Available online at http://www.journalijdr.com

ISSN: 2230-9926

IJDR

International Journal of Development Research
Vol. 14, Issue, 09, pp. 66685-66690, September, 2024
https://doi.org/10.37118/ijdr.28766.09.2024

REVIEW ARTICLE

OPEN ACCESS

A REVIEW ON APPLICATION OF AQUACULTURE DRUGS FOR SUSTAINABLE AQUACULTURE

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ARTICLE INFO

ArticleHistory:

Received 17th June, 2024
Received in revised form
06th July, 2024
Accepted 18th August, 2024
Published online 30th September, 2024

Key Words:

Aquaculture drugs, Sustainable aquaculture, Antimicrobial resistance,
Fish health, Regulatory frameworks.

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ABSTRACT

The increasing global demand for aquaculture products has necessitated the development of sustainable farming practices to meet food security goals.Use of drugs in aquaculture is practiced mainly for management of diseases, growth promotion, and health maintenance of fish. This will eventually ensure efficient processing in the field. This review therefore intends to give an overview of the drugs applied in aquaculture including antibiotics, antifungals, antiparasitics, and probiotics, their applications, and their particular contribution towards achieving sustainable aquaculture. Though these drugs contribute immensely to increased survival rates of fish and, subsequently, decrease in economic losses, uncontrolled or overuse of such drugs may lead to problems such as AMR, pollution, and other modifications in aquatic ecosystems. The paper strongly emphasizes responsible use of drugs and, besides these, expounds on other alternatives such as immunostimulants and herbal products that recently gained popularity due to their eco-friendliness. It further highlights the regulatory frameworks of drug use in aquaculture and the need to follow established guidelines that would prevent any danger to human health, the environment, and the sustainability of the industry. Future research should be toward developing better therapeutic agents that are more efficient and safer and strategies for monitoring and managing residues of drugs used. Therefore, an integrated approach combined with technological advancements, responsible usage of drugs, and environmentally friendly alternatives should be considered to make the aquaculture sector sustainable in the long run.

Citation**:** ***Panchakarla Sedyaaw and Dr. Bhatkar, V.R. 2024.*** *"A review on Application of Aquaculture drugs for Sustainable Aquaculture". International Journal of Development Research*, 14, (09), 66685-66690.

INTRODUCTION

Aquaculture, often referred to as fish farming, is one of the fastest-growing food production sectors globally. As global demand for seafood continues to rise, aquaculture has emerged as a crucial industry to meet this demand and alleviate the pressure on wild fish stocks. According to the Food and Agriculture Organization (FAO), aquaculture now contributes more than 50% of the world's seafood supply, with estimates suggesting that this proportion will continue to grow in the coming decades (FAO, 2022). However, the rapid expansion of aquaculture has brought about a host of challenges, including disease outbreaks, environmental degradation, and concerns about the use of chemicals and drugs in fish farming. The sustainable use of aquaculture drugs has become a pivotal area of research and policy-making to ensure the long-term viability of the industry without compromising environmental health or food safety. The use of drugs in aquaculture encompasses a broad range of substances, including antibiotics, antifungals, antiparasitics, and disinfectants. These substances are essential for managing disease outbreaks and maintaining the health of farmed aquatic species. However, improper or excessive use of these drugs can lead to several negative consequences, such as antimicrobial resistance (AMR), contamination of aquatic ecosystems, and the accumulation of drug residues in seafood, posing risks to human health (Miranda *et al*., 2023). In recent years, there has been a growing emphasis on promoting the responsible use of aquaculture drugs and developing alternative disease management strategies to enhance sustainability in the industry. This review aims to provide an overview of the current applications of drugs in aquaculture and their impact on sustainable aquaculture practices. By examining the various categories of drugs used in fish farming, the associated risks, and the regulatory frameworks governing their use, we seek to highlight the challenges and opportunities for promoting more sustainable practices in the industry. Furthermore, this review will explore emerging trends in aquaculture drug research, including the development of environmentally friendly therapeutics, probiotics, and immunostimulants, which hold promise for reducing reliance on traditional chemical treatments.

Sustainable Aquaculture Practices: In aquaculture, disease outbreaks can lead to significant economic losses and threaten the viability of fish farms. To prevent and control these outbreaks, producers rely on various drugs, including antibiotics, antifungals, and antiparasitics. Antibiotics are frequently used to treat bacterial infections, while antifungals and antiparasitics are applied to manage fungal and parasitic diseases. These drugs are essential for maintaining the health of farmed species, particularly in high-density farming systems where the risk of disease transmission is elevated (Cabello *et al*., 2020). However, the overuse and misuse of these drugs can lead to several problems, including the development of antimicrobial resistance (AMR), environmental contamination, and the accumulation of drug residues in aquatic ecosystems and food products (Miranda *et al*., 2023). Antimicrobial resistance occurs when bacteria evolve to become resistant to antibiotics, rendering these drugs less effective. In aquaculture, the use of antibiotics can promote the development of resistant bacterial strains, which can then spread to wild aquatic species, other ecosystems, and potentially humans through the consumption of contaminated seafood. This poses a significant public health threat and has been recognized as a global issue by organizations such as the World Health Organization (WHO) and the Food and Agriculture Organization (FAO) (Lulijwa *et al*., 2020). Moreover, drugs used in aquaculture can persist in the environment, affecting non-target species and disrupting aquatic ecosystems. For instance, some antiparasitic drugs used to control sea lice in salmon farming have been shown to harm benthic organisms, such as crustaceans and mollusks, and reduce biodiversity in the surrounding environment (Defoirdt *et al*., 2019). These environmental impacts highlight the need for more sustainable practices in aquaculture, particularly concerning the use of drugs.

Strategies for Sustainable Aquaculture and Reducing Drug Use: To promote sustainability in aquaculture, it is essential to reduce the reliance on chemical treatments and implement more environmentally friendly practices. Several strategies have been proposed to achieve this, including improved biosecurity measures, the use of probiotics and immunostimulants, and the development of vaccines.

1. ***Biosecurity and Farm Management Practices:*** One of the most effective ways to reduce the need for drugs in aquaculture is by implementing biosecurity measures. Biosecurity involves practices designed to prevent the introduction and spread of diseases in aquaculture systems. This includes measures such as maintaining proper water quality, controlling the density of farmed species, and ensuring that fish are sourced from disease-free hatcheries. Proper biosecurity can reduce the incidence of disease outbreaks, thereby minimizing the need for antibiotics and other drugs (Gudding *et al*., 2021). In addition to biosecurity, sustainable farm management practices such as integrated multi-trophic aquaculture (IMTA) can help reduce environmental impacts. IMTA involves the co-cultivation of species from different trophic levels, such as fish, shellfish, and seaweed, in the same system. This approach helps to create a more balanced ecosystem, where waste from fish farming can be utilized by other organisms, reducing pollution and improving water quality. By promoting healthier ecosystems, IMTA can lower the risk of disease outbreaks and reduce the need for chemical treatments (Chopin *et al*., 2020).
2. ***Probiotics and Immunostimulants:*** Probiotics and immunostimulants are emerging as promising alternatives to traditional drugs in aquaculture. Probiotics are beneficial microorganisms that can be added to the diet of farmed species to improve their gut health and boost their immune system. By enhancing the overall health of fish and other aquatic organisms, probiotics can help reduce the incidence of diseases, thus lowering the reliance on antibiotics (Ringo *et al*., 2020). Similarly, immunostimulants are substances that enhance the immune system of farmed species, making them more resistant to infections. These can include natural compounds such as plant extracts, yeast derivatives, and beta-glucans. Immunostimulants have been shown to increase the effectiveness of vaccines and improve the overall health of fish, reducing the need for antibiotics and other drugs (Harikrishnan *et al*., 2022). The use of probiotics and immunostimulants is seen as a more sustainable approach to disease management in aquaculture, as they do not contribute to antimicrobial resistance or environmental contamination. Furthermore, these natural products are biodegradable and have minimal impact on the surrounding environment.
3. ***Vaccination:*** Another approach to reducing the use of antibiotics in aquaculture is vaccination. Vaccinationworks very well against bacterial and viral infection threats. In fact, there is a very low need for antibiotics as vaccination programs have been correctly used in aquaculture systems, primarily in salmon aquaculture, where vaccines have significantly reduced the level of antibiotic use (Evans *et al*., 2021). Vaccines are very critical when it comes to control mechanisms, especially in disease prevention, though developing and applying them can be cumbersome. The vaccine must be species-specific and targeted for the specific pathogens existing within the studied aquaculture system. Additionally, it may not work well in certain environmental conditions, such as high-water temperatures that impair the ability of fish to develop immunity. However, despite all these challenges, vaccination remains one of the keystones of sustainable aquaculture-a preventative measure with no environmental and health risks due to chemicals.

Antiviral agents: For example, viral infections are among the irresistible diseases in farmed fish; they pose a great monetary issue to aquaculture farmers (Ganjoor, 2016). Viral infections have been for long refractory to specific antiviral chemotherapy since the cycle of the infection is considerably too strongly interwoven with typical cell metabolism so that any attempt to interrupt the spread of infection would inevitably kill, or at least seriously injure, too, the uninfected cell (De Clercq, 2001). It has become increasingly apparent that infection spread can be suppressed without injurious effects on the host by specific chemotherapy of viral diseases with the illustration of virus-specific events as focuses for chemotherapeutic assault and the coming of various particular antiviral agents, it has turned out to be progressively evident that specific chemotherapy of viral diseases can be accomplished (Pushpa *et al*., 2013). The use of antiviral drugs in aquaculture is limited and has gone unreported.

Antibacterial agents: Similar to the case in terrestrial animal production to have a sufficient fish production, several classes of antibiotics are applied in aquaculture for the treatment of bacterial infections (Mo *et al*., 2017). Antibiotics have been applied in aquaculture, mainly for therapeutic purposes and as a preventive requirement (Sapkota *et al*., 2008). Antimicrobials are pharmaceutical drugs designed with the capability of killing or inhibiting the growth of microorganisms. They work through different mechanisms of action when administered. These drugs act through any of the three pathways: by disrupting cell membranes, by disrupting protein or DNA association or by inhibiting enzyme activity (Burridge *et al*., 2010). The top antibiotics used by intensive aquaculture producers include the following: oxytetracycline, oxolinic acid, chloramphenicol, erythromycin, furazolidone, trimethoprim, sulfadiazine, ampicillin, florfenicol, flumequine, and sulfadimethoxine. Sulfonamides are employed universally in aquaculture to prevent infections caused by pathogens due to their critical action. Still, little is considered about the residues and dietary risks associated with cultured fish. Among them, the predominant class of antibiotics used include sulphadiazine (SDZ), sulphamethoxazole (SMZ), sulpha methazine (SDD), and sulphamonomethoxine (SMM) and were present during the culture period at significant levels (>100 g/kg fish) (Song *et al*., 2017). Sulphamethazine (SMZ) is among the most broadly used sulphonamide compounds in fish culture, however, its physiologic effects in fish are unknown. This antibiotic is very frequently traced to surface waters and sediments due to its high usage (Zhao *et al*., 2016). Tribrissen (sulfadiazine: trimethoprim, 5:1) is a broad-spectrum sulphonamide antibacterial agent also used to treat furunculosis (Aeromonas salmonicida) and vibriosis infection in salmon e.g., Vibrio anguillarum. Tribrissen acts by inhibiting folic acid metabolism.

Antiseptics and disinfectants: The disinfection can reduce the risk of disease transmission within the premises of aquaculture and from the premises into the environment by deactivating pathogens with disinfectants (Sekkin and Kum, 2011). The use of disinfectants on water may be carried out as part of specific conditions for disease control or sanitization. There is a wide range of active chemical agents, many of which have been in use for centuries for antisepsis, decontamination, and preservation. In general, disinfectants present a much broader spectrum of activity than antibacterial agents, and whereas antimicrobials have a tendency for specific intracellular targets, biocides may have numerous and diverse targets (McDonnell and Russell, 1999). Chemicals or by-products contain chlorine, formalin, iodophors, ozone and UV light (Rodgers and Furones, 2009). Formaldehyde is still widely used in aquaculture because of its wide antiparasitic activity, although it is classified as a human carcinogen (IARC, 2004). Formalin is a potential and potent disinfectant used to kill bacteria or as preservative for biological specimens. With a concentration of about 37% formaldehyde by weight, formalin is normally sold as an aqueous solution (Bruno *et al*., 2011). It acts by reacting with cell proteins and nucleic acids, altering both its form and function (Ali *et al*., 2015). Mutagenic and carcinogenic effects are also associated with malachite green, also highly used against parasitic treatment. Chlorine is widely used in hatcheries and farmed ponds, but its use promotes the expression of several antibiotic-resistance genes in bacteria (Murray *et al*., 1984). Chloramine-T is a disinfecting chemical that inactivates a few pathogen types. It is described to be one of the most powerful antimicrobial agents, especially as an antiviral agent to be used in disinfection (Ganjoor, 2016). It dissolves in water in the process of immersion therapy, forming hypochlorous acid that enters through the cell wall, prevents enzymatic activity, and causes cellular death (Burridge *et al*., 2010). Hydrogen peroxide distinguished as a compelling antifungal, antibacterial and antiviral compound with low impact on the ecosystem (Bruno *et al*., 2011).

gradually lose their mobility, equilibrium, consciousness, and finally their reflex action. In the fisheries and aquaculture sectors, anaesthetics are also useful in minimizing stress connected with handling and transport. The application of anaesthetics in Indian aquaculture has primarily been mainly for long-distance transportation of the highly prized commercial broodstock and fish seed. The most commonly used anesthetic drugs on fish are MS-222 (Tricaine), benzocaine, isoeugenol, metomi date, 2-phenoxyethanol, and quinaldine (Ackerman *et al.,* 2011).

Vaccines: Vaccines are prepared from antigens are derived from pathogens and converted to non-pathogenic by reducing the virulence through various ways which regulates immune response in fish and increase disease resistance capacity. Fish vaccination was 1st discovered in 1942 against Aeromonas salmonicida infection (Ayalew and Abunna, 2018). Protection at primary level can be attained through vaccination. Again, the licensing and registration of new vaccine is much easy rather than antibiotics (Ayalew and Abunna, 2018). Recently, there are some commercial vaccines markedly available for infectious bacterial and viral diseases of fish diseases in aquaculture. Report indicates that the first commercially fish vaccines ever developed happened to be bacterial ones, which were marketed in the USA in the late 1970s (Roar and Muiswinkel, 2013. These were whole-cell immersion vaccines that worked very effectively in preventing various bacterial infections. Advancement in biotechnology and immunology has developed and commercialized various vaccines developed for fish like recombinant DNA vaccines, Nano vaccines, subunit vaccines, genetically modified vaccines, and Polyvalent vaccines.

Table 1. FDA approved aquaculture drugs (permitted for application in fisheries and aquaculture) (USFDA, 2017)

Sr.No.	Drug	CommercialName	Usage	Approved Species
1.	Chorionicgonadotropi n	Chorulon®	For improving spawning function in male and female brood finfish	Brood finfish
2.	Formalin	Formaldehyde solution	Forthe control of Protozoa and Monogenetic Trematodes,and on the eggsofSalmon,Troutand Pike (esocids) for control of Fungiof the family Sapro-	Finfishand theireggs, Penaeid shrimp Salmon, Trout, Catfish and Bluegill
3.	Florfenicol	Aquaflor®Type A	Forthe controlofmortalityduetoentericsepticemiaofcatfish.The tolerance forflorfenicolamine (the markerresidue)in muscle (the targettissue)is1 ppm.	Channelcatfish salmonids
4.	Tricaine methanesulfonate	Tricaine-S MS-222	It may not be used within 21daysofharvesting fish for food. Thedrug should be limited to hatcheryorlabo-ratoryuse.	Ictaluridae (catfish), Salmonidae, Esocidaeand Percidae
5.	Oxytetracycline dihydrate	Terramycin®200	Forfeed use. In Salmonids, 21 days; Catfish, 21 days; Lobster, 30days. Oxytetracy -cline tolerance in the flesh is 2.0ppm	Catfish, Salmonids, Lobster
6.	Oxytetracyclinehydroc hloride	Oxymarine™, Terramycin 343, Phennoxy343, Tetroxy Aquatic	Forfeed use. In Salmonids, 21 days; Catfish, 21 days; Lobster, 30days. Tolerance inthe flesh is2.0 ppm	Finfish fryandfingerlings
7.	Sulfadimethoxine/Orm etoprim	Romet-30®	Withdrawal times are:Salmonids, 42days; catfish, 3 days	Catfish, salmonids
8.	Sulfamerazine	Sulfamerazine	It may not be used with in 21days of harvest. Note:Thisproductiscurrentlynotmarketed	Trout(rainbow, brook, brown)

(Source: Singh and Singh 2018)

Antiparasitic agents: The drugs that bear varying chemical features as well as mechanisms of action have provided excellent information for a better understanding of the parasite science as well as physiology (Elandalloussi *et al*., 2005). Many antiprotozoal drugs have been screened to-date with differing mechanisms of action. Cycloheximide is an inhibitor of protein synthesis that has proven to inhibit oyster pathogens. The classic antimalarial chloroquine has been shown to interfere with the metabolic processes that are involved with the uptake or digestion of haemoglobin in the Plasmodium food vacuole. Its complete mechanism of action remains unknown, and it is hypothesized to inhibit either nucleic acid or protein synthesis (Klonis *et al*., 2011).

Anaesthetics used for Fish: Anaesthetics are chemical or physical agents that depress the excitability of animals and make them

Table 1 gives FDA approved aquaculture drugs (permitted for application infisheries andaquaculture). Among all, the inactivated bacterin vaccines and live attenuated vaccines have been proved to be efficient ones by immersion method.

Drug administration: Application procedures vary significantly depending on the drug, life stage of fish and the rearing system. However, regulated drugs, whichever, are applied to aquatic animals through the culture water, feed or direct injection (Inglis, 2000).

Immersion treatment: In immersion treatment, the drugs are added directly into the culture water and are generally applied as a bath (prolonged and indefinite), dip, or flush. In the prolonged bath treatments, the water flow is incidentally stopped, and the correct amount of the targeted item is added to the rearing unit (Noga, 2000).

Water is returned to the rearing unit after a set time, and the treatment is washed out of the rearing unit. The compound should be adequately mixed and distributed in order to ensure uniform concentrations. In addition, enough water circulation must be made and the quality of water tested depending on the duration of treatment and stocking density, as it holds no water current during treatment. Indefinite baths are just like extended baths; otherwise, than that, the rearing system has a considerable volume without replacement. Low drug concentrations are used and left to diffuse slowly by normal mechanisms (adsorption, chelation, photodegradation etc.) or limited water exchange is done due to indefinite baths. In the case of dip treatments, there is usage of high drug concentrations in which small numbers of fish are exposed for a brief period of time, more often not more than a minute (Treves-Brown, 2013).

Oral treatment: The medication or medicine should be administered into the fish's body to treat certain illnesses, especially systemic diseases. This is most regularly done using medicated feed (Noga, 2000). Some drugs could be applied as a top dressing to feeds by blending pellets with cured oil or gelatine solution and enabling the pellets to dry before feeding the cultured fishes. Other drugs require inclusion in feeds only by licensed commercial feed manufacturers to manufacture medicated feed. Less flexibility exists for medicated feeds as a general rule. Since the diseases cause the fish to feed slower or to quit feeding altogether, oral medicines need to reach the fish prior to likely infections for effective outcomes. In this respect, just like all feeds, medicated feeds also need to be stored in a cool and dry place as well as must be consumed before the expiry date.

Injection treatment: Injection treatment is commonly used and is easier to be applied for large sized or precious fishes, for example broodstock. Any small population size is intended to be treated with injection treatment. Infusions are most often administered In dip treatments, high drug concentrations are applied in which a few fish are dipped for a short exposure time, mostly not exceeding one minute (Treves-Brown, 2013). Plunge meds are generally only used with pretty innocuous mixes (e.g., salt), and in the circumstance wherein the fish must be treated any rate (e.g. when there is to be fish movement starting with one rearing unit and then onto the next). Flush treatment is the addition of a drug solution at the inflow to a rearing unit, and allowing it to flush through the system. They are very commonly possible in raceways or other corresponding running water systems (Park *et al*., 2012). This type of application is inappropriate for controlled substances with a narrow margin of safety, as it can be very difficult to ensure uniform distribution and dispersion of the substance throughout the water body parts. intramuscularly or intraperitoneally. In both these scenarios, proper caution must be taken such that the needle does not perforate any organs of the body to minimize any severe injuries to the fish. Intramuscular (IM) injections are normally administered in the dorsal musculature at an approximate depth of 0.5 - 1.0 cm, with the needle inserted roughly ~45° to the side of the body. The intraperitoneal (IP) infusions are provided primarily close to the base of the pelvic fins at a ~45° angle to the ventral surface, while its needle is moved along the body axis to avoid the interior organs (Kinkel *et al*., 2010).

Gavage: Gavage is one of the oral methods, which has been widely applied in the research of the dose's precision accuracy. The method involves a stomach tube attached to a syringe containing a drug and directly injected into the fish stomach (Park *et al*., 2012). Before administering the drug to the fish, they must be anaesthetized or sedated. This strategy is applied only from time to time in the aquaculture industry as it is labor-intensive and as it is not nice to the fish.

Topical application: Topical application is rarely used in the aquaculture industry, and it is applied directly on skin ulcers of high-value fish (Verma *et al*., 2010). The use of anaesthesia is essential, and the preparations are usually oil-based.

Risks Associated with Aquaculture Drugs: While antibiotics are an essential component of aquaculture to maintain the health of farmed species, it has evolved into one of the threats posing various risks: the challenge of antimicrobial resistance (AMR), which has been identified as a significant global public health issue. The overuse and abuse of antibiotics in aquaculture have encouraged antibiotic-resistant bacteria, which spread through the aquatic environment into the human food chain. Besides this threat, it poses the risk of treatment failure in aquaculture besides endangering the efficacy of antibiotics in human medicine (Watts *et al*., 2022). Besides AMR, there is another significant environmental issue associated with the use of drugs in aquaculture: direct environmental impact. Drugs excreted through the excreta of the farmed species directly into the surrounding waters persist and accumulate in sediments. This makes the ecosystems aquatic and, thus, contaminated and reaches non-target organisms of including fish, crustaceans, and plankton. For example, there are researches relating usage of some antiparasitic medicines to hazardous effects on marine invertebrates and benthic communities (Defoirdt *et al*., 2019). Additionally, some drugs may break down into harmful by-products, which promotes environmental degradation. Drug residues in seafood is yet another concern from the food safety viewpoint. Consumers who consume seafood containing residual levels of antibiotics or other drugs can be exposed to these substances and thus may face allergic reactions or increased development of antibiotic-resistant bacteria within the gut flora. Most agencies for regulatory control in countries have, therefore, put in place maximum residue limits (MRL) for drugs within seafood for purposes of ensuring food safety. Still, implementing these boundaries can be challenging, particularly in countries with a weak regulatory environment or where regulations are not strictly enforced (Zhao *et al*., 2023).

Regulatory Frameworks for Aquaculture Drugs: To address the risks associated with the use of drugs in aquaculture, various regulatory frameworks have been established at national and international levels. These frameworks aim to ensure the responsible use of drugs in aquaculture, minimize environmental contamination, and protect public health. In many countries, the use of antibiotics and other drugs in aquaculture is tightly regulated, with requirements for veterinary oversight and strict limits on drug residues in seafood (Gudding *et al*., 2021). Several countries establish law frameworks that describe how antibiotics and other chemicals should be used responsibly in aquaculture. In most of the countries, there exist regulatory frameworks that limit the use of antibiotics and chemicals. Usually, the regulations comprise MRLs for drugs in seafood. This is for the protection of consumers, as it establishes that what is left of any drug residue in food products should be kept minimal. In some countries, veterinary oversight must precede the use of antibiotics in aquaculture, which establishes the appropriateness of administrating the drug only when needed and at effective dosages (Zhao *et al*., 2023). At the international level, the OIE has also published guidelines in conjunction with the FAO on prudent use of antimicrobials within aquaculture. This includes proper use, surveillance of antimicrobial resistance, and promotion of alternative antimicrobial agents that are not antibiotics. In this way, aquaculture producers will be left more sustainable and with lower risks because of its correlated practices with drug application (Watts *et al*., 2022). Table2 hives the list of banned antibiotics and other pharmacologically active substances inaquaculturein India (Asperthe notification by Coastal Aquaculture Authority of India, 2022) (Dinesh *et al*. 2023).

Emerging Trends and Alternatives: There has been a greater interest in the development of alternative disease management strategies that decrease dependency on conventional aquaculture drugs. Probiotics, prebiotics, and immunostimulants have emerged as alternatives to antibiotics and chemical treatments. Probiotics are the beneficial microorganisms that can be added to fish diets or water for enhanced health of the farmed species, due to better gut microbiota and immune responses (Ringo *et al*., 2020). Conversely, prebiotics are nondigestible compounds that stimulate the proliferation of beneficial bacteria within the gut.

Future Directions and Challenges: It includes one of the many vital directions to be considered in future by aquaculture, one of which is the development of alternative strategies for minimizing dependence on chemical treatments. Few examples have been portrayed as promising alternatives against antibiotics use, such as probiotics, prebiotics, and immunostimulants. These substances could make farmed species more resistant to infections by strengthening their immune system, thus reducing chemical treatments. The example of probiotics has proved a better gut health in fish, enhanced immune responses, and prevention against the proliferation of pathogenic bacteria (Ringo *et al*., 2020). There is also a rise in studies on natural plant extracts and bioactive compounds with antimicrobial properties that are environmentally friendly solutions to disease control in aquaculture (Sutjaritjai *et al*., 2023).

Sl.No	Antibioticsandotherpharmacologicallyactivesubstances	Maximumpermissibleresiduallevelin ppm
1.	Chloramphenicol	Nil
2.	Nitrofuransincluding: Furaltadone, Furazolidone,	Nil
	Furylfuramide, Nifuratel, Nifuroxime, Nifurprazine,	
	Nitrofurantoin,Nitrofurazone	
3.	Neomycin	Nil
4.	Tetracycline	0.1
5.	Oxytetracycline	0.1
6.	Trimethoprim	0.05
7.	Oxolinicacid	0.3
8.	Nalidixicacid	Nil
9.	Sulphamethoxazole	Nil
10.	Aristolochiaspp.andpreparationsthereof	Nil
11.	Chloroform	Nil
12.	Chlorpromazine	Nil
13.	Colchicine	Nil

Another promising line is the development of species-specific and pathogen-specific vaccines for aquaculture. Vaccination has, for example, decreased the use of antibiotics in some sectors such as salmon farming. But more research is needed to widen the range of species and diseases that vaccines are developed for. This calls for investment in genomic and molecular tools to understand better the biology of pathogens and immune responses in their host so that vaccines can be designed more targeted and effective (Evans *et al*., 2021).

CONCLUSION

As a result, aquaculture has now become very relevant within the global food systems, providing an indispensable source of protein for a growing world population; hence, the use of aquaculture drugs, such as antibiotics, antifungals, and antiparasitics, remains very crucial in controlling disease and maintenance of farmed species health. On the other hand, the reckless and overuse of these drugs have therefore raised tremendous concerns in terms of environmental sustainability, human health, and the long-term sustainability of this aquaculture industry. Using drugs in aquaculture is double-edged. On one hand, they are indispensable in controlling disease outbreaks, particularly in the intensive aquaculture system with high stocking density, which increases pathogen transmission risks. However, the misuse and overuse of antibiotics and other chemicals in aquaculture had led to antimicrobial resistance, a serious threat to public health. These resistant bacteria from the aquaculture systems can then potentially spread into wild ecosystems and onwards to humans through the food chain. The accumulation of drug residues in water environments inflicts injury on an ecosystem indirectly by affecting non-target species with a decrease in biodiversity. As a response, sustainable aquaculture techniques become a mandatory guideline for the industry: realizing less dependence on chemical treatment with a healthy and productive farmed species. Many of these have been realized, such as more effective measures of biosecurity, new approaches to disease management such as probiotics, immunostimulants, and vaccines, and the realization of integrated multi-trophic aquaculture systems. Biosecurity is one of the most important tenets of sustainable aquaculture. A lot of the use of chemicals on farms can be avoided if disease introduction and spread are prevented. This also ranges from ensuring good water quality to controlling stocking densities and the source of farmed species from disease-free hatcheries. It is a preventive measure that reduces the chances of occurrence of diseases and improves the general health of the farming system, enhancing productivity and sustainability.

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