Understanding Antimicrobial Resistance in Aquaculture Causes and Consequences

Amna Abbas[1,*], Sajid Abdullah[1] and Andleeb Zahra[1]

[1]Department of Zoology, Wildlife and Fisheries, University of Agriculture, Faisalabad, Pakistan
*Corresponding author: amnaabbasuaf5@gmail.com

Abstract

Aquaculture productivity and per capita fish consumption have risen dramatically over the last two decades. Intensified aquaculture systems are more susceptible to disease outbreaks that can lead to significant losses. Antimicrobial drugs are frequently utilized as a therapeutic practice to tackle disease outbreaks. Their excessive use has led to antimicrobial resistance (AMR), where pathogenic organisms evolve to survive favorably. This chapter demonstrates the concepts of antimicrobial resistance in aquaculture, its causes of emergence, its harmful consequences, and mitigation strategies. Multiple drivers like misuse of antimicrobials, contaminated feed, climate change, and antimicrobial-laden water discharge also drive AMR in aquaculture. These causes create selective pressure, also fostering reservoirs of resistant microbes and mobile resistant genes in fish pathogenic agents and other aquatic pathogens. The harmful consequences of AMR are profound like poor treatment efficiency, propagation of resistive genes to the environment, loss of consumers' trust, disruption of aquatic environments, economic losses, and public health concerns, etc. Multiple approaches like improved disease management, probiotics or prebiotics, vaccines, phage therapy, and CRISPR techniques must be employed to mitigate AMR.

Keywords: Aquaculture, Antimicrobial resistance (AMR), Public health issues, Ecological issues, Vaccines, Mitigation approaches.

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Introduction

Aquaculture is a major food-producing industry that is expanding at high rate on a global level and the rapid growth of this industry carries with it, the possibility of numerous challenges (Naylor et al., 2023). Intensive aquaculture systems, characterized by high fish density, inadequate hygiene conditions, and physical stressors (i.e., high density, management or transportation, aquatic predator species, pollution, etc.), as well as water quality problems (i.e., pH levels, temperature variations, and ventilation), offers a range of issues. Such intensification results in disease outbreaks in aquaculture implying disorders occur by pathogenic organisms like bacteria, viruses, fungi, and parasites that flourish in aquatic ecosystems (Shoemaker et al., 2015). Such disorders can spread quickly in high stocking-density culture systems, leading to significant health issues and productivity losses (Behringer et al., 2020).

Diseases in aquaculture are predominantly controlled by utilizing antimicrobial drugs to stop and treat disorders common in intensified culture systems due to high densities, poor water quality parameters, and stress (Assefa & Abunna, 2018). These antimicrobials are often administered via medicated aquafeeds or directly into the water, efficiently targeting pathogenic organisms and lowering death rates (Romero et al., 2012). Nonetheless, the frequent and sometimes indiscriminate utilization of antimicrobial drugs offers selective pressure on microbial communities, encouraging the existence and propagation of resistant strains. This resistant strain can lead to microbial populations, making therapeutics less efficient and spreading quickly. The rise of Antimicrobial resistance (AMR) can take place via horizontally, by the diffusion of mobile resistance genes, allowing the acquisition of mobile genetic elements such as plasmids, and transposons, thereby propagating genetic factors, or vertically by point mutations (Markiewicz & Popowska, 2020).

Antimicrobial resistance in aquaculture is principally associated with the unnecessary and often unregulated usage of antimicrobials to control outbreaks in cultured aquatic animals (Bhat & Altinok, 2023). Administering unregulated antimicrobials as a protective measure develops selective pressure, which permits resistive strains to flourish. Poor biosecurity measures, like insufficient sanitation and high densities, aggravate the propagation of diseases, urging the over-dependence on antimicrobials. Furthermore, aquaculture wastewater carrying residual antimicrobials without treatment or partly treated enters natural water environments and promotes the growth and propagation of resistive genes in the aquatic bodies (Singh et al., 2024). Horizontal gene transfers among bacteria, accelerated by the close contact of different microbial populations in aquaculture systems, speeds up the spread of resistant characters. Mutually, these factors build reservoirs of resistant strains and genes that harm the efficacy of antimicrobial drugs, not only in the aquaculture sector but also in human or veterinary medicines (Santos & Ramos, 2018).

Antimicrobial resistance is posing significant dangers to both human health and the surroundings (Jasovsky et al., 2016). As pathogenic microbes in aquaculture become resistant to commonly used antimicrobial drugs, the efficiency of treatments reduces, leading to prolonged or untreated diseases in cultured animals. This not only leads to high death rates and financial problems but also takes part in spreading resistant strains into the aquatic environments (Watts et al., 2017). Such resistant strains can transmit to human pathogenic microbes via the food chain or environmental exposure, lowering the efficacy of antimicrobial therapeutics utilized in human medicines. Eventually, the emergence of resistant strains lowers aquaculture sustainability, human health, as well as the efficacy of antimicrobial drugs worldwide.

The necessity for control of antimicrobial resistance in aquaculture is critical and poses threats to human health, the surroundings, as well as the sustainability of the aquaculture sector. Efficient mitigation measures are critical not only to safeguard public health as well as the environment but also to guarantee the continuous viability or growth of the aquaculture industry. Focusing AMR in aquaculture needs urgent action to apply control measures, raise sustainable practices, as well as lower the broad utilization of antimicrobials in the sector. Controlling an AMR in the aquaculture sector needs a multifaceted strategy that involves proper regulations, the use of alternatives to antimicrobials, and selective selection (Santos & Ramos, 2018).

This chapter examines the understanding of antimicrobial resistance in aquaculture, its causes, consequences, and potential mitigation strategies, highlighting the significance of sustainable practices in tackling this increasing harm.

1. Antimicrobial Resistance in Aquaculture

Antimicrobial drugs have been employed to hinder the development and proliferation of a widespread variety of pathogenic microbes in human as well as veterinary medicines, since the invention of penicillin by Alexander Fleming in 1929 (Palma et al., 2020). Successive expansion by Ernst Chain as well as Howard Florey during World War II proceeded to the antimicrobial drugs revolution, which has been evolved by the expansion of many other categories of antimicrobial drugs. Today, antimicrobial drugs play a chief part in modern livestock yield production for inhibition and management of disorders and growth enhancement (Hao et al., 2014). Incorporating antimicrobials in food animals has been unchecked in several countries due to poor rules or policies and poor management. The global development in aquaculture production has caused rising dependency on antimicrobial drugs with residues in the products produced for public use (Okocha et al., 2018).

Emergence of Antimicrobial Resistance

In aquaculture, antimicrobial drugs are regularly incorporated into the aquafeed, which is then distributed in the water bodies. In some cases, antimicrobial drugs may be incorporated into the water directly. This leads to selective pressure within the exposed ecosystems, typically aquatic environments (Felis et al., 2020). The utilization of antimicrobial drugs in aquaculture can encompass extensive environmental implementation that influences various pathogenic organisms. Numerous pathogenic species may sustain poor circumstances or unfavorable changes in their surroundings by acquiring mutations that enhance their survival in novel environments. Different antimicrobial-resistive drugs, especially antibiotic-resistive bacterial species, and resistive genes are discussed in Table 1. Pathogenic organisms like bacteria also benefit from mobile genetic materials like plasmids or transposable elements. Through these components, bacterial species can access a substantial reservoir of migratory genes that transfer from one bacterial cell to another, large pool of migrant genes that transmit from one bacterial cell to another cell to another and facilitating the dissemination throughout bacterial population (Preena et al., 2020).

Table 1: Different Antibiotic-Resistant Bacteria and their Linked Genes and Carriers.

Resistance Category	Antibiotic Drugs	Bacterial Species	Antibiotic-Resistant Gene	Source of Sample	References
	Oxolinic acid	*Escherichia coli*	qnrA, qnrB and qnrS	Water and sediments	(Robicsek et al., 2006)
Quinolone Resistance	Nalidixic acid	*F. columnare*	gyrA, gyrB	Sea bass	(Chokmangmeepisarn et al., 2021)
	Enrofloxacin; Norfloxacin	*S. agalactiae*	gyrA, parC	Tilapia	(Chokmangmeepisarn et al., 2021)
Tetracycline Resistance	Tetracycline	*Streptococcus Agalactiae*	tetM	Tilapia	(Liang Jingzhen et al., 2018)
	Oxytetracycline	*Epilithonimonas* spp.	tet (X)	Rainbow Trout	(Concha et al., 2021)
		Pseudomonas and *Stenotrophomonas*	tetA	Water and Zebra Fish	(Almeida et al., 2021)
Beta Lactam Resistance	Ceftriaxone; Ceftazidime	*Klebsiella pneumoniae*	bla_{CTX-M}	Tilapia	(Thongkao & Sudjaroen, 2019)
	Sulfonamides; Colistin	*E. coli*	bla_{CTX-M}, bla_{TEM}, mcr-1 gene	Red tilapia, Striped Catfish	(Thaotumpitak, 2021)
Sulfonamides Resistance	Sulfonamides	*Vibrio* and *Mycobacterium*	sul1 and sul2	Water and sediment	(Hoa et al., 2008)
Integrons and Gene Cassettes Associated With Resistance	Tetracyclines; Sulphonamides	Different bacterial strains	sul1, sul3	Rainbow Trout	(Capkin et al., 2017)
	β lactams	*K. pneumoniae*	int 1	Tilapia	(Thongkao & Sudjaroen, 2019)
Polymyxins	Colistin	*E. coli*	mcr-1	Fish gut	(Hoa et al., 2022)
Plasmid Mediated Resistance	Tetracyclines; β lactams	Different species	Tetracyclines efflux pumps (tetA-D) and β lactams (ampC, bla_{pse})	Rainbow Trout	(Bhat & Altinok, 2023)

Resistance Development Mechanism

Numerous methods of antimicrobial resistance disseminate to a diversity of pathogen species. Microbes may achieve genes encoding enzymes, like beta-lactamases, that break beta-lactams. Antimicrobial drugs like antibiotics inactivating enzyme reactions involve phosphorylation, adenylation, as well as acetylation (Moo et al., 2020). Bacterial species may obtain multiple genes for metabolism, resulting in a modified cell wall that lacks binding sites for antimicrobial agents, or bacteria may attain genetic alternation that restrict the availability of treatment drugs to the intracellular target location. Similarly, a significant outcome of the extensive use of antimicrobials in livestock and aquaculture is the emergence of drug-resistant pathogenic microbes (Hossain et al., 2022).

Categorization of Antimicrobial Resistance

There are two main categories of antimicrobial resistance: acquired resistance and natural resistance (Abushaheen et al., 2020). The inherent ability of certain bacterial species or genera to resist external factors is a notable characteristic. It continues as it is transmitted from the parent cell to its offspring unless later alterations make it susceptible. This helps microorganisms to resist antibiotics because of their natural properties. Consistently recognized and maintained within bacterial species is this inherent resistance. Acquired resistance shows only when exposed to antibiotics. This type of resistance, called induced resistance, is not an inherent property of microorganisms; rather, it arises as a response to external stimuli. Bacteria can acquire resistance through many processes, including horizontal gene transfer (HGT) and mutation within chromosomal DNA (Samtiya et al., 2022).

Dissemination of Antimicrobial Resistance

Antimicrobial resistive genes are propagated through three mechanisms, as discussed in Figure 1:

a) Conjugation: It is a horizontal gene transfer facilitated by cell-cell contact through pili junction. It is linked with a movable genetic element, i.e., plasmid, which can move more rapidly than a whole chromosome (Zarei-Baygi & Smith, 2021).

b) Transduction: It is also a horizontal genetic transfer with phages, which mediates intracellular DNA material transmission from an affected cell of bacteria to the receiving cell. Bacteriophages are viruses that infect bacteria and can gather and move genetic material to host cells. Phages can transmit both chromosomal genetic material and plasmid genetic material (Von-Wintersdorff et al., 2016).

c) Transformation: This is a different mechanism from other genetic material transfer mechanisms, in which the extracellular resistant genes can be introduced into competent cells of non-resistant strains by the process of spontaneous transformation. In this process, bacterial strains can take up DNA from their surroundings, introduce it into their genetic material, and acquire new genetic traits (Lerminiaux & Cameron, 2019).

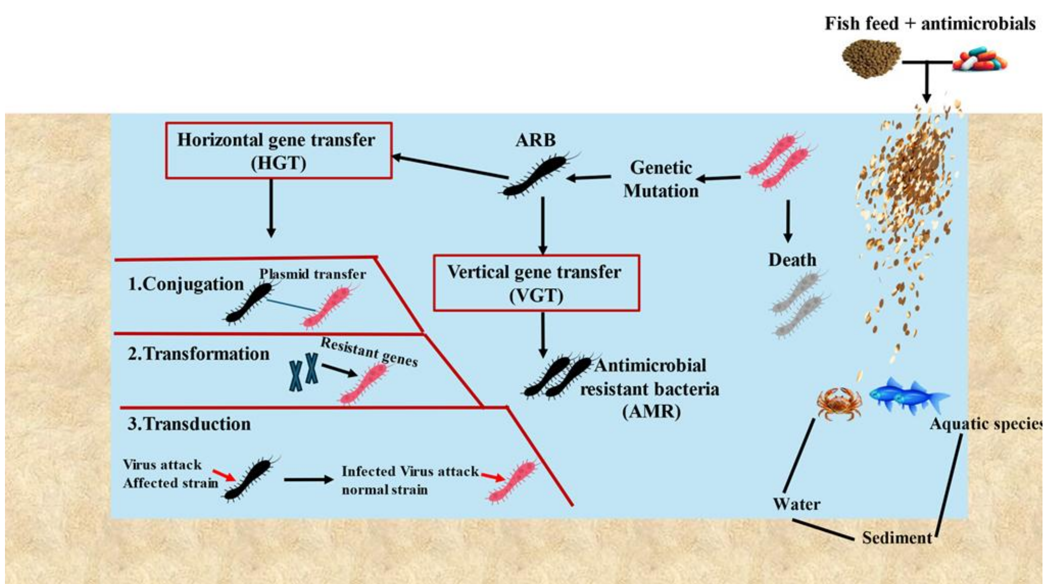

Fig. 1: Antimicrobial Resistance and Dissemination Patterns in Aquaculture.

2. Causes of Antimicrobial Resistance in Aquaculture Sector

There are a diverse variety of causes of the emergence of antimicrobial resistance in aquaculture, shown in Figure 2, that are discussed below:

Overuse of Antimicrobial Drugs (ABs)

The improper use or overdependence on antibiotics may be ascribed to misdiagnoses frequently conducted by the farmers themselves. In aquaculture, antibiotics contribute to mitigating substantial economic losses and preventing widespread mortality associated with inadequate biosecurity and hygiene practices. Recently, fish growers all over the world, lately not only adopting restricted antimicrobial and antibiotic usage but also recognizing the new industry regulations and standards. The incorporation of ABs in aquafeed can affect the emergence of resistant bacteria in the intestines of aquatic organisms, leading to the proliferation of carriers of resistant pathogens and genetic material (Ibrahim et al., 2020).

Biologically Active Antimicrobial Residues in Aquatic Environment

The most usual method for the administration of antimicrobial drugs to aquatic species includes mixing antimicrobials with medicated aquafeed. Nevertheless, fish are not fully effective in antimicrobials' metabolism, through their bodies they are leading to transferring a major portion and then being discharged into the surroundings, often in an unchanged form. It has been assessed that about 75 percent of the antimicrobials are released unaltered into water bodies that are administered to aquatic species as a treatment. These released antimicrobials are still biologically active and eventually emerge antimicrobial resistance in aquatic bodies (Harris et al., 2012).

Wastewater Treatment Plants

Treatment plants for wastewater have the potential to be a significant source of resistant bacteria or resistant genes, and pathogenic effluents from these treatment plants can be released into aquatic ecosystems. Likewise, livestock discharges or agriculture runoff can add resistant microbes to marine systems. Additionally, waste from therapeutic companies or hospitals and runoff stimulate complex interactions between microbes and the public (Kumar & Pal, 2018).

Antimicrobial Residues in Sediments or Water

The primary concern is that antibiotic residues may persist in the sediments or water of culture systems even after the drugs have been eliminated from the system (Gyesi et al., 2022). When antimicrobials are utilized in livestock farming, they can drop some residues in aquatic bodies via leaching, runoff, or discharge. These remains can further contribute to the emergence of resistance. These residues can adversely influence the natural environment, involving the selection and propagation of resistant microbes and genes.

Production of Biofilms in Culture Systems

These represent additional potential hotspots for the development of antimicrobial resistance in aquaculture. As such, the overuse of antimicrobials in aquaculture may lead to the development of biofilms. Biofilms can form on multiple surfaces in aquaculture systems, such as nets, tanks, and pipes. The biofilms have the potential to the growth and spread of pathogens that are resistant to antimicrobial agents. A physical barrier can be formed by the extracellular polymeric components that are present in the biofilm matrix. This barrier inhibits antimicrobial drugs from accessing the pathogens that are responsible for the infection, hence make the pathogens less sensitive to antimicrobial treatment. In addition, bacteria that are found in biofilms are able to increase the efficiency with which they interchange genetic material, which can lead to an increase in the possibility of horizontal transmission of resistance genes (Pandey & Kumar, 2022).

Addition of Manure

The introduction of manure into the fish systems discharges inorganic nutrients, which enhances the growth of photosynthetic species that are then consumed by the fish species. Aquafeed carries antimicrobial treatments, that are added to improve growth performance or for controlling disorders. So, antimicrobial drugs and resistive strains are passed into the culture systems and then go into the fish's body. Furthermore, the direct treatment of fish in the aquaculture system increases the antimicrobial resistance in the fish gut. Nonetheless, adding animal-based manure into integrated farms could be linked with a high emergence of antimicrobial-resistive species, which may harm fish quality and their shelf life (Watts et al., 2017).

Integrated Fish Culturing

Integrated farming generates higher productivity with lower input, with the fish getting limited supplementary aquafeed. Comparatively, the livestock in integrated farms, like fish, chickens, and cattle, is cultured intensively, so antimicrobial treatments are applied as growth enhancers. Within integrated fish culturing systems, treatment drugs, their remains, and resistive strains pass into the fish culture systems via animal excreta and excessive feeding and eventually become potential causes of antimicrobial-resistive agents (Preena et al., 2020).

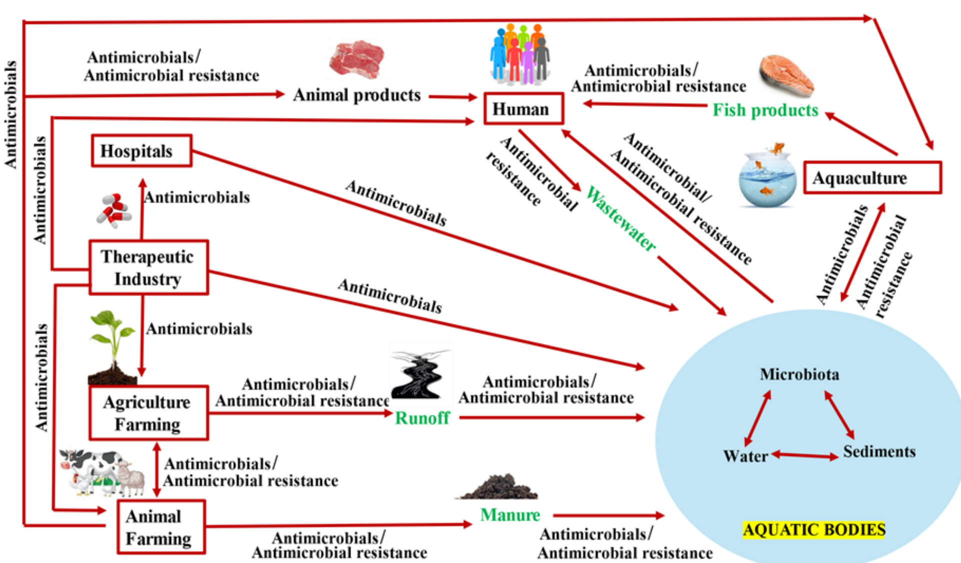

Fig. 2: Diverse Variety of Causes of Emergence of Antimicrobial Resistance in Aquaculture.

Variation in Climate

The increasing temperatures may result in a variation in the physiology of cells of microbiota, so triggering the development of AMR (Santos & Ramos, 2018). The increasing temperatures are a systematic modulator that accelerates the transfer of resistance, like within aquatic environments. A study evaluated that countries with a 10 °C warmer environment experienced faster spreading of antimicrobial resistance to other countries. The stated rise in AMR varied from 0.33 to 1.2 percent each year. The patterns of high temperatures may raise further propagation of AMR worldwide, making mitigation approaches more complex (Pepi & Focardi, 2021).

3. Consequences of Antimicrobial Resistance in Aquaculture

Today, the expansion and spread of antimicrobial resistance have evolved into a worldwide problem that is influenced by utilization of antimicrobials in both human and non-human contexts (Radhouani et al., 2014). This growing concern has significant consequences and impacts, both within the aquaculture industry and for broader public health, as represented in Figure 3. Some of the key consequences and impacts include:

1) Ecological Influences

❖ Disruption of Natural Environments: The resistant bacteria that flourish in aquaculture may transfer to natural environments via runoff, wastewater discharge, or direct discharge of treated wastewater back into lakes, rivers, or oceans. In such ecosystems, the resistant bacteria could contaminate wild aquatic animals, harm natural microbiota, and make a more competitive ecosystem for resistive pathogenic organisms that could outcompete native, non-resistant microbial pathogens (Priya et al., 2024).

❖ Influence on Wild Populations: When antibiotic-resistant pathogens transfer to wild fish populations, they may reduce the overall health of wild fish, leading to higher mortality rates or reduced reproduction (Milijasevic et al., 2024). This could undermine efforts to protect wild species and manage fish populations in marine and freshwater environments. In turn, this could impact local fisheries, further exacerbating economic problems.

2) Economic Impacts

❖ Higher Health Expenditures: Increased antibiotic-resistant diseases can raise healthcare expenditures, as more advanced medications may be needed to control resistant disorders (Dadgostar, 2019). This not only influences health but also places pressure on healthcare systems worldwide. These expenditures may indirectly impact the aquaculture systems, specifically in areas where health is already under pressure due to such resistive disorders (Lafferty et al., 2015).

❖ Alternative Treatments' Expense: Aquaculture practices may require adopting substitutive approaches for disorders control, like applying vaccines, probiotics, and natural remedies instead of antimicrobial drugs. These substitutes, while potentially efficient, may be costlier and less available than conventional treatment drugs (Bhat & Altinok, 2023).

❖ Trading Limitations: Areas with higher levels of treatment resistance may encounter trading limitations from other areas that have strict regulations about the safety of food items and antimicrobial treatment resistance (Maron et al., 2013). If seafood exports are observed to be polluted with resistive strains, then whole areas may encounter bans and penalties, leading to significant economic losses for aquaculture practices.

❖ Loss of Consumer Confidence: Purchasers are highly aware of health risks linked with antimicrobial resistance, particularly in aquaculture products. High public concerns regarding seafood safety, particularly if resistant pathogenic microbes are identified, can result in lowered demand for fish products (Jennings et al., 2016). This loss of consumers' confidence could result in economic issues for the sector, specifically in competitive markets.

3) Public Health Impacts

Aquatic bodies are a great source of resistive pathogenic organisms which can be transferred to humans as well as develop infectious diseases in public because resistive characteristics lead to failures in treatments (Serwecinska, 2020). Propagation of diseases to the human population can be via direct contact with water or aquatic species, through drinking water, handling or utilization of fisheries' products (Cabello et al., 2013). High frequency of treatment failures, as well as higher severity of diseases due to resistance, may lead to long-term illness, a high rate of bloodstream infections, high hospitalization, and a high death rate (Preena et al., 2020).

4) Impact on the Welfare of Cultured Species

❖ Higher Suffering in Cultured Fish: When antimicrobial resistance lowers the efficiency of common antimicrobial drugs, it may result in long-term and untreated diseases in cultured aquatic species. This leads to weakened health, reduced growth performance, and a high death rate. Aquatic animals that remain diseased for longer periods may suffer from chronic disorders that adversely impact their welfare. Because of resistance, antimicrobial treatments become less efficient; farmers may be required to apply more extreme practices (Hossain et al., 2022).

❖ Great Stress on Population: When outbreaks occur in culture systems, animal populations may encounter a high rate of stress that can make them more vulnerable to disorders (Behringer et al., 2020). Stress ruins aquatic species' immunity responses, eventually leading to poor health performance, which is challenging to defeat without efficient management practices.

4) Mitigation Approaches to Control Antimicrobial Resistance in Aquaculture

As shown in Figure 3, there are multiple alternatives to using antimicrobial treatments in the aquaculture sector. The most important alternatives are probiotics, prebiotics, immunostimulants, vaccinations, essential oils, and phage therapy.

i. Prebiotics and Probiotics: Prebiotics are undigestible food additives that can encourage the growth and development of bacteria in the digestive tract. Hence offering a stable gut bacterial community and enhancing the performance of aquatic species (Akhter et al., 2015). There are multiple prebiotics that are generally used in aquatic farming, like mannan oligosaccharides, fructo-oligosaccharides, chitin, chitosan, etc., (Carbone & Faggio, 2016).

Probiotics are living microbes which offer health advantages when taken up in suitable amounts like lactic acid bacteria, *Bacillus* spp. etc., these bacteria, mainly yeast or bacteria are known for their beneficial impacts on hosts, typically animals and humans. It contributes to the maintenance of a suitable microbial environment, especially in the gut, encouraging digestive activity and eventually improving the immunity system (Hai, 2015).

ii. Immunostimulants: They include substances that improve aquatic species' immunity systems. They also help control disorders and lower the demand for antimicrobials. Like β-Glucans are polysaccharides that are derived from yeast cell walls, bacterial cell walls, and fungi cell walls, improving immunity (Wang et al., 2017). Vitamin C is an antioxidant that protects aquatic species from oxidative stress. They help in the improvement of fish growth as well as their survival in unfavorable settings by activating their immunity systems, resulting in a higher generation of antibodies or white cells (Dawood et al., 2018).

iii. Vaccination: Vaccines are made up of pathogenic organisms like viruses, bacteria, etc., that are deactivated, attenuated, or altered genetically in artificial pathways to prevent harmful outbreaks. These are referred to as fundamental tools for the control of infectious disorders and also act as an essential way to reduce the utilization of antimicrobial treatments in aquaculture farming (Mondal & Thomas, 2022).

iv. Essential Oils: Herbal extracts act as promising additives and substituents due to their efficacy, eco-friendly nature, and lowered treatment resistance (Reverter et al., 2014). The effectiveness of these plant-based medicines in controlling infectious disorders is due to their immune enhancement, antioxidative, or antipathogenic impacts of their active elements (i.e., polyphenols, alkaloids, saponins, etc).

v. Antimicrobial Peptides (AMPs): They are small, genes-encoded peptides found in living bodies like bacteria, plants, humans, etc.; these peptides perform a significant role in the upkeep of microbiota and the innate immune system of aquatic species. Like D-Caerin is presented with high antimicrobial activity effectively against *Vibrio* infections (Milijasevic et al., 2024).

vi. Bacteriophage Therapy: Phages are viruses in nature that can kill bacterial pathogens. They are composed of protein shells comprising nucleic acids and proteins (Ramos-Vivas et al., 2021). In antimicrobial-resistant aquaculture systems, phage therapy acts as a holistic approach to controlling pathogenic microbes in aquaculture production systems.

vii. Hygiene Management: The execution of sanitary practices is essential for the prevention and management of AMR in aquaculture. For instance, the poor sanitary conditions in the pond environment result in the bioaccumulation of residues as sediments at the ponds bottom, therefore raising the probability of survival of pathogens resistant to antimicrobial treatments (Milijasevic et al., 2024). Regular and correct application of hygienic habits can help to lower the demand for antibiotics. When implemented regularly and correctly, hygienic techniques can subsequently reduce the need for antimicrobials. This involves the implementation of appropriate hygienic conditions throughout all phases of aquaculture production, from farming to processing (e.g., management of waste and control of fish health with isolation of diseased animals, sterilization of equipment, facilities, pools, and vehicles, control of access to farms/ponds) (Thornber et al., 2020).

viii. CRISPR Strategy: It is a novel gene editing technique that has been introduced in genetic engineering recently. It is a bacterial immune system referred to as clustered regularly interspaced short palindromic repeats-CRISPR (Garcia-Mier et al., 2019). Those genes which can enhance antimicrobial resistance are primarily present in plasmids. Plasmids can move resistive genes between multiple bacterial species. This plasmid searches out the resistant genes for gentamicin and cuts the DNA material, eventually eradicating the resistance (Gupta et al., 2024).

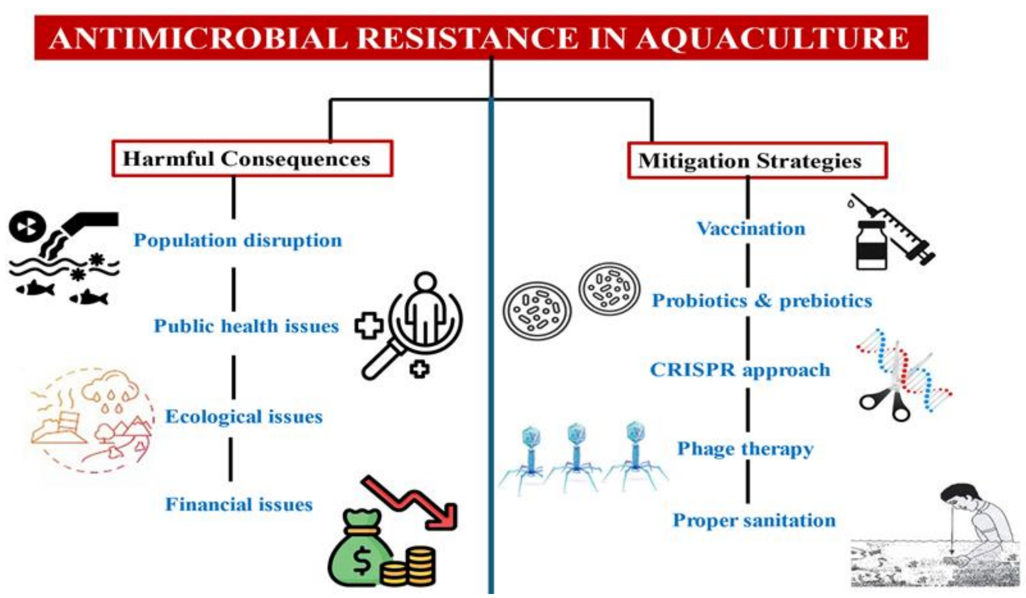

Fig. 3: Consequences of Antimicrobial Resistance in Aquaculture and Their Mitigation Approaches.

Conclusion

Intensive aquaculture systems encounter disease outbreak challenges that are overcome by using antimicrobial drugs, while multiple factors lead to antimicrobial resistance (AMR). Antimicrobial resistance (AMR) in aquaculture is a critical problem that has emerged because of the overuse of antimicrobials, the use of manure in culture systems, climatic variations, integrated farming systems, etc. These factors drive the occurrence of resistant strains and movable resistant genes in aquaculture systems. These resistant elements not only adversely impact the effectiveness of treatments in aquaculture but also offer a significant risk to human health through horizontal gene transfer and polluted natural ecosystems. The major adverse impacts of AMR include lowered therapeutic efficacy, human health risks, disturbances in aquatic environments, and, eventually, financial problems for the aquaculture sector. Addressing these problems demands a multifaceted approach involving proper disease management, careful antimicrobial drug use, usage of the CRISPR technique, proper vaccination, etc. By adopting such mitigation approaches, the aquaculture sector can prevent the risks of AMR while assuring its long-term viability and sustainability.

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