REVIEW

Antimicrobial resistance: a concern related to streptococcosis in tilapia farming

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ABSTRACT. Despite all the technical-scientific knowledge about streptococcosis, the high prevalence of bacterial infections caused by *Streptococcus* spp. in Nile tilapia farming implies the frequent, often irresponsible, use of antibiotics. The use of chemotherapy in aquaculture environments remains an efficient practice in the treatment of bacterial infections and disease prevention. Research have shown that the emergence of antimicrobial resistance (AMR) in farmed fish is one of the main challenges faced in aquaculture. It is known that emerging AMR in aquaculture can be transferred to clinically important strains from the natural environment through horizontal gene transfer (HGT) affecting the entire aquatic ecosystem. Maintaining health in tilapia farms promotes the sustainability of production systems and, consequently, improves the final quality of farm products. Therefore, the objective of this review was to provide information on the prevention, control and eradication of diseases in Nile tilapia farms, and how such management plays a fundamental role in maintaining public health by ensuring adequate sanitary conditions for animals intended for human consumption.

Key words: Antibiotics, aquaculture, pisciculture, probiotic, bacteriosis.

Resistencia antimicrobiana: la estreptococosis como preocupación relacionada con el cultivo de tilapia

RESUMEN. A pesar de todo el conocimiento técnico científico sobre la estreptococosis, la alta prevalencia de infecciones bacterianas causadas por *Streptococcus* spp. en el cultivo de la tilapia del Nilo, implica el uso frecuente y muchas veces irresponsable de antibióticos. El uso de quimioterapia en los ambientes de acuicultura sigue siendo una práctica eficiente en el tratamiento de infecciones bacterianas y prevención de enfermedades. La investigación ha demostrado que la aparición de resistencia antimicrobiana (AMR) en los peces cultivados es uno de los principales desafíos que enfrenta la acuicultura. Se sabe que la AMR emergente en la acuicultura puede transferirse a cepas clínicamente importantes desde el entorno natural, a través de la transferencia de genes horizontales (HGT) y afectar a todo el ecosistema acuático. Mantener la salud en las granjas de tilapia promueve la sostenibilidad de los sistemas de producción y, en consecuencia, mejora la calidad de los productos finales de las granjas. Por lo tanto, esta revisión aborda cómo la prevención, el control y la erradicación de enfermedades en las granjas de la tilapia del Nilo, juegan un papel fundamental en el mantenimiento de la salud pública al garantizar las condiciones sanitarias adecuadas para los animales destinados al consumo humano.

Palabras clave: Antibióticos, acuicultura, piscicultura, probiótico, bacteriosis.

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INTRODUCTION

In the last decade, aquaculture has played an important role in global productive and economic growth due to the high demand for animal protein for human consumption (Bjørndal et al. 2023). Aquaculture supplies half of all fish consumed in the world, and within this scenario, the Nile tilapia (*Oreochromis niloticus*) stands out as one of the most cultivated aquatic animals in the world. It is estimated that the cultivation of the species is present in more than 130 countries, with an annual production of 4.5 million tons (FAO 2022).

Nile tilapia has contributed to the development of aquaculture worldwide (FAO 2022) since ancient Egyptian days (Amal and Zamri-Saad 2011), and remains an important freshwater farmed species (Khanjani et al. 2022) since it is considered a fish very resistant to environmental variations and diseases compared to other cultivable species (Arumugam et al. 2023). Aquaculture has made tilapia a globalized fish and probably no other fish species is as popular as tilapia. Among the various existing tilapia species, the most important for aquaculture belong to the genus *Oreochromis* (FAO 2022), including the Nile tilapia *O. niloticus*, Mozambican tilapia *O. mossambicus*, blue tilapia *O. aureus* and *O. uroleps* hornorum (Prabu et al. 2019; Debnath et al. 2023). In Brazil, Nile tilapia is cultivated from the Amazon River basin to Rio Grande do Sul (Ribeiro 2001; BAP 2023), as it survives and grows in varied environmental conditions.

Productive performance is a determining factor for tilapia production (Castilho-Barros et al. 2020). However, for these productive indexes to be achieved, it is necessary for producers to intensify aquaculture practices on properties, increasing the fish density in nurseries (Zimmermann et al. 2023), where the application of an intensive cultivation regime must follow basic protocols of sanitary management and control of environmental variables. Nevertheless, the rapid growth and expansion of aquaculture has been accompanied by the vertiginous growth of infectious diseases due to the widespread dispersal of pathogens, causing great economic losses in aquaculture farms in Asia, Central and South America (Bouwmeester et al. 2021; Valero and Cuesta 2023). Despite all the advances in relation to fish diseases and how to avoid them through good management practices in aquaculture, streptococcosis is recurrent in fish farms around the world (Van Doan et al. 2022).

Disease outbreaks

The emergence of disease outbreaks leads to the recurrent and indiscriminate use of chemotherapeutics in aquaculture, increasing the administration of antibiotics as part of routine prophylaxis and therapy. However, the use of antibiotics without a careful assessment of their appropriate indications can lead to the emergence of resistant strains through selective mutation, leading to the emergence of antimicrobial resistance among fish pathogens (Serrano 2005; Yang et al. 2013; Monteiro et al. 2018; Uma and Rebecca 2018; Mastrochirico-Filho et al. 2019; Niu et al. 2019; Preena et al. 2020; Wanyan et al. 2023). Consequently, infections can become more difficult to treat and often cannot be controlled. In this way, it is very likely that super-resistant bacteria can thrive in the presence of antibiotics, causing infections and mortality outbreaks in fish farms without awareness of this problem.

Although the prevention and control of diseases in modern aquaculture already uses environmentally friendly therapeutic methods, antimicrobial chemotherapeutics remain as primary tools, constantly used in the prevention and treatment of bacterial infections (Niu et al. 2019; Preena et al. 2020; Dang et al. 2021). This is a big mistake because the effectiveness of the treatment depends on the prescription of appropriate antibiotics, taking into account the spectrum of action (antifungal, anaerobic, Gram-positive, Gram-negative, broad spectrum), antibacterial activity (bactericidal or bacteriostatic), the chemical group (amino acids, sugars, acetates/propionates, chemotherapy), and the mechanism of action (cell wall synthesis, membrane permeability, protein synthesis, nucleic acids) (Ferri et al. 2022). Therefore, the correct selection and use of antibiotics, which must be directly linked to information about the phenotypic and genetic diversity of pathogens (Serrano 2005; Smith 2008), contributes to an assertive diagnosis.

Importance of assertive diagnoses

Diagnostics play an important role in fish health management and disease control (Mougin and Joyce 2023). The confirmatory diagnosis of a disease is generally considered complicated and costly, which may be true in some emerging diseases, but not in cases with already standardized protocols and validated diagnoses (Raja and Jithendran 2015). The development of protocols allowing multiple detection and identification of several pathogens in a single assay involves techniques based on DNA analysis (Yuan et al. 2019). In aquaculture farms, diagnostic methods must be part of the permanent routine, aiming at the sanitary maintenance of the properties. Analyses, such as multiplex - PCR (Polymerase chain reaction) and qPCR (Polymerase chain reaction quantitative real time), can be used as reliable and specific diagnostic tools to detect colonization and infections caused by pathogenic bacteria in aquaculture. This technique can be used to speed up diagnosis time, anticipating devastating outbreaks caused by this pathogen (Imperi et al. 2010; Sebastião et al. 2015; Chapela et al. 2018).

Bacterial diseases that can be routinely found in aquaculture farms, and that directly affect production, have as their main etiological agents Gram-negative organisms, such as *Aeromonas hydrophila*, *A. salmonicida*, *Vibrio anguillarum*, *V. harveyi*, *Flavobacterium psychrophilum*, *Edwardsiella tarda*, *Citrobacter freundii*, *Pseudomonas fluorescens*, *Yersinia ruckeri,* and *Francisella noatunensis*; and even Gram-positive such as *Streptococcus agalactiae*, *Staphylococcus*, and *Mycobacterium* sp. (Lewbart 2001; Sørum 2005; Igbinosa et al. 2012; Leal et al. 2014; Figueiredo et al. 2016; Tavares-Dias and Martins 2017; Mastrochirico-Filho et al. 2019; Owatari et al. 2020). Among these, the most prevalent bacterial pathogen in freshwater fish farms is *S. agalactiae* (Van Doan et al. 2022), and the consumption of fish infected by this pathogen can manifest circumstantial public health issues, solutions to which are very difficult to apply (Suebsing et al. 2013; Haenen et al. 2023).

Antimicrobial resistance, streptococcosis and tilapia farming

On a global scale, there are frequent reports that fish from aquaculture, such as carp, salmon, and tilapia, as well as crustaceans, such as shrimp, are hosts of antimicrobial resistant bacteria (Ye et al. 2013; Watts et al. 2017; Pokhrel et al. 2018; Niu et al. 2019; Yuan et al. 2019). Currently, commercially regulated antibiotics such as oxytetracycline and florfenicol, are used predominantly in Brazil to treat bacterial diseases in the aquaculture industry (Carraschi et al. 2011a, 2011b; Monteiro et al. 2018; Valenti et al. 2021).

Antimicrobial resistance in aquaculture is an emerging concern (Wanyan et al. 2023) (Table 1). With the increasing global demand for seafood, the aquaculture industry has expanded rapidly, leading to the intensive use of antibiotics to control disease, particularly in fish (Xiong et al. 2015; Pepi and Focardi 2021). According to Zhang et al. (2023), occurrence of antibiotic use and risk may vary according to different stages of aquaculture, where the highest concentration of antibiotics (9,032.08 ng L^{-1}) in ponds was detected in the late stage of aquaculture. Fluoroquinolones and tetracyclines were commonly used antibiotics in aquaculture around the Yellow Sea, with high detection frequencies (17% to 83%).

Antibiotic exposure can significantly increase the relative abundance of antibiotic resistance genes (ARGs) and mobile genetic elements (MGEs) in

Table 1. Occurrence of antimicrobial resistance identified in tilapia.

Detected in	Host	Main highlights	Study location	Key references
Streptococcus sp.	*Oreochromis niloticus*	The positive samples showed the following resistance genes: tet(O) (29.1%), tet(M) (12.7%), and erm(B) (1.8%).	Costa Rica	Oviedo-Bolaños et al. (2021)
Streptococcus pluranimalium, *Streptococcus dysgalactiae*, *Streptococcus anginosus*	*Oreochromis niloticus*	Multiple resistance was observed and the most fre-quent antibiotic combination was penicillin, ampicil-lin, vancomycin, chloramphenicol, rifampicin, oflox-acin, clindamycin, erythromycin and tetracycline representing eight classes.	Egypt	Osman et al. (2017)
Streptococcus agalactiae	*Oreochromis* sp.	*S. agalactiae* isolates examined showed resistance to erythromycin (42.9%), penicillin (35.7%), clindamy-cin (28.6%), enrofloxacin (35.7%), tetracycline (32.1%), gentamicin (28.6%), norfloxacin (28.6%), ofloxacin (14.3%) and doxycycline (7.14%).	China	Deng et al. (2019)
Aeromonas spp., *Enterobacteriaceae* (intestines), *Escherichia coli*	*Oreochromis* sp.	Antibiotic-Resistant bacteria associated with retail aquaculture products were found in 100% of the products examined. Among 505 multidrug-resistant isolates examined, close to one-fourth contained intI and sul1 genes: 15% contained sul2 and 5% contained tet(E). Incidences of β-lactamase--encoding genes blaTEM, blaCMY and erythromycin resistance determinants ermB and ermC were 4.5, 1.7, 1.3, and 0.3%, respectively.	Guangzhou, China	Ye et al. (2013)
Edwardsiella tarda	Red tilapia (*Oreochromis* sp.)	All the isolates were resistant to colistin sulphate and oxolinic acid. High levels of resistance to amoxicillin, ampicillin, ceftazidime, oxytetracycline and sulpha-methoxazole/trimethoprim were observed as well.	Thailand	Niu et al. (2019)

Table 1. Continued.

Detected in	Host	Main highlights	Study location	Key references
Streptococcus spp., *Aeromonas* spp., *Edwardsiella* spp., *Plesiomonas shigelloides*, *Pseudomonas aeruginosa*, among others	*Oreochromis niloticus*	232 bacteria were isolated. 40 strains were classified as multidrug resistant (MDR). With several bacteria demonstrating resistance to Brazilian aquaculture-legalized drugs (tetracycline and florfenicol).	Brazil	Costa et al. (2021)
Enterobacteriaceae and Vibrionaceae, *Stenotrophomonas* sp., *Shpingomonas* sp., *Acinetobacter* sp., *Burkholderia cepacia*, among others	Nile tilapia fillets (*Oreochromis niloticus*)	Both in the rearing environment and in the tilapia fillets, it was observed that the bacterial isolates were mainly resistant to ampicillin and erythromycin.	Brazil	Lima et al. (2006)

the gut of fish, suggesting that aquatic animals may contribute to the spread of resistance genes by conjugation in the water (Sáenz et al. 2019). For instance, the occurrence of multiple antibiotic resistance in bacteria isolated from hybrid red tilapia (*Oreochromis* sp.) was verified in northern Thailand, showing that all isolates were resistant to colistin sulfate and oxolinic acid, as well as high levels of resistance to amoxicillin, ampicillin, ceftazidime, oxytetracycline and trimethoprim were observed. The multiple antibiotic resistance index ranged from 0.25 to 0.92, indicating exposure to contamination sources where antibiotics were frequently used (Niu et al. 2019).

Likewise, high concentrations of chemotherapeutic agents such as sulfamethoxydiazine, sulfamethazine, sulfamethoxazole, oxytetracycline, chlorotetracycline, doxycycline, ciprofloxacin, norfloxacin and enrofloxacin can remain in the sediment and in the water of culture environments, leading to the emergence of resistant bacterial strains (Xiong et al. 2015; Shen et al. 2020), as well as remaining in the musculature of fish intended for human consumption, implying a potential risk to public health (Monteiro et al. 2018; Pepi and Focardi 2021).

The transmission of ARGs occurs in several ways, one of the main ones is through horizontal gene transfer (HGT) between different microorganisms (Jeon et al. 2023). This can occur through processes such as conjugation, where a plasmid containing resistance genes is transferred from one bacterium to another via a conjugation bridge (Watts et al. 2017; Jeon et al. 2023). Furthermore, the possibility of transfering antimicrobial resistance genes from Gram-positive bacteria to Gram-negative bacteria is a real concern (Manohar et al. 2020). Additionally, transformation is also an important mechanism in which bacteria acquire ARGs directly from the environment, such as DNA fragments released by dead microorganisms (Watts et al. 2017; Mahoney et al. 2021). These mechanisms of horizontal transmission of ARGs are worrying, as they can result in the emergence of multidrug-resistant bacteria, capable of resisting multiple antibiotics (Figure 1).

Rules for purchasing antibiotics intended for the treatment of fish in the aquaculture industry vary between countries, and their use in fish farming must be monitored (Sørum 2005; Dang et al. 2021). The detection of antibiotics residues in culture environments provides information about the potential harmful consequences to the ecosystem, human and animal health (Niu et al. 2019; Okeke et al. 2022). The growing concern about the environment and the presence of antibiotic residues in fish from the aquaculture industries implies the adoption of sustainable practices and efficient methods to detect these contaminants (Monteiro et al. 2018; Zhang et al. 2023). Generally, methods used to monitor antibiotic residues include screening and confirmation techniques such as immunoassay, microbiological assay, or biosensor techniques, which are widely used for rapid screening of antibiotic residues (Niu et al. 2019; Wanyan et al. 2023). Among benefits are the short analysis time, high sensitivity, selectivity for some immunoassays, simplicity, and automation. For confirmatory methods, the sample pre-treatment technique plays a crucial role in the analysis of veterinary drug residues, where drug extraction and cleaning from the complex matrix is one of the most difficult steps in antibiotic analysis (Luiz et al. 2015; Monteiro et al. 2018).

Over the years, several extraction methods have been proposed for sample preparation in antibiotic analysis, such as quick, easy, cheap, effective, rugged, and safe-QUEChERS; liquid-liquid extraction-LLE; solid-phase microextraction-SPM; dispersive liquid-liquid microextraction-DLLM; pressurized liquid extraction-PLE; and to detect, methods are typically based on liquid chromatography coupled with mass spectrometry (LC/MS)

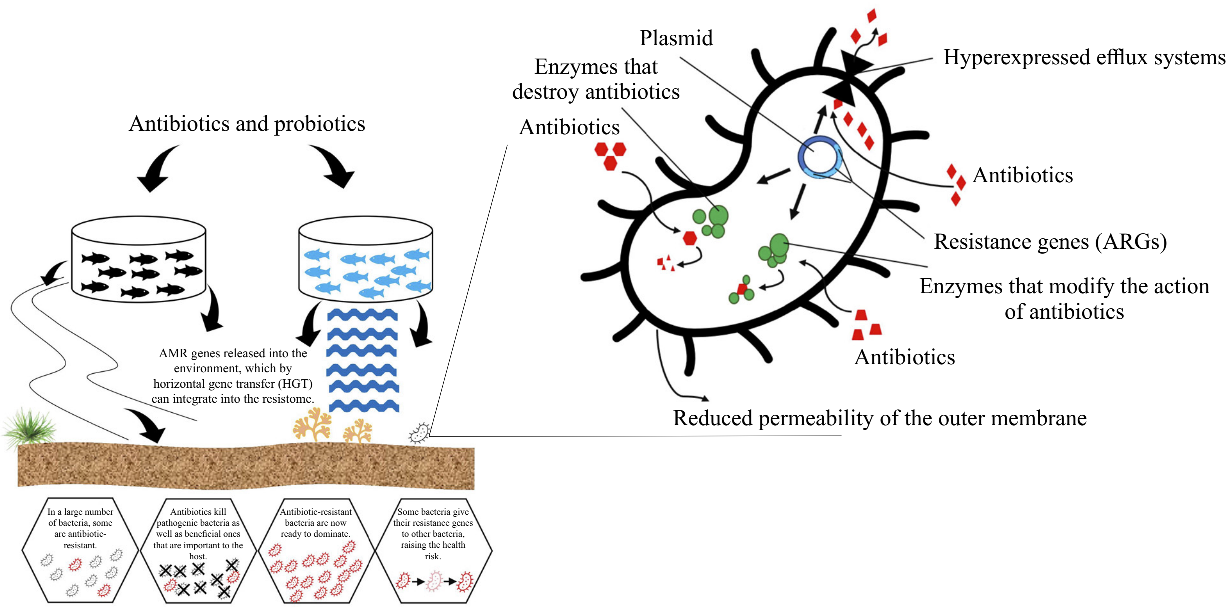

Figure 1. Exemplification of antimicrobial resistance (AMR) gene dispersal from aquaculture sites to the environmental resistome. The image illustrates in a simplified way the mechanisms of horizontal transmission of ARGs by conjugation to the emergence of resistant bacterial strains. Adapted from Watts et al. (2017) and Mahoney et al. (2021).

(Wang et al. 2011; Samsonova et al. 2012; Lombardo-Aguei et al. 2014; Jank et al. 2015; Liang et al. 2016; Monteiro et al. 2018).

Sanitary problems, related to the intensification of aquaculture practices, have long aroused the interest of the scientific community in the search for new strategies to control and eradicate diseases (Caipang et al. 2020; Ringø 2020; Van Doan et al. 2020; 2022). The detection and identification of potentially harmful microorganisms in any aquaculture environment or aquaculture production phase is essential for quality control and continuous improvement, as they can prevent disease outbreaks and mortality on fish farms.

Streptococcus spp. is one of the main pathogens in tilapia farming worldwide (Haenen et al. 2023) that can cause hemato-immunological and subclinical inflammatory changes in the liver, spleen and intestine of tilapia. It can remain affecting internal organs, compromising physiological functions vital to the health of fish without the appearance of clinical signs in animals, which can make tilapia an asymptomatic carrier of the pathogen (Owatari et al. 2020). According to Amal and Zamri-Saad (2011), Raabe and Shane (2019) and Wang et al. (2022), *Streptococcus* sp. has spherical or ovoid morphology and 0.5-2.0 μm in diameter. Occur in pairs or chains when grown in liquid media. Devoid of movement, do not form spores. An important feature for identifying *Streptococcus* is that it is Gram-positive appearing purple/blue on Gram stain, whereas most common disease-causing bacteria are Gram-negative appearing pink on Gram stain. It is facultatively anaerobic, requiring nutritionally rich media for growth. Commonly, it invades red blood cells to produce greenish discoloration (α-hemolysis) or complete clarification (β-hemolysis) on blood agar. In addition, it is also a kind of fermentative bacteria in metabolism, mainly producing lactic acid but no gas and negative catalase.

Group B *S. agalactiae* (GBS), another emerging fish pathogen, has been shown to cause significant morbidity and mortality among a variety of freshwater and marine fish species worldwide. It was first reported in freshwater scintillators (a device that allows identifying particles by fluorescence) in 1966. In recent decades, this bacterium has been reported in fish in the United States, Israel, Japan, Kuwait, Thailand, Honduras, and Brazil. This pathogen has also been isolated from other fish species, including rainbow trout, yellowtail, catfish, croaker, *Mullet* spp. and *Pampus argenteus* (Amal and Zamri-Saad 2011; Van Doan et al. 2022). One of the most important factors for transmission of *S. agalactiae* are newly introduced fish on farms (Haenen et al. 2023). Bacteria excreted in feces of infected fish survive in the water and are infectious to other healthy fish. In addition, it is believed that infected moribund fish that, eventually can be ingested by other fish, are responsible for outbreaks of streptococcosis, as well as the cohabitation of dead or infected fish with healthy fish, resulting in the infection of healthy fish. On the other hand, it is believed that horizontal transmission of pathogens among fish is the most common mechanism of dissemination, in which infection can occur through injuries and skin abrasions. This mechanism usually involves fish that have been cultured at high densities. Furthermore, *Streptococcus* transmission can occur between different fish species, wild and farmed fish, within the same aquatic environment, since wild fish and farmed fish have been found to be infected with the same bacterial strains (Nguyen et al. 2002; Kim et al. 2007; Amal and Zamri-Saad 2011). The search for sustainable and effective alternatives to fight the pathogen is a fundamental key element for the continuous growth of tilapia farming, as they provide less environmental impact, better waste management, and make intensive fish production environmentally friendly (Rector et al. 2023).

Environmentally friendly practices

The loss of the equilibrium state of organisms in relation to functions and the establishment of a defense and/or disease condition are metabolic processes with high-energy consumption for the host. Here, the infectious state promotes a complete change in metabolic priorities in relation to nutrient requirements associated with the immune system (Lochmiller and Deerenberg 2000). Exogenous nutrient sources must provide minimum levels of these specific nutrients to meet the basic requirements necessary for normal immune system performance and to protect and repair tissues from possible collateral damage. In certain situations, providing additional nutrients at levels above those required for normal maintenance and growth of fish, or even providing some compounds that are not needed, can sustain and/or enhance functions of the immune system, increasing its effectiveness against an invading pathogen. In this sense, there are several nutritional tools that can be implemented to achieve this goal of improving the immune system (Dawood et al. 2022; Wang et al. 2023). In this scenario, bioproducts or functional foods arise, developed from organisms and/or their constituent parts that, when properly administered in aquaculture, can confer significant improvements to the immune system and consequently increase the resistance of fish to diseases.

Among bioproducts commonly used in aquaculture, prebiotics and probiotics (Pereira et al. 2017; Owatari et al. 2019), postbiotics, such as organic acids (Jesus et al. 2019; Ang et al. 2020; Pereira et al. 2020) and phytotherapics (Owatari et al. 2018) can be highlighted, which are promising innovations contributing to the sustainable development of aquaculture. Improvement in the immune system of fish has been proven when treated with active plant principles added to the diet (Cardoso et al. 2023). Active plant constituents can strengthen or stimulate the immune response by interacting with various parameters of the immune system such as peroxidase activity, lysozyme, total protein levels, albumin, and globulin, causing immunostimulatory effect or immunostimulatory activity in animals (Ahmadi et al. 2012; Owatari et al. 2018).

In aquaculture, postbiotics are gaining strength as functional feed additives, useful as alternatives to antibiotics (Ang et al. 2020). Briefly, they are soluble factors resulting from the synthetic metabolic activity of living bacteria, such as organic acids and organic salts (Ang et al. 2020; Jesus et al. 2021), that when used together with phytotherapics, which are active raw materials of plant origin (Valladão et al. 2015), can confer a synergistic, beneficial effect on animals (Amenyogbe et al. 2020). For example, the isolated use of protected forms of sodium butyrate benefits the development and intestinal health of Nile tilapia during the sex reversal period (Jesus et al. 2019), while the use of sodium butyrate associated with *Lippia origanoides* essential oil had positive effects on the intestinal microbiota, intestinal structure, liver and spleen integrity, suggesting greater efficiency of compounds when used together in the nutrition of juvenile Nile tilapia (Jesus et al. 2021). Nutritional strategies that increase Nile tilapia resistance to diseases have gained prominence in recent years. Proper nutrition must be prioritized in aquaculture, as it plays a key role not only in fish health, but also generating savings and preventing disease outbreaks.

FINAL CONSIDERATIONS

Currently, a universal consensus establishes the importance of pathogen prevention and control in aquaculture (Wright et al. 2023; Mougin and Joyce 2023). Diets enriched with bioproducts such as organic acids, essential oils, prebiotics, and probiotics are a reality in health maintenance in tilapia farming (Beltrán y Esteban 2022; Faust et al. 2023). The use of antibiotics to control bacterial diseases in aquaculture needs feasible alternatives, as it will become unsustainable in the medium term and ineffective due to the evolution of antimicrobial resistance in pathogens, which can be transmitted to other microbes by horizontal gene transfer (HGT) via plasmids and other genetic elements from cultured fish and humans (Smith 2008; Preena et al. 2020). Recently, Domenech et al. (2020) identified potent inhibitors of *S. pneumoniae* competence called COM-blockers, and observed that proton motive force disruptors block bacterial competence and horizontal gene transfer in infected mice. Such a discovery could help reduce the spread of antibiotic resistance in aquaculture.

Additionally, the use and beneficial effects of feed additives in aquaculture have become well known and documented by several researchers (Pereira et al. 2017; Caipang et al. 2020; Ringø 2020; Van Doan et al. 2020; Beltrán et al. 2022). Nevertheless, studies have demonstrated the presence and expression of antimicrobial resistance genes in probiotics used in aquaculture (Uddin et al. 2015; Uma and Rebecca 2018; Tóth et al. 2021), becoming an aggravating potential in the development and spread of microbial resistance. A healthy and prosperous future for the planet through more sustainable aquaculture practices must be planned with tools seeking sustainability to make the difference between past and future aquaculture. The result of the combined action of different effect and consequence factors makes bioproducts (probiotics, prebiotics, postbiotics, phytotherapics, etc.) strengthen and be widely used in the aquaculture sector as sustainable alternatives to the use of antibiotics. However, knowledge of the effectiveness of bioproducts on the control of emerging bacterial diseases and their sensitivity to antimicrobials commonly used in the treatment of diseases in world aquaculture, as well as the presence of resistant genes in probiotic strains, are necessary. With adequate control, it is possible to guarantee healthy and sustainable tilapia production.

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Conflict of interest statement

The authors declare there are no conflicts of interest.

Data availability statement

Data sharing not applicable to this article as no datasets were generated during the study.

Author contributions

Marco Shizuo Owatari: conceptualization; writing-original draft, final writing, methodology, visualization. José Luiz Pedreira Mouriño: writing-original draft, writing-review and editing. Maurício Laterça Martins: resources and supervision, writing-original draft, writing-review and editing.

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