4	Erysipelothrix	*Erysipelothrix rhusiopathiae*	Whenever fish and shellfish handled	Joint pain and flu like symptoms
5	Campylobacter	*Legionella pneumophila*	fresh water fish	pneumonia
6	Vibrionaceae	*Vibrio spp.*	Marine and fresh water fish	Wound infections, GIT illness
7	Botulism	*Clostridium botulinum*	Various fish species	Muscle paralysis, respiratory disorder and even death
8	Pseudomonadaceae	*Pseudomonace spp.*	Various fish species	Abnormal breathing, skin infections
9	*Aeromoniasis*	*Aeromonas hydrophila*	Fresh water fish	GIT infection
10	Hafniaceae	*Hafnia alvei*	Various fish species	Skin lesions
11	Enterobacteriaceae	*Enterobacteriaceae spp*	Various fish species	Sepsis
12	*E. coli*	*E. coli*	Various fish species	Stomach cramps and vomitting
13	Salmonellosis	*Salmonella spp.*	Various fish species	Fever and intestine infection
14	Klebsiella	*Klebsiella spp.*	Various fish species	Wound infection and sepsis
15	Yersinia	*Yersinia spp.*	Various fish species	GIT infection

Several bacterial infections in fish species, including *Aeromonas septicemia* (Thirumalaikumar et al. 2021), Edwardsiellosis (Buján et al. 2018), Columnaris (Declercq et al. 2013), Streptococcosis (Luo et al. 2017), and vibriosis (Ji et al. 2020) have been reported in the aquaculture sector (Bhatnagar et al. 2023). There are several bacterial pathogens which transfer from fish to humans are explained below.

extracellular environment for potential dangers and danger by recognizing pathogen-associated molecular patterns (PAMPs) (Tartey and Takeuchi 2017). It could be feasible to regulate the immune response and improve the efficacy of existing treatments for drug-resistant strains by focusing on the inflammasome pathway. However, more research and clinical trials are needed to assess and confirm the efficacy and security of such an approach.

2. SALMONELLOSIS

Salmonella species are well-known pathogens responsible for foodborne infections worldwide. While commonly associated with poultry and eggs, salmonella can be transmitted to people through fish as well (Fig. 2). Fish act as a carrier for the transmission of the disease. Ingesting raw or undercooked fish contaminated with Salmonella can lead to salmonellosis, characterized by symptoms such as diarrhea, fever, and abdominal cramps (Bibi et al. 2015). Proper cooking, cross-contamination prevention, and maintaining good hygiene practices are essential in reducing the risk of Salmonella infections (Yacoub et al. 2023).

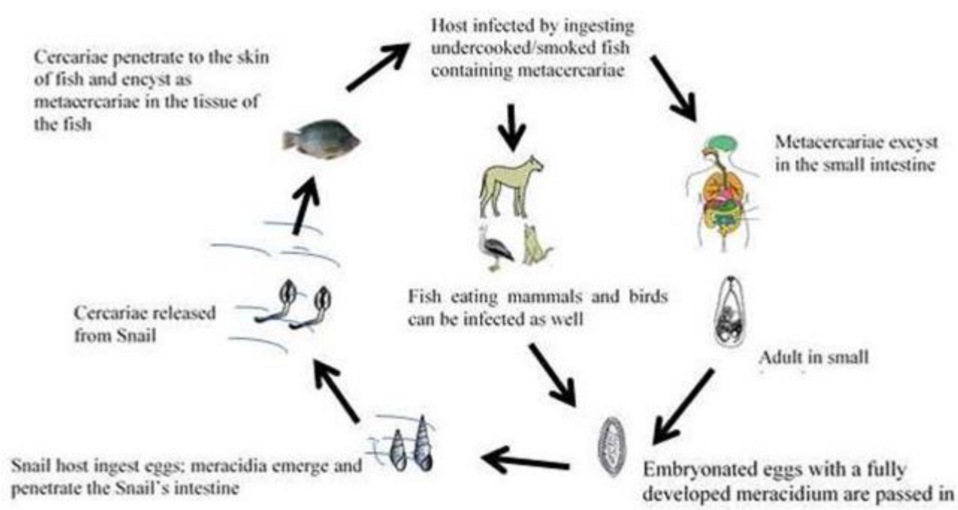

Fig. 2: Life cycle and transmission of salmonella (Bibi et al. 2015).

3. STREPTOCOCCOSIS

Streptococcosis is a neurological bacterial disease that mostly affects warm-water fish in tropical habitats, whether in freshwater or saltwater. The best circumstances for streptococcal epidemics include high stocking numbers, poor water quality, and high temperatures. Tilapia Fish can become infected with streptococcus as early as 5 grams old, and it persists throughout every stage of the tilapia life cycle. *Streptococcus agalactiae* and *Streptococcus iniae* are the two most common streptococcal infections in tilapia. Using specific health requirements MSD further divides *S. agalactiae* into two biotypes (Biotype 1 and Biotype 2). Serotype-specific strains of *S. agalactiae* produce each infection of a specific biotype (Li et al. 2014).

3. 1. *STREPTOCOCCUS INIAE*

Streptococcus iniae is an emerging zoonotic pathogen found in various aquatic environments, including fish farms (Berzak et al. 2019). It can cause invasive infections in humans who come into contact with infected fish, leading to bacteremia and meningitis as shown in Fig. 3. Fish handlers and those with open wounds are particularly susceptible. Stringent biosecurity measures, prompt diagnosis, and appropriate antimicrobial treatment are crucial to prevent and manage *S. iniae* infections.

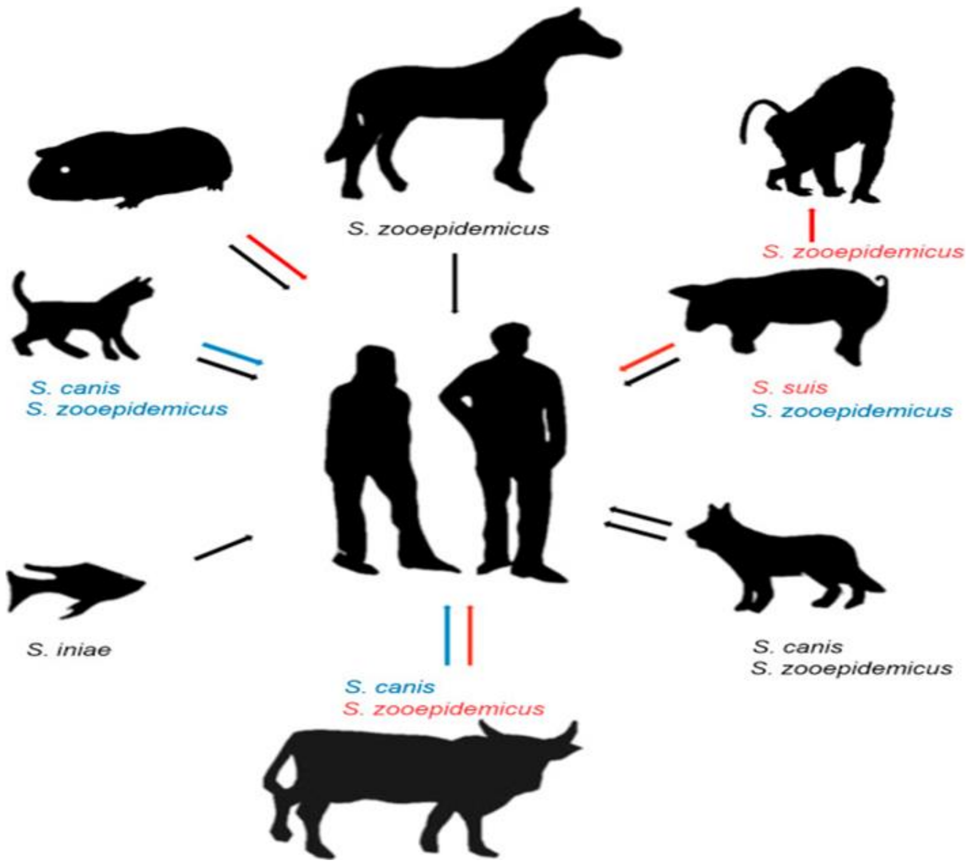

Fig. 3: Host pathogen relation of zoonotic streptococcus (Soares 2015).

External clinical symptoms of this fatal condition include exophthalmos (eye protrusion), conspicuous hemorrhages, corneal opacity, whirling at the water surface, and erosion of the caudal fin. 'C' or 'S'-shaped body posture, sluggish behavior, and bleeding abscesses around the mouth are further signs of unhealthy fish. A swollen spleen, abdominal distention, a pale liver, organ adhesion, and inflammation are examples of internal symptoms.

The chance of more fish acquiring an infection can be increased by overfeeding, stress and open cage culture. In order to further protect tilapia from streptococcus, MSD Animal Health suggests sanitizing equipment, separating diseased fish from healthy ones and vaccinating fish at the appropriate time.

4. ERYSIPELOTHRIX

Erysipelothrix is a Gram-positive bacterium which has a significant role in fish zoonoses (Boylan 2011). This bacterium causes Skin infections and acute sepsis and is related to Sea Mammals. *E. rhusiopathiae* (commanly known as *E. insidiosa*) is the most important specie, which is important from the zoonotic point of view as causes disease in humans and animals which affect vascular tissue, connective tissue, and Skin issues (Fig. 4).

Clinical symptoms include inflammation of muscle cells (myositisis), inflammation of skin necrotizing dermatis) and inflammation of other cells (cellultis). *E. rhusiopathiae* is a common fish bacterium but different countries have recorded mortality (Pomaranski et al. 2018; Pomaranski et al. 2020). A new type of ornamental fish called Aeromonas hydrophila has just been discovered in fish (Hoseinifar et al. 2023). It leads to a great economic loss in aquaculture (Liu et al. 2020). Additionally, *E. rhusiopathiae* has zoonotic potential and has a definite occupational connection to the meat and fish sectors and it can cause erysipeloid in people (Opriessnig et al. 2020). Only contact with fish mucus the disease can occur in human beings. Although *E. rhusiopathiae* is not infectious to fish, it can infect humans due to its prolonged life in fish mucus and possible stability. Infections through dog scratching and bites have also been reported (Verma and Kumar 2018).

Fig. 4: Erysipelothrix infection in humans from fish (Slide player).

Erysipelothrix infections in humans are consequently brought on by contact with infected animals, their faeces, or products. Clinical symptoms of the illness include skin infections, particularly on the hands (Fig. 5), endocarditis, and sepsis. Among those who are at a high risk for Erysipelothrix infections are fishermen and veterinarians. This bacterium is linked to endocarditis (Wood and Steele 2019). Here are some more pictures of infection in humans (Fig. 6).

5. CAMPYLOBACTER

Campylobacter is a zoonotic agent that can be detected in the digestive system of various animals. (Facciolà et al. 2017). The most likely way that a food handler contracts campylobacter jejuni infection is via touching their hands to a work surface or untreated water. The two enteropathogens of this genus that are of greatest importance are *Campylobacter jejuni* and *C. coli* (Deblais et al. 2023). Mode of transmission of campylobacter is presented in Fig. 7.

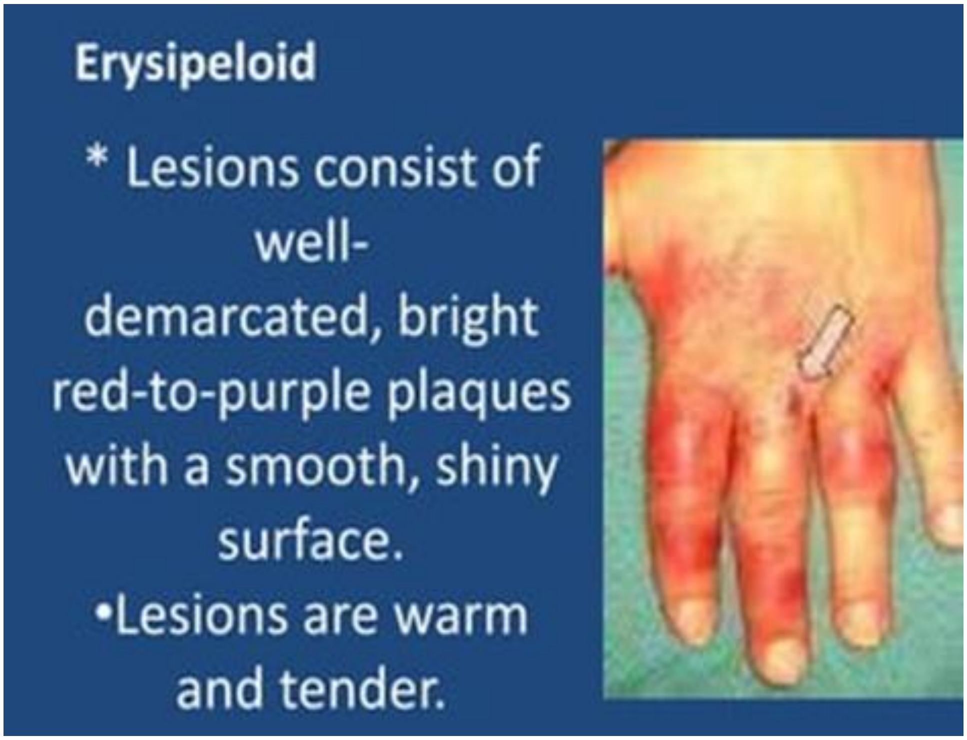

Fig. 5: Erysipeloid lesions (Slide.share).

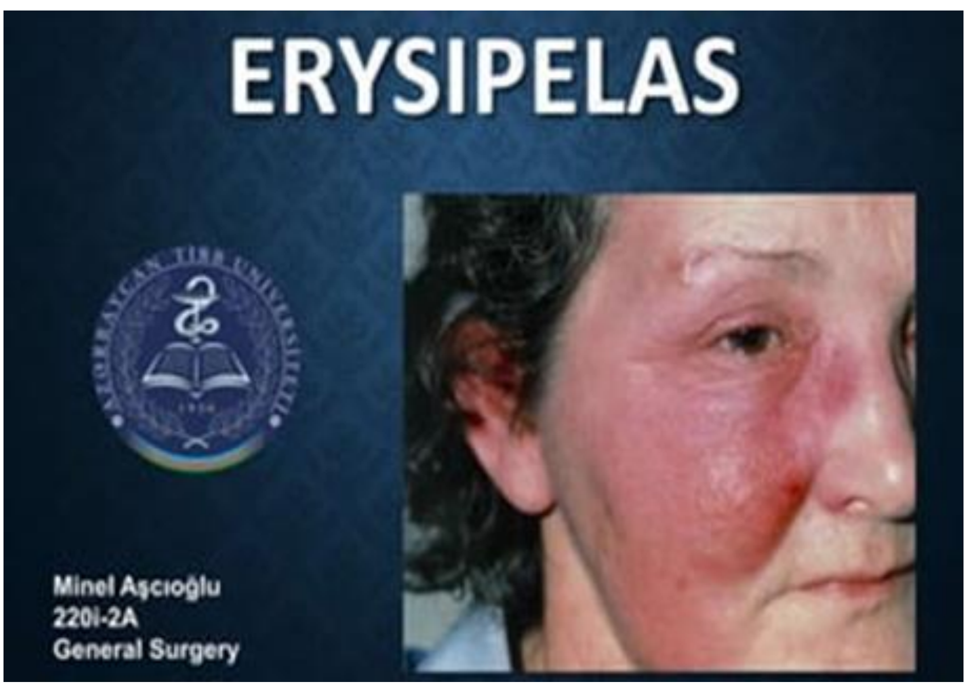

Fig. 6: Erysipelas (Erysipelas pptx. 2023).

In fish populations throughout Europe, North and South America, Australia and New Zealand, the bacteria are prevalent. By employing bacterial motility, disrupting intracellular signaling, intestinal cell adhesion and invasion, causing cell death, dodging the host immune system and acquiring iron for their growth and survival, the bacteria that cause campylobacteriosis present as enteritis (Amin et al. 2023). Recently, a water-borne disease called *Plesiomonas shigelloides* has been reported in freshwater fish (Duman et al. 2023).

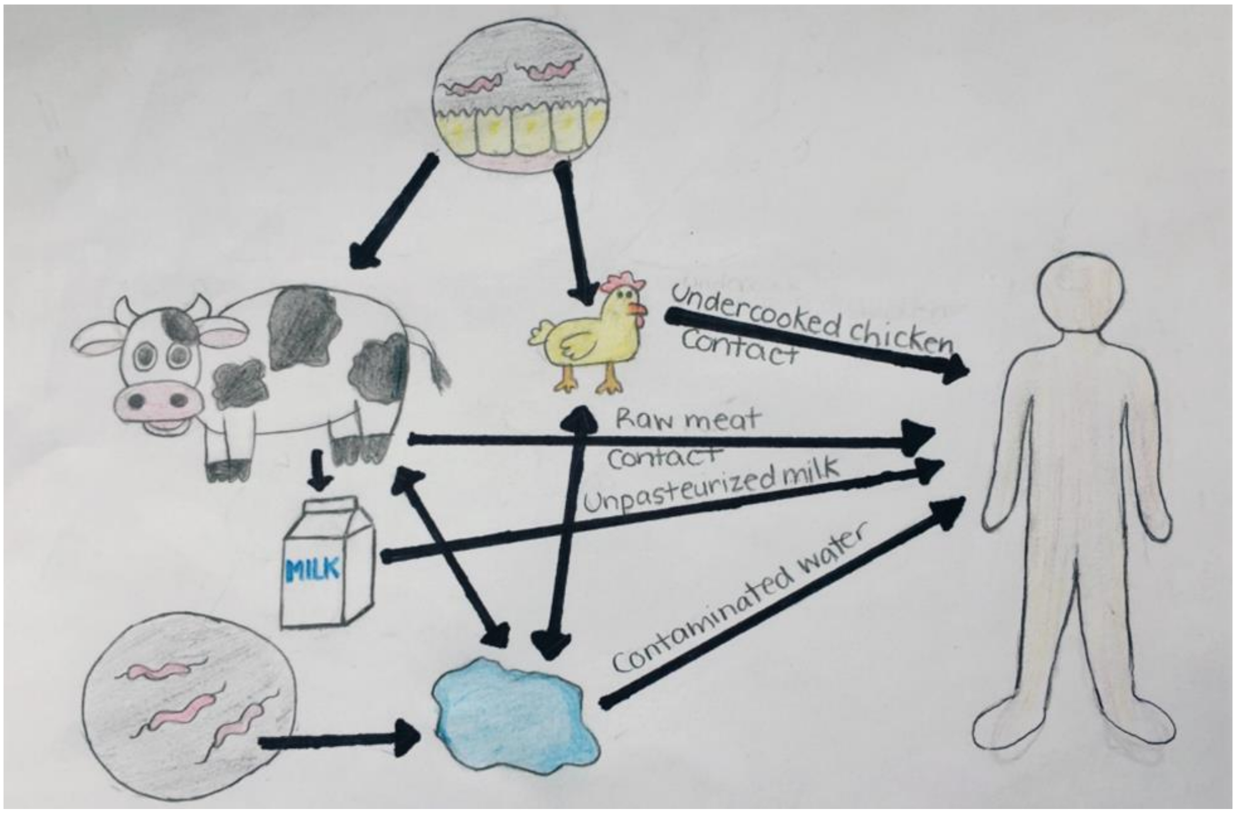

Fig. 7: Mode of Transmission of Campylobacter (Esson et al. 2016).

Legionella pneumophila which was also identified from a patient who worked at a fish market, is the bacteria that causes Legionnaires' disease/pneumonia. It spreads by aerosols and water. Salmonids, eels, goldfish, sole, sturgeon, trout, carps and turbot are all prone to yersiniosis, a contagious bacteremia also known as red mouth disease. Blood stains in the eye and exophthalmos are common symptoms of the disease (Yang et al. 2023).

The only way to completely eliminate Campylobacter from contaminated foods is by bactericidal treatment such as heating (such as cooking or pasteurisation) or irradiation. Despite the fact that Campylobacter infection tends to go away on its own, a recent assessment found that up to 80% of the population may have taken an oral antibiotic such a fluoroquinolone or macrolide for control (Dai et al. 2020).

6. VIBRIONACEAE

Vibrionaceae belongs to a family of gram-negative bacteria that can transmit disease in fish. Some of the species that commonly affect fish include *Vibrio anguillarum*, *Vibrio harveyi*, and Vibrio vulnificus (Helmi et al. 2020). Vibrionaceae infections in fish are often caused by the ingestion of contaminated food or water. Fish that are stressed or immunocompromised are more susceptible to infection.

The pathogenesis of Vibrionaceae infections in fish can vary depending on the species of bacteria involved. Some species produce toxins that can damage fish tissues, while others invade and multiply within the fish's cells. Vibrionaceae can be transmitted to fish through contaminated water, food, or equipment. Some species of Vibrionaceae can also be transmitted from infected fish to healthy fish (Takemura et al. 2014). The mode of transmission from aquatic environment to humans is shown in Fig. 8.

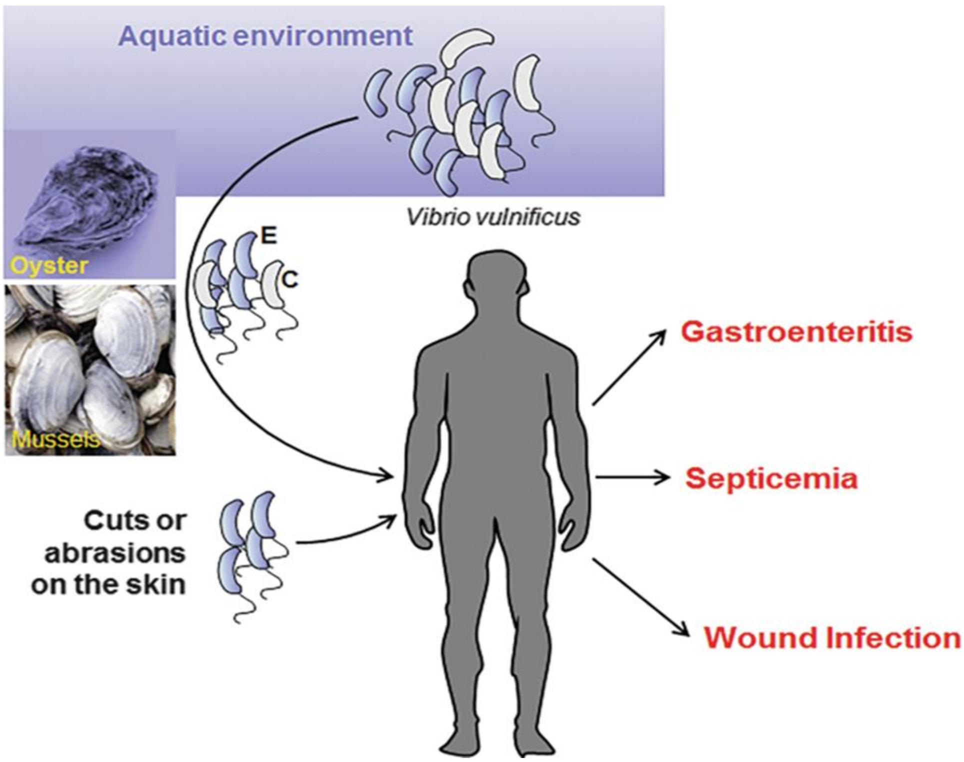

Fig. 8: Vibrio zoonosis (Bhunia and Bhunia 2018).

Vibrionaceae infections can occur in both wild and farmed fish populations. The incidence of these infections can vary depending on factors such as water temperature, salinity, and the presence of other pathogens. The clinical signs of Vibrionaceae infections in fish can include lethargy, loss of appetite, skin lesions, and hemorrhaging. In severe cases, the infection can be fatal (Ma et al. 2023).

Control measures for Vibrionaceae infections in fish include maintaining clean water and equipment, minimizing stress in fish populations, and implementing biosecurity measures to prevent the spread of infection. Antibiotics such as oxytetracycline and florfenicol can be used to treat Vibrionaceae infections in fish. However, however, excessive usage of antibiotics may result in the development of bacterial strains that are resistant to them (Banchi et al. 2022).

There are vaccines available for some species of Vibrionaceae that can be used to protect fish populations from infection. These vaccines are typically administered through injection or immersion in a vaccine solution. Postmortem lesions in fish infected with Vibrionaceae can include skin ulcers, hemorrhaging, and necrosis of internal organs such as the liver and spleen (Loo et al. 2023).

7. BOTULISM

Botulism in fish is caused by the bacterium *Clostridium botulinum*, which produces a potent neurotoxin that can cause paralysis in fish and other animals (Fig. 9). The spore-forming bacteria *Clostridium* *botulinum* is responsible for the botulinum toxins production. The botulinum toxin is produced when *C. botulinum* spores germinate and grow in an anaerobic environment, such as a decomposing fish carcass or contaminated sediment (Novakova et al. 2023).

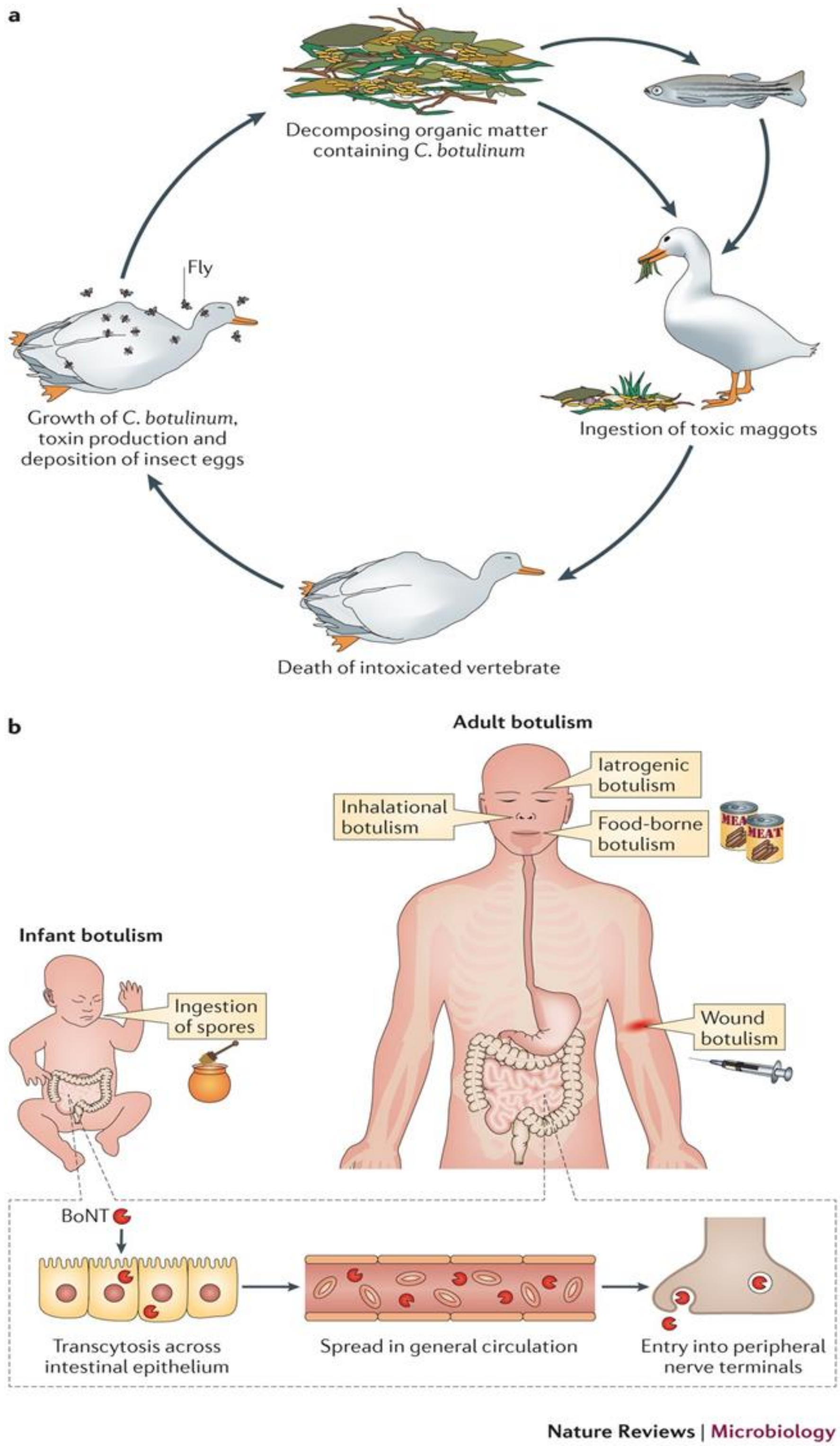

Fig. 9: Botulism toxicity (Rossetto et al. 2014).

The botulinum toxin is ingested by fish, which causes paralysis by blocking the release of acetylcholine, a neurotransmitter that stimulates muscle contractions. Fish can be exposed to botulinum toxin by eating contaminated feed or through contact with contaminated water or sediment. The toxin can also be transmitted from fish to fish through cannibalism. Botulism outbreaks in fish are most common in warm, stagnant waters with high organic loads. It can affect both wild and farmed fish populations (Peñuelas et al. 2022).
Fish with botulism may exhibit a variety of symptoms, including lethargy, loss of appetite, swimming in circles, and difficulty breathing. In severe cases, fish may be unable to swim or maintain buoyancy. Preventing the growth of *C. botulinum* spores is the key to controlling botulism in fish. This can be achieved by maintaining clean water quality and promptly removing dead or decaying fish from the environment (Goin et al. 2022).
There is no effective treatment for botulism in fish. Affected fish should be culled to prevent the spread of the toxin. There is no vaccine available for fish against botulism. Fish that have died from botulism may exhibit bloating, redness of the eyes and gills, and a lack of rigor mortis. The internal organs may also show signs of congestion and hemorrhage (Mirbehresi et al. 2022).

8. PSEUDOMONADACEAE

Pseudomonads is one of the most devastating fish infections that can cause hemorrhagic septicemia and ulcerative syndrome1. Numerous bacterial infections have an impact on a variety of aquatic species and cause significant economic losses on a global scale. *Pseudomonas aeruginosa* is a normal component of the fish microbiota but under stressful conditions like malnutrition and overcrowding, the bacteria have become highly opportunistic and pathogenic, causing illnesses like hemorrhagic septicemia, gill necrosis, abdominal distension, splenomegaly, friable liver and congested kidney (Holloway 2020). The various diseases caused by pseudomonads are listed in Fig. 10.
Frateuria, Pseudomonas, Xanthomonas and Zoogloea are the four genera that make up the family of gram-negative bacteria known as Pseudomonadaceae. These genera contain widespread saprophyte species that are harmful to people, animals, plants and soil microbes.
Pseudomonas aeruginosa is an environmental microorganism that can infect individuals in medical centers when they come into contact with polluted water or soil. The symptoms of pneumonia include an infection of the lungs, fever and chills, chest discomfort, fatigue and coughing up occasionally with yellow, green or dark mucus (Behzadi et al. 2021).
P. aeruginosa can cause infections in the human blood, lungs, or other parts of the body after surgery. Additionally, fish like tilapia are harmed by this bacterium. It can be found in short chains, pairs or even a single unit (Gajdács et al. 2021).
Following rigorous quarantine guidelines is the greatest way to stop Pseudomonas bacteria from spreading throughout your aquarium. In this way, the disease won't spread to the other fish in your tank if an anxious fish from capturing, transport and the new habitat begins to exhibit clinical symptoms (Duman et al. 2023).
An aminoglycoside plus an antipseudomonal beta-lactam (such as penicillin or cephalosporin) can be used in conjunction to treat pseudomonas infections. An aminoglycoside may be used with carbapenems (such as imipenem and meropenem) and antipseudomonal quinolones (Ali et al. 2023).

9. *AEROMONAS HYDROPHILA*

Fish that are infected with *Aeromonas hydrophila* develop "Motile Aeromonas Septicemia" (MAS), "Hemorrhagic Septicemia," "Ulcer Disease," or "Red-Sore Disease." There are various names for this condition that refer to the lesions brought on by this bacterium, including ulcers on the fish skin and septicemia, in which the bacteria or bacterial toxins are present in many of the fish organs. A common gram-negative rod-shaped bacterium called *Aeromonas hydrophila* lives normally in the gastrointestinal system and is frequent exclusion from fresh water ponds. These bacteria cause a disease that mostly affects freshwater fish, including catfish, many types of bass and numerous tropical or ornamental fish (Nawaz et al. 2023). The of action of *Aeromonas hydrophila* is shown in Fig. 11.

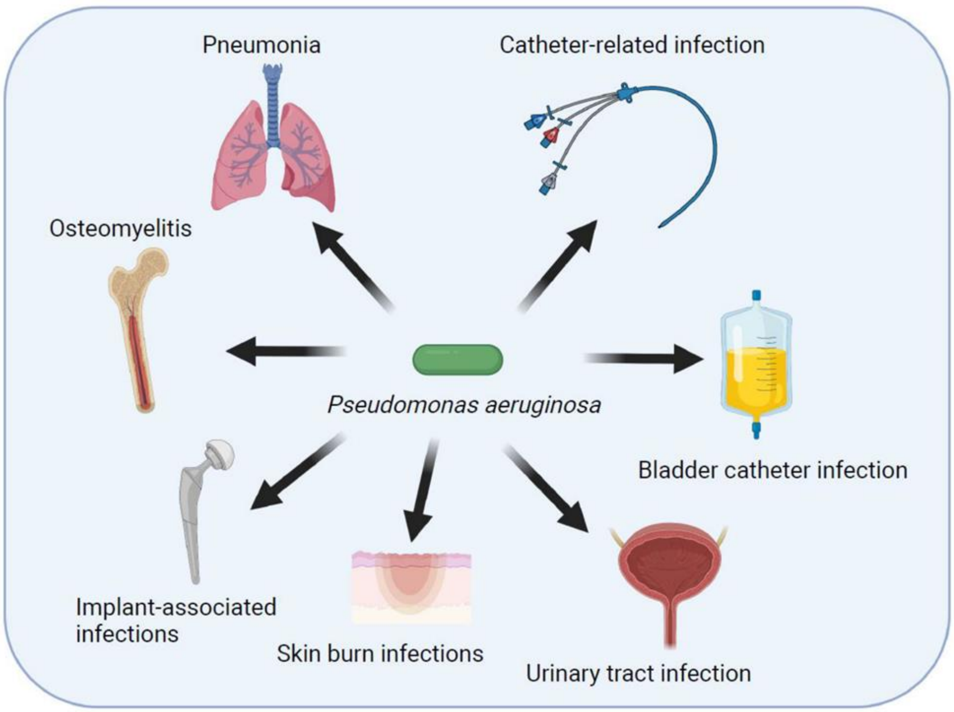

Fig. 10: Pseudomonads pathogenicity (Tuon et al. 2022).

Aeromonas hydrophila has frequently been referred to be an opportunistic pathogen. This seems to be a contradiction in terminology because most "opportunistic" bacteria often do not produce disease until other variables are present, but "pathogen" germs always cause disease. The term "opportunistic pathogen" indicates, however, that *Aeromonas hydrophila* is always capable of causing disease if given the chance. The organism is widespread in nature, as was previously mentioned, and is even present in fish intestines. when occurring naturally. *Aeromonas hydrophila* infections in fish are probably not a major issue. However, additional factors need to be taken into consideration when using intense fish-fanning systems, whether they be indoor aquariums or outdoor ponds. The existence of the disease is related to the fish stressed circumstances (Dorick et al. 2023).

Fish under adverse conditions due to poor water quality, such as high nitrite levels, low levels of dissolved oxygen (DO) or high levels of carbon dioxide (CO_2) are more prone to become infected with *Aeromonas hydrophila*. Additionally, lower water temperatures are linked to a seasonal occurrence of more rep-ted fish mortalities in the spring.

Symptoms of *Aeromonas hydrophila* infection in fish might vary widely. These include skin ulcerations, lack of appetite, strange swimming patterns, pale gills, unexpected death in apparently healthy fish and pale gills. The skin ulcer may appear anywhere on the fish, and it frequently has a vivid red tissue border around it. The gills, kidneys, liver, spleen, pancreas and skeletal muscle are additional organs that are frequently impacted by this condition. The severity of the symptoms varies depending on the organism infectiousness, the fish susceptibility to infection, the presence or absence of bacteremia or septicemia and the fish sensitivity to stress. The diagnosis of this disease based only upon symptoms is extremely inaccurate and may be financially devastating for the fish producer due to the diversity of these symptoms (Semwal et al. 2023).

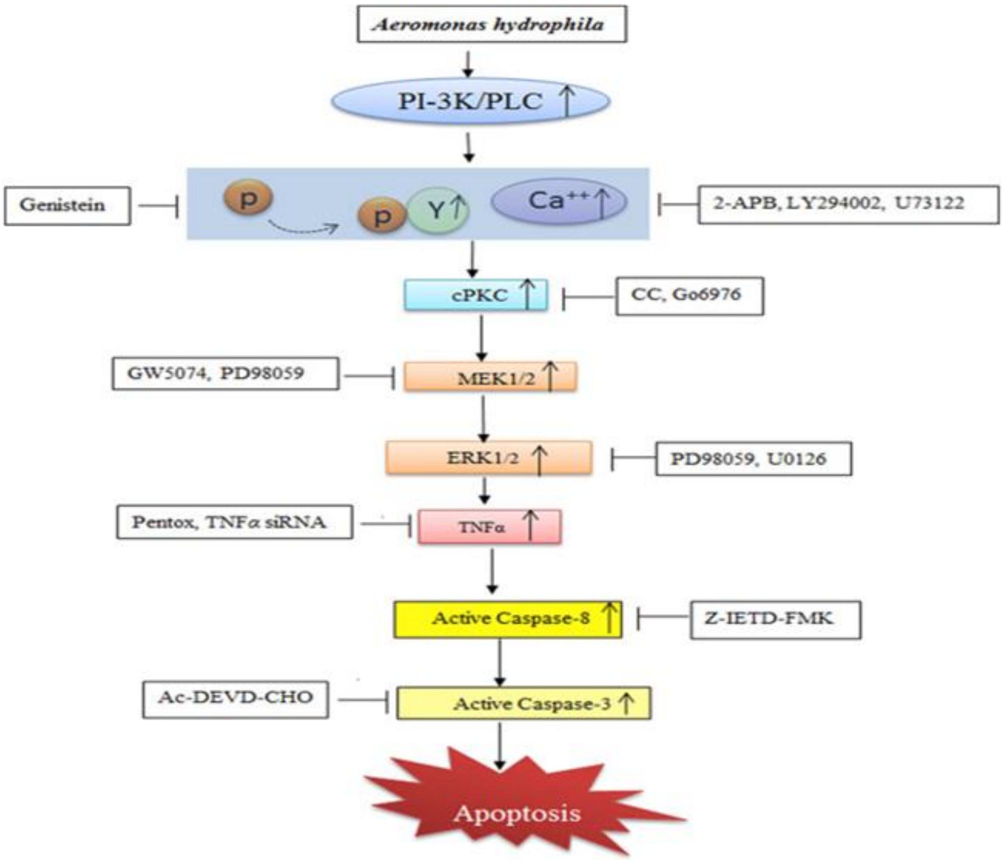

Fig. 11: *Aeromonas hydrophila* mode of action (Shelly et al. 2017).

Obviously, avoiding being infected with Aeromonas hydrophila is the best defence against infection. Although it might seem ridiculous, fish are far less likely to have this disease if stress factors are reduced by correct handling, stocking levels, nutrition, transportation and water that is not handled properly, is overcrowded, or is carried in inadequate circumstances. Poor sanitation, filtration and nutritional levels characterize the environment. Terramycin, an oxytetracycline and Remet-30 a potentiated sulfonamide is the only two antibiotics now used to treat this infection. A dip or bath is another approach for using antibiotics, though it is a bit of a contentious practice, and it is unclear if it is effective or successful. The indoor tank systems biofilters might be completely destroyed by this procedure, and it's conceivable that the fish may not get antibiotics (Ulzanah et al. 2023).

10. HAFNIACEAE

Hafniaceae is a family of flowering plants that belongs to the order Brassicales. The family consists of a single genus, Hafnia, which contains only one species, Hafnia alvei. This European native tiny annual herb may be found in a range of environments, including grasslands, meadows and cultivated fields (Cordovana et al. 2020).

Hafnia alvei is not typically used for any medicinal or culinary purposes, but it is known to produce a yellow pigment called hafnium. Hafnium is used in various industrial applications, including in the production of nuclear reactor control rods, as a component in electronic devices, and as a coating for gas turbine blades (Ramos-Vivas 2020).

The etiology of Hafniaceae, as a family of plants, would focus on understanding the evolutionary history and genetic makeup of this group of plants. Hafnia alvei, the only species within the family Hafniaceae, is a small annual herb with limited economic importance or medicinal value. As such, research into its etiology has been limited. That being said, researchers have studied the distribution and ecological characteristics of Hafnia alvei, the only species within Hafniaceae, to gain a better understanding of its natural history and ecology. Hafnia alvei is widely distributed in Europe and has been found in a variety of habitats including grasslands, meadows and cultivated fields. It is considered a common and widespread plant species, but further research is needed to fully understand its ecological preferences and how it interacts with other plant and animal species in its environment (Cordovana et al. 2020).

In fish, Hafnia alvei infection has been associated with a range of clinical signs, including skin ulcers, fin rot, septicemia, and hemorrhagic septicemia. Other possible signs of infection may include lethargy, loss of appetite, and abnormal behavior. The severity of the clinical signs may depend on a variety of factors, including the species of fish, the strain of the bacterium, and the environment in which the fish is living. In some cases, infection with Hafnia alvei may be asymptomatic or may only cause mild clinical signs (Ramos and Dámaso 2000).

Maintaining good water quality, removing uneaten feed and waste, and ensuring proper disinfection of equipment and surfaces can help reduce the risk of bacterial infections in fish. Before introducing new fish to an existing population, quarantining them can help stop the spread of infections like Hafnia alvei. To stop the transmission of disease between fish populations, appropriate biosecurity measures should also be followed. In cases where infection is severe or widespread, the use of appropriate antimicrobial agents may be necessary to control the infection. However, it is important to use antimicrobials judiciously and in accordance with local regulations to prevent the development of antibiotic resistance (Zhu and Miller 2004).

11. ENTEROBACTERIACEAE

The Enterobacteriaceae family which is commonly found in aquatic environments and the digestive tract of fish can cause various human infections. Escherichia coli, Klebsiella, and Salmonella are one of the zoonotic fish agents that has been found in Iran, demonstrating human infection and transfer to others (Azimi et al. 2021). The life cycle of enterobacteria is shown in Fig. 12. These bacteria commonly infect humans through open wounds, scratches or contact with fish, which results in an infection and inflammation at the site of the bacterium's entrance or systemic illnesses. Human illnesses with various members of this family of bacteria have occasionally been connected to food sources, such as consuming imported dried fish contaminated with *S. Typhimurium* (Oliveira et al. 2017).

12. *E. COLI*

Fish are now a new vector for this bacterium in water sources. *E. coli* strains in many fish species have been identified. Different *E. coli* strains can be retained by fish and spread to other water sources. Although *E. coli* is not a part of the normal fish microbiota. It is commonly isolated from fish intestines and found in contaminated water. *E. coli* has been seen invading other fish tissues such the gills, kidneys, muscles, and bladder (Kusunur et al. 2022; Yohans et al. 2022).

13. SALMONELLA

Salmonella enterica subspecies enterica is effective in the development of intestinal sickness through fish, aquaculture products and water. Salmonella is not a common fish bacterium; however, its existence depends on the water quality and aquatic habitat. *Salmonella typhimurium* and *Salmonella enteritidis* which are naturally spread by contaminated seafood are the most common causes of salmonellosis in humans. Environmental contamination and bacterial dissemination are significantly facilitated by Salmonella's survival in fish digestion and its detection in human faeces. Salmonella-infected fish consumption can result in symptoms including diarrhea, cramping in the stomach, fever, and bacteremia. Smoked fish contaminated with salmonella can also spread germs to people through their gills and skin (Zhou et al. 2022).

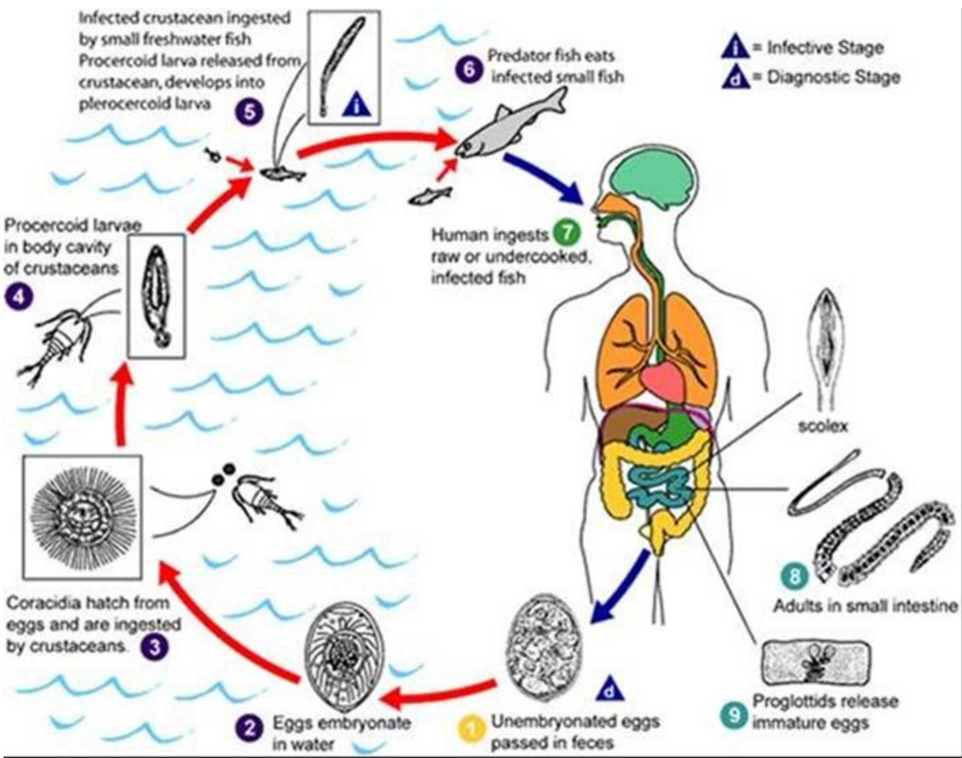

Fig. 12: Life cycle of enterobacteria (Shabani et al. 2019).

14. KLEBSIELLA

samples of water were taken from a dam, ocean, silt, and the intestinal contents of freshwater fish and prawns. There have been reports of K. pneumoniae isolation and diagnosis from farmed fish in India that had vacuolation and necrosis of hepatocytes in addition to clinical bleeding issues around the tail. Due to their zoonotic status and multi-drug resistance Klebsiella spp. (Klebsiella pneumoniae complex) is a threat to human transmission. Along with aberrant immune reactions, the direct effect of endotoxin also contributes to the appearance of Klebsiella infection in fish (Srinivasan et al. 2022).

15. YERSINIA

Yersinia is another gram-negative bacterium that affects both fresh and marine water fish. Over the past few decades, the incidence of *Y. ruckeri*-caused enteric red mouth (ERM) disease has significantly grown.

A few examples of the elements that influence a bacterium pathogenicity are the secretory system, pili, enzymes, toxins, outer membrane proteins, flagella, iron acquisition system, heat sensitivity factor and biofilm formation. The bacteria were isolated from a wound infection in a person who had come into contact with water, increasing the possibility that it was zoonotic but still requiring additional investigation (Wrobel et al. 2019). The mode of transmission is shown in Fig. 13.

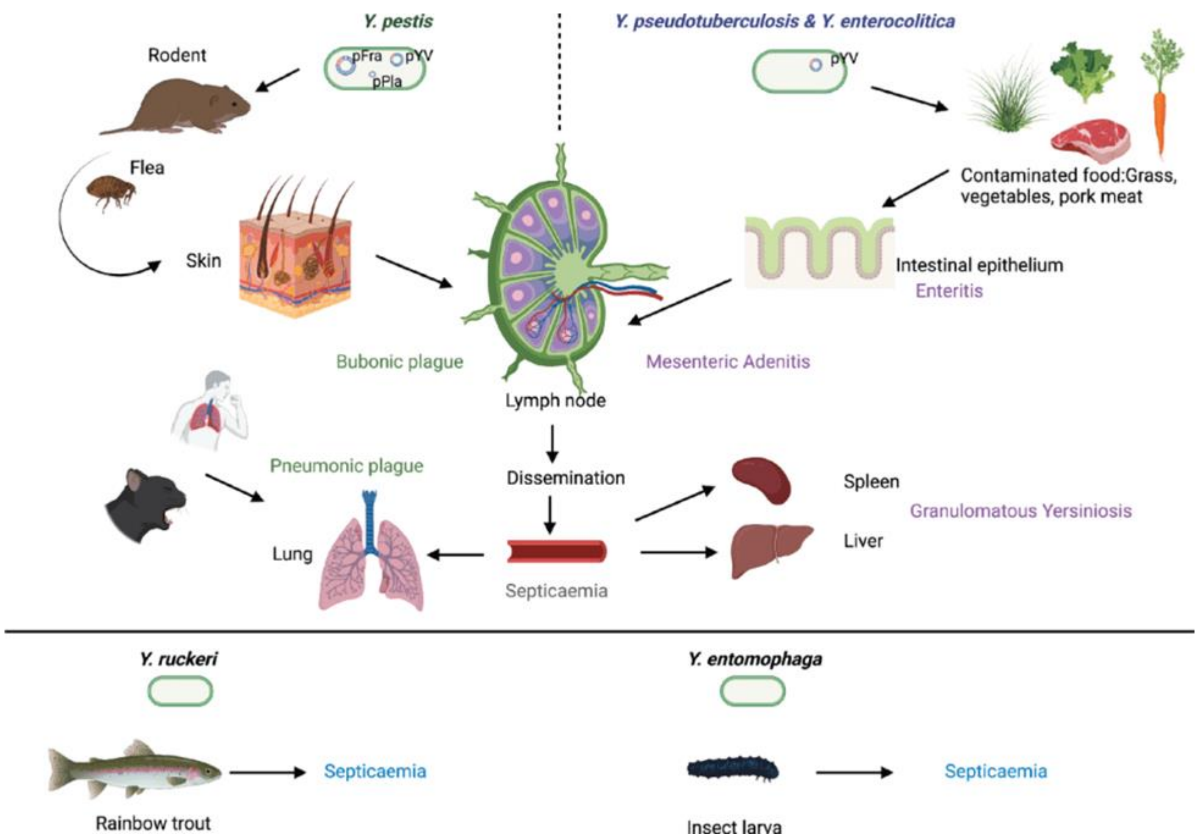

Fig. 13: Pathogenicity of Yersinia (Le Guern and Pizarro-Cerdá 2022).

16. TRANSMISSION AND RISK FACTORS

The transmission of bacterial zoonotic diseases from fish to humans involves various factors, including:

16.1 AQUACULTURE AND FISH FARMING PRACTICES

Intensive fish farming methods may lead to stressful and crowded circumstances which promote the spread of bacteria among fish populations. When animals are handled or processed by humans, high-density rearing can increase the danger of zoonotic infections.

16.2 TRADE AND GLOBALIZATION

The spread of zoonotic infections to other areas is facilitated by the global trading of fish and marine products. Contaminated fish from one part of the world transfer to other countries, contributed to disease outbreaks.

16.3 ENVIRONMENTAL AND CLIMATE CHANGE FACTORS

Aquatic ecosystems affected by climate change, which might influence the distribution and predominance of bacteria in fish populations. Pollution, fluctuating water salinity, and rising sea temperatures all have an impact on bacterial survival and proliferation, thereby raising the likelihood of zoonotic diseases.

17. TRANSMISSION OF BACTERIAL ZOONOSIS IN FISH

17.1 FISH TO HUMAN TRANSMISSION

- The primary route of transmission for bacterial zoonotic infections is the consumption of raw and uncooked fish.
- Contaminated water systems and the presence of bacterial pathogen in fish organs lead to infection in humans.

17.2 OCCUPATIONAL EXPOSURE

- During every day of their jobs, Fisherman, boaters, fish handlers are more likely to come into direct contact with diseased fish or polluted water which increases their risk of developing bacterial zoonosis.

17.3. RECREATION ACTIVITIES

- Recreation activities involves fishing, swimming, gardening, animals handling, ducks rearing might increase the risk of zoonotic infection.

18. HUMAN PATHOGENESIS AND CLINICAL SYMPTOMS

18.1 GASTROINTESTINAL INFECTION

- Many bacterial pathogens can cause common gastrointestinal symptoms like diarrhea, vomiting, and stomach discomfort.
- Salmonella spp., Vibrio parahaemolyticus, and other bacterial pathogens are frequently responsible for gastroenteritis caused by infected fish.

18.2 SKIN AND SOFT TISSUES INFECTION

- When handling fish, bacterial diseases like Streptococcus iniae and Vibrio vulnificus can enter the body through skin wounds or cuts, resulting in cellulitis and skin infections.

18.3 SYSTEMATIC INFECTIONS

- Several bacterial zoonotic pathogens can lead to serious systemic health issues specially in those who have weak immune systems.
- For instance, Vibrio vulnificus infections can result in septicemia which is potentially life-threatening.

19. CONTROL AND PREVENTION STRATEGIES

To minimize the risk of bacterial zoonotic diseases of fish several key control and preventive strategies can be implemented.

19.1 GOOF AQUACULTURE PRACTICES

Development of ethical and environmentally friendly aquaculture practices will help in lowering the risk of bacterial infections in fish populations. In order to prevent the development and propagation of zoonotic infections, it is essential to manage farms properly, check the quality of the water, and monitor disease outbreaks.

19.2 SAFETY OF FOOD AND HYGIENE

Implementing strict hygiene protocols must be used when handling, processing and transporting fish in order to avoid cross-contamination and reduce the possibility of zoonotic disease transmission.

19.3 REGULATORY MEASURES

Regulations for the farming of fish, processing, and trading can be established and enforced to ensure fidelity to food safety standards and lower the danger of zoonotic epidemics.

19.4 PUBLIC HEALTH EDUCATION

Promote awareness and early infection identification by educating consumers, fish handlers and medical experts about the dangers of bacterial zoonotic diseases due to fish.

Public health issues caused by bacterial zoonotic infections in fish must be successfully addressed, leading to the need for a multidisciplinary strategy. To protect both human health and the long-term viability of the fishing business, we can build focused preventative measures by understanding the biological mechanisms of zoonotic infections, their transmission methods, and risk factors. Public health organizations, policymakers, and stakeholders in aquaculture may work together to lower the risk of bacterial zoonotic diseases in fish and guarantee the security of seafood consumers across the world.

REFERENCES

Ali H et al., 2023. Molecular Detection of some Virulence Factors of Pseudomonas aeruginosa Isolated from Freshwater Fishes at Qalubiya Governorate, Egypt. Benha Veterinary Medical Journal 43: 80-84.

Amin SQ et al., 2023. Campylobacteriosis. One Health Triad, Unique Scientific Publishers, Faisalabad, Pakistan 2: 87-93.

Azimi T et al., 2021. Detection and characterization of Enterobacteriaceae family members carried by commensal Rattus norvegicus from Tehran, Iran. Archives of Microbiology 203: 1321-1334.

Banchi E et al., 2022. Improving environmental monitoring of Vibrionaceae in coastal ecosystems through 16S rRNA gene amplicon sequencing. Environmental Science and Pollution Research 29: 67466-67482.

Behzadi P et al., 2021. It’s not easy being green: a narrative review on the microbiology, virulence and therapeutic prospects of multidrug-resistant *Pseudomonas aeruginosa*. Antibiotics 10: 42.

Berzak R et al., 2019. Prevalence of nervous necrosis virus (NNV) and Streptococcus species in wild marine fish and crustaceans from the Levantine Basin, Mediterranean Sea. Diseases of Aquatic Organisms 133: 7-17.

Bhatnagar A et al., 2023. Assessment of bactericidal role of epidermal mucus of *Heteropneustes fossilis* and *Clarias batrachus* (Asian cat fishes) against pathogenic microbial strains. Aquaculture and Fisheries 8: 50-58.

Bhunia AK and Bhunia AK, 2018. Vibrio cholerae, Vibrio parahaemolyticus, and Vibrio vulnificus. Foodborne Microbial Pathogens: Mechanisms and Pathogenesis 315-329.

Bibi F et al., 2015. Occurrence of Salmonella in freshwater fishes: A review. Journal of Animal and Plant Sciences 25: 303-310.

Boylan S, 2011. Zoonoses associated with fish. Veterinary Clinics: Exotic Animal Practice 14: 427-438.

Buján N et al., 2018. *Edwardsiella piscicida*: a significant bacterial pathogen of cultured fish. Diseases of Aquatic Organisms 131: 59-71.

Cordovana M et al., 2020. Evaluation of the MBT STAR-Carba assay for the detection of carbapenemase production in Enterobacteriaceae and Hafniaceae with a large collection of routine isolates from plate cultures and patient-derived positive blood cultures. Microbial Drug Resistance 26: 1298-1306.

Dai L et al., 2020. New and alternative strategies for the prevention, control, and treatment of antibiotic-resistant Campylobacter. Translational Research 223: 76-88.

Deblais L et al., 2023. Prevalence and load of the campylobacter genus in infants and associated household contacts in rural eastern Ethiopia: A longitudinal study from the Campylobacter Genomics and Environmental Enteric Dysfunction (CAGED) Project. Applied and Environmental Microbiology 89: 00424-23. https://doi.org/10.1128/aem.00424-23

Declercq AM et al., 2013. Columnaris disease in fish: a review with emphasis on bacterium-host interactions. Veterinary Research 44: 1-17.

Dorick JM et al., 2023. Effect of aquaponic water and substratum material on biofilm formation by Aeromonas hydrophila. International Journal of Food Microbiology 404: 110316.

Duman M et al., 2023. Description of a Novel Fish Pathogen, *Plesiomonas shigelloides* subsp. oncorhynchi, Isolated from Rainbow Trout (*Oncorhynchus mykiss*): First Genome Analysis and Comparative Genomics Fishes 8: 179.

Duman M et al., 2023. Tentative Epidemiological Cut-Off Values and Distribution of Resistance Genes in Aquatic Pseudomonas Species Isolated from Rainbow Trout. Current Microbiology 80: 157.

Esson D et al., 2016. Genomic variations leading to alterations in cell morphology of Campylobacter spp. Scientific Reports 6: 38303.

Facciolà A et al., 2017. Campylobacter: from microbiology to prevention. Journal of Preventive Medicine and Hygiene 58: 79.

Farzadnia and Naeemipour M, 2020. Molecular techniques for the detection of bacterial zoonotic pathogens in fish and humans. Aquaculture International 28: 309-320.

Gajdács M et al., 2021. Insights on carbapenem-resistant Pseudomonas aeruginosa: phenotypic characterization of relevant isolates. Acta Biologica Szegediensis 65: 105-112.

Goin P et al., 2022. Pauci-symptomatic foodborne botulism due to *Clostridium botulinum* type B with predominant ophthalmologic presentation possibly after consumption of honey. Anaerobe 75: 102578.

Helmi AM et al., 2020. A review of vibriosis in fisheries: public health importance. Systematic Reviews in Pharmacy 11: 51-58.

Holloway BW, 2020. Pseudomonads. In *Genetics and breeding of industrial microorganisms* (pp. 63-92). CRC Press.

Hoseinifar SH et al., 2023. Sustainable Ornamental Fish Aquaculture: The Implication of Microbial Feed Additives. Animals 13: 1583.

Hrapkiewicz K et al., 2013. Clinical laboratory animal medicine: an introduction. John Wiley & Sons.

Irshath AA et al., 2023. Bacterial pathogenesis in various fish diseases: Recent advances and specific challenges in vaccine development. Vaccines 11: 470.

Iwasaki A and Medzhitov R, 2010. Regulation of adaptive immunity by the innate immune system. Science 327: 291-295.

Ji Q et al., 2020. A review: progress in the development of fish Vibrio spp. vaccines. Immunology Letters 226: 46-54.

Köster S et al., 2014. Crystal structure of listeriolysin O reveals molecular details of oligomerization and pore formation. Nature Communications 5: 3690.

Kusunur AB et al., 2022. Multidrug resistance of Escherichia coli in fish supply chain: A preliminary investigation. Journal of Food Safety 42: 12972.

Lassen SG et al., 2016. Two listeria outbreaks caused by smoked fish consumption—using whole-genome sequencing for outbreak investigations. Clinical Microbiology and Infection 22: 620-624.

Le Guern AS and Pizarro-Cerdá J, 2022. Yersinia. Pathogenesis of Bacterial Infections in Animals, Fifth Edition Chapter 9: 200-220. https://doi.org/10.1002/9781119754862.ch9

Li YW et al., 2014. Chronic streptococcosis in N ile tilapia, *Oreochromis niloticus* (L.), caused by *Streptococcus agalactiae*. Journal of Fish Diseases 37: 757-763.

Liu J et al., 2020. Isolation and characterization of bacteriophages against virulent *Aeromonas hydrophila*. BMC Microbiology 20: 1-13.

Loo KY et al., 2023. The Burden of Vibrio sp. Infections–A Scoping Review. Progress In Microbes & Molecular Biology 6: 2023. https://doi.org/10.36877/pmmb.a0000340

Luo X et al., 2017. Isolation, pathogenicity and characterization of a novel bacterial pathogen Streptococcus uberis from diseased mandarin fish *Siniperca chuatsi*. Microbial Pathogenesis 107: 380-389.

Ma JY et al., 2023. A systematic review, meta-analysis and meta-regression of the global prevalence of foodborne Vibrio spp. infection in fishes: A persistent public health concern. Marine Pollution Bulletin 187: 114521.

Matsuda Y et al., 2023. Activation of inflammasomes and mechanisms for intracellular recognition of Listeria monocytogenes. Microbiology and Immunology 2023: 1-9. DOI: 10.1111/1348-0421.13091.

Mirbehresi H et al., 2022. Epidemiological aspects of poisoning Infectious-toxic bacteria of botulism on food poisoning in Iran; A review study. Egyptian Journal of Veterinary Sciences 53: 25-30.

Nawaz M et al., 2023. Transcriptome profiling and differential expression analysis of altered immune-related genes in goldfish (*Carassius auratus*) infected with *Aeromonas hydrophila*. Fish & Shellfish Immunology 137: 108789.

Novakova E et al., 2023. Norwegian Fermented Fish as Possible Source of Foodborne Botulism–is the Risk of Contracting Botulism from Fermented Fish Still Relevant?. Journal of Microbiology, Biotechnology and Food Sciences 12: 10116-10116.

Oliveira RV et al., 2017. Disease infection by Enterobacteriaceae family in fishes: a review. Journal of Microbiology and Experimentation *4: 00128.*

Opriessnig T et al., 2020. Erysipelothrix Spp.: past, present, and future directions in vaccine research. Frontiers in Veterinary Science 7: 174.

Peñuelas M et al., 2022. Botulism in Spain: Epidemiology and Outcomes of Antitoxin Treatment, 1997–2019. Toxins 15: 2.

Pomaranski EK et al., 2018. Characterization of spaC-type *Erysipelothrix* sp. isolates causing systemic disease in ornamental fish. Journal of Fish Disease 41: 49-60.

Pomaranski EK et al., 2020. Description of *Erysipelothrix piscisicarius* sp. nov., an emergent fish pathogen, and assessment of virulence using a tiger barb (*Puntigrus tetrazona*) infection model. International Journal of Systematic and Evolutionary Microbiology 70: 857-867.

Ramos A and Dámaso D, 2000. Extraintestinal infection due to Hafnia alvei. European Journal of Clinical Microbiology and Infectious Diseases 19: 708-710.

Ramos-Vivas J, 2020. Microbiología de Hafnia alvei. Enfermedades Infecciosas y Microbiología Clínica 38: 1-6.

Rossetto O et al., 2014. Botulinum neurotoxins: genetic, structural and mechanistic insights. Nature Reviews Microbiology 12: 535-549.

Semwal A et al., 2023. A review on pathogenicity of *Aeromonas hydrophila* and their mitigation through medicinal herbs in aquaculture. Heliyon 9: 14088.

Shabani N et al 2019. Assessment of Various Subtypes of *Salmonella serotypes* and *Salmonella enteritidis* as Important Human Pathogens According to Standard Microbiological Methods. Journal of International Dental and Medical Research 12: 900-906.

Shelly A et al., 2017. *Aeromonas hydrophila*-induced alterations in cytosolic calcium activate pro-apoptotic cPKC-MEK1/2-TNFα axis in infected headkidney macrophages of Clarias gariepinus. Developmental & Comparative Immunology 76: 392-402.

Soares SCP, 2015. Tempo de tratamento de osteomielite por Staphylococcus aureus: análise secundária de dados. https://repositorio.ufba.br/handle/ri/16871.

Srinivasan KR et al., 2022. Production of bioflocculant from Klebsiella pneumoniae: evaluation of fish waste extract as substrate and flocculation performance. Environmental Technology 1-14.

Takemura AF et al., 2014. Associations and dynamics of Vibrionaceae in the environment, from the genus to the population level. Frontiers in Microbiology 5: 38.

Tartey S and Takeuchi O, 2017. Pathogen recognition and Toll-like receptor targeted therapeutics in innate immune cells. International Reviews of Immunology 36: 57-73.

Thirumalaikumar E et al., 2021. Oral delivery of pVAX-OMP and pVAX-hly DNA vaccine using chitosan-tripolyphosphate (Cs-TPP) nanoparticles in Rohu, (*Labeo rohita*) for protection against Aeromonas hydrophila infection. Fish & Shellfish Immunology 115: 189-197.

Tuon FF et al., 2022. Pathogenesis of the Pseudomonas aeruginosa biofilm: A review. Pathogens 11: 300.

Ulzanah N et al., 2023. Peptide hydrolysate from fish skin collagen to prevent and treat *Aeromonas hydrophila* infection in Oreochromis niloticus. Veterinary Research Communications 47: 487-494.

Verma AK and Kumar A, 2018. Erysipeloid: occupational disease. Journal of Entomology and Zoology Studies 6: 923-926.

Wood RL and Steele JH, 2019. Erysipelothrix infections. In Handbook of Zoonoses, Second Edition, Section A (pp. 83-91). CRC Press.

Wrobel A et al., 2019. Overcoming fish defences: the virulence factors of *Yersinia ruckeri*. Genes 10: 700.

Yacoub et al., 2023. Fish Bacterial Pathogen in Gills, Skin, Kidney, Intestines, and its Water at Elmahmoudia and Edfina. Alexandria Journal for Veterinary Sciences 76.

Yohans H et al., 2022. Levels of Escherichia coli as Bio-Indicator of Contamination of Fish Food and Antibiotic Resistance Pattern Along the Value Chain in Northwest Ethiopia. Veterinary Medicine: Research and Reports 13: 299-311. https://doi.org/10.2147/VMRR.S373738.

Zhou X et al., 2022. A global dataset for prevalence of Salmonella Gallinarum between 1945 and 2021. Scientific Data 9: 495.

Zhu D and Miller RA, 2004. Hafnia-Based Materials Developed for Advanced Thermal/Environmental Barrier Coating Applications. Research and Technology 2003.

Ziarati M et al., 2022. Zoonotic diseases of fish and their prevention and control. Veterinary Quarterly 42: 95-118.