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Sustainable Shrimp Farming: The Potential of Water Reuse and Non-GMO Antimicrobials Antibiotics for a Responsible Future

Sustainable Shrimp Farming: The Potential of Water Reuse and Non-Antibiotic Antimicrobials for a Responsible Future

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Abstract

This review article explores the potential of water reuse in sustainable shrimp farming as a strategy to address the challenges of intensive water resource use and minimize scarcity and pollution. Inadequate water management is a critical problem in shrimp farming and can contribute to significant impacts on human and environmental health. Furthermore,
Antibiotic use in aquaculture is a factor driving the global antimicrobial resistance crisis. The adoption of innovative water reuse systems, combined with the application of non-antibiotic antimicrobials, emerges as a promising approach to achieving more responsible production aligned with the United Nations (UN) Sustainable Development Goals (SDGs), promoting sustainability and minimizing contamination. A literature review demonstrates the need for more in-depth studies on the feasibility and potential of integrated systems, as well as on the long-term effects of non-antibiotic antimicrobials on pond microbiota and shrimp health.

Keywords: Sustainable Aquaculture, Drug Alternatives, Environmental Impact, 2030 Agenda.

Abstract

This review article explores the potential of water reuse in sustainable shrimp farming as a strategy to address the challenges of intensive water resource use and minimize water scarcity and pollution. Inadequate water management is a critical problem in shrimp farming, with significant impacts on human and environmental health. Furthermore, the use of antibiotics in aquaculture is a factor driving the global antimicrobial resistance crisis. The adoption of innovative water reuse systems, combined with the application of non-antibiotic antimicrobials, emerges as a promising approach to achieve more responsible production aligned with the Sustainable Development Goals (SDGs) of the United Nations (UN), promoting sustainability and minimizing contamination. The literature analysis demonstrates the need for more in-depth studies on the feasibility and potential of integrated systems, as well as on the long-term effects of non-antibiotic antimicrobials on the microbiota of ponds and shrimp health.

Keywords: Sustainable Aquaculture, PharmaceuticalsAlternatives to Antibiotic Pharmaceuticals, Environmental Impact, 2030 Agenda.

Introduction

The use of treated reused water allows drinking water to be prioritized for purposes basic, while reused water can be used for other purposes, such as agriculture, irrigation of green areas and street cleaning (Fagundes et al., 2020).

The main technologies for wastewater treatment aiming at reuse include processes such as adsorption on activated carbon, advanced oxidation with ozone, chlorine dioxide and hydrogen peroxide, membrane separation (microfiltration, ultrafiltration, nanofiltration and reverse osmosis), reverse electrodialysis, ion exchange, distillation and precipitation chemistry (Moura et al., 2020; Carvalho et al., 2013). However, the intensification of treatments for water reuse brings to light the need to consider the formation of by-products of disinfection (DBPs). Compounds such as trihalomethanes (THMs) or haloacetic acids (HAAs) may arise from the use of chemical disinfectants such as chlorine and ozone, requiring monitoring rigorous to ensure the safety of water and the final product (Hoffmans et al., 2025).

Regarding microbiological hazards, pathogens found in drinking water reuse, relevant to human health and the environment, are categorized into bacteria, helminths, protozoa, and viruses. Recent studies indicate the presence of microorganisms pathogens in reused water that may pose microbiological risks to public health, persisting even after chlorine disinfection treatment, such as Norovirus (Moura et al., 2020). For the environment, microbiological risks include changes in natural microbiota of aquatic ecosystems, the introduction of pathogenic species that can affect local fauna and flora and, mainly, the proliferation of resistance genes antimicrobial activity in bacterial populations, impacting biodiversity and resilience of ecosystems. Nascimento et al. (2014) details how antimicrobial resistance spreads in various aquatic ecosystems (rivers, lakes, cultivation ponds, wastewater treatment plants) sewage), including aquaculture. The author points out that resistant bacteria can be found in these environments and, more importantly, that there is concern about the transfer of resistance genes for human pathogens.

Shrimp farming, an activity of global socioeconomic importance, faces challenges environmental and public health issues that are intrinsic to its predominant production model. Although it is a vital source of food and income, the intensification of this practice leads to consequences that go beyond the exclusively environmental scope, impacting areas socioeconomic, political and technological (Silva et al., 2025). Among the practices that generate greatest concern, the intensive use of water and the routine use of antibiotics stand out for control diseases in nurseries. These approaches not only compromise water resources and aquatic ecosystems (Bostock et al., 2010; Diana et al., 2013), but also result in worrying presence of antibiotic residues in nurseries and final products for human consumption (Manage, 2018). Contamination by these antibiotic residues contributes significantly to the increase in antimicrobial resistance (Costa-Pierce, 2021), representing a growing risk to human health and the integrity of ecosystems aquatic.

The urgent threat of antimicrobial resistance, recognized by the World Health Organization, World Health Organization (WHO) as one of the largest for global health (WHO, 2015; Monteiro, 2020), requires immediate and innovative solutions. For shrimp farming to be sustainable, medium and long term, it is essential that these different proportions are addressed through research and innovation (Silva et al., 2025).

In this context of the search for sustainability, the global actions established by the United Nations United Nations provide an essential direction to follow. In 2015, the Organization of The United Nations (UN) launched the 2030 Agenda for Sustainable Development, a plan comprehensive action plan that aims to eradicate poverty, protect the planet and ensure peace and prosperity for all. At the heart of this agenda are the 17 Development Goals Sustainable Development Goals (SDGs), which are interconnected and indivisible global goals, addressing everything from eradicating hunger and poverty to climate action and protecting aquatic and terrestrial life. They represent a universal call to action for a more sustainable future, balancing the environmental, social and economic dimensions (UN, 2015).

The urgent adoption of more sustainable practices in shrimp farming, including the implementation efficient water reuse systems and the replacement of antibiotics with non-steroidal anti-inflammatory alternatives. antibiotics, it is essential to minimize environmental impact, reduce contamination by residues and combat antimicrobial resistance. The union of these strategies aims to optimize the use of water (SDG 6) and promote responsible consumption and production (SDG 12), but also protect aquatic life (SDG 14) by reducing pollution and preventing resistance to antimicrobials and directly impacts health and well-being (SDG 3) by reducing exposure antibiotic residues and the spread of superbugs.

This article addresses the interconnection between water use and reuse in shrimp farming and the role fundamental role of non-antibiotic antimicrobials in mitigating contamination by residues of antibiotics in farmed shrimp. The problems arising from the use of antibiotics will be analyzed. antibiotics in aquaculture, the occurrence and impacts of their residues, the benefits of water reuse systems and the potential of non-antibiotic antimicrobials as solutions for safer and more sustainable production. We also sought in the literature review to understand better understand what are the doubts and uncertainties about the effectiveness and long-term impacts of reuse of water and non-antibiotic antimicrobials, and whether they are viable for use. In particular, This work aims to identify the knowledge gaps that prevent the implementation of these

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technologies and propose directions for future research that facilitate the transition to a sustainable shrimp farming.

Material and Methods

This article consists of a bibliographic review that addresses: sustainable shrimp farming, with focus on the potential of water reuse and the application of non-antibiotic antimicrobials. bibliographic research involved consulting scientific articles, books, reports international organizations and other relevant sources in the Web of Science databases, Scopus and Google Scholar on sustainable shrimp farming, focusing on the potential for reuse water and in the application of non-antibiotic antimicrobials. The search terms used included "sustainable shrimp farming", "water reuse in aquaculture", "non-toxic antimicrobials" antibiotics", "antibiotic residues in aquaculture", "antimicrobial resistance and aquaculture", "biofloc technology", "recirculating aquaculture systems" and "Objectives of Sustainable Development (SDGs) and aquaculture". The selection of articles considered the relevance to the topic, methodological quality, and timeliness of the information. The analysis of the data was qualitative, seeking to identify the main trends, challenges and potentialities related to water reuse and the use of non-antibiotic antimicrobials in sustainable shrimp farming. A specific focus was given to the literature that discusses the application practice and the results of pilot studies or field projects that integrate these approaches.

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Antibiotic Use in Aquaculture and the Residue and Resistance Crisis Antimicrobial

The use of pharmaceutical products, especially antibiotics, in livestock farming activities animal, including aquaculture and livestock (poultry, pigs and cattle), constitutes the main route of introduction of these compounds into the environment. This continuous release can lead to significant contamination of both aquatic and terrestrial environments (WOAH, 2022). In shrimp farming, the use of antibiotics for prophylaxis, metaphylaxis and treatment of diseases is a practice cited as common and driven by the intensification of production systems and by high stocking density, which favors the occurrence of infectious outbreaks (Manage, 2018; Luu et al., 2021) Once applied, antibiotics can be released into the ponds and surrounding environment in a variety of ways: through uneaten medicated foods, animal feces, or directly by discharging effluents containing non-prescription drugs. metabolized and their metabolites. In aquaculture, direct release into surface waters is particularly problematic, and may result in a significant accumulation of these drugs in the sediments of nurseries and adjacent water bodies (Zhang et al., 2018; WOAH, 2018). This accumulation can lead to modification of the functions of the aquatic ecosystem, affecting the natural microbiota, food chains and the health of non-target organisms (Li et al., 2019; Rocha et al., 2019).

Monitoring studies in various shrimp producing regions have often detected the presence of residues of various antibiotics in water and sediment samples and, crucially, in tissues of cultured shrimp (Li et al., 2023). Analytical techniques advanced techniques (such as LC-MS/MS) allow the identification and quantification of these residues in increasingly lower concentrations, pointing to widespread contamination in many production systems globally.

The presence of these traces of antibiotics in the environment poses several serious dangers. Initially, it attests to a significant impact on the evolution and spread of resistance antimicrobial activity (AMR) in the aquatic environment. Antibiotics present in residues, even in low concentrations, act as selection agents, favoring the development and proliferation of resistant bacterial strains (Van Boeckel et al., 2019). These bacteria can, in turn, transfer their resistance genes to other bacteria, including pathogens that affect human and animal health through transfer mechanisms horizontal gene exchange (Nascimento et al., 2014). The multiplication and spread of bacteria multidrug-resistant is a growing global public health problem, with the potential to become common treatments are ineffective, increase morbidity and mortality, and generate high costs for health systems worldwide (BRAZIL, 2019). The World Health Organization Animal Health (WOAH) (2016), in its Strategy on Antimicrobial Resistance, highlights the importance of the *One Health* approach , in Brazil called "Uma Só Saúde" to combat this problem, recognizing the interconnection between human, animal, plant and environmental.

Antibiotics and the Environment

The production, use and disposal of antibiotics often lead to contamination of natural ecosystems with their residues (Kovalakova et al., 2020). The continued spread of antibiotics in ecosystems can impact organisms at different levels of the chain feed and cause harmful effects on unintended species, with mortality, behavioral changes, genetic damage and changes in growth rates, reproduction and feeding of bacteria, fungi, protozoa, algae, microcrustaceans and fish (Jijie et al., 2021). Several studies point to the identification of antibiotics in both surface waters, such as rivers and lakes, as well as in groundwater (Duan et al., 2022). The presence of these substances in the environment can affect both aquatic and terrestrial life, as well as potentially contribute to increased resistance of microorganisms to antibiotics (Gothwal & Shashidhar, 2015). A critical point is the bioaccumulation of these compounds in aquatic organisms and their potential for transfer to the human food chain, raising concerns about food safety, particularly resistance antimicrobial (AMR).

Water Reuse Systems: Reducing Waste Dispersion and Water Consumption

The adoption of water reuse systems, such as Biofloc Technology (BFT) (De Schryver et al., 2008; Crab et al., 2012) and the Recirculating Aquaculture System (RAS) (Martins et al., 2010), constitutes an essential means of reducing the spread of traces of antibiotics in the environment. These recycling and reuse methods are crucial, as studies indicate that could reduce the final discharge of effluents from shrimp farming by up to 90%, resulting in considerable water savings (Leitão et al., 2011). By drastically reducing the effluent release, such systems retain potential pollutants in a delimited circuit, simplifying the treatment and disposal of unwanted substances, including waste antibiotics. Studies such as that of Fedorova et al., (2022), demonstrate the effectiveness of antibiotic systems water reuse in the removal of pharmaceuticals in aquaculture, strengthening the capacity of these technologies in mitigating waste dispersion. The literature review on systems reuse, such as the biofloc technology (BFT) described by Crab et al. (2012), demonstrates the efficiency in improving water quality and reducing water consumption. However, studies futures should focus on more accurate analysis regarding implementation and production to assess feasibility. Furthermore, we consider that the reduced demand for drinking water relieves pressure on water sources and reduces the volume of water that could be contaminated by antibiotics during treatments. Stability in water quality offered by reuse systems can also benefit shrimp health, possibly reducing the need for antibiotics.

Water Reuse in Shrimp Farming

The reuse of water from shrimp farms, instead of discharging it directly into rivers and lakes after harvest, offers multiple benefits. Water consumption in shrimp farming is notoriously high, mainly concentrated in the water exchange stages in the ponds and fishing. The disposal of aquaculture effluents, rich in organic matter and solids in suspension, can significantly alter the characteristics of receiving water bodies and generate negative impacts on the local biota. Given this reality, and aiming to promote the economy of water and mitigate polluting effects, Brazilian environmental legislation establishes criteria for the classification of water bodies and guidelines for sustainable management. In this context, the CONAMA Resolution No. 357/2005 provides for the classification of water bodies and the conditions and standards for the release of effluents (BRAZIL, 2005), while Federal Law No. 12.651/2012, known as the New Forest Code, defines parameters for the protection and sustainable use of Permanent Preservation Areas (APPs) (BRAZIL, 2012). When used in irrigation, this practice not only promotes the conservation of water resources (Fagundes et al., 2020), but also enriches the soil, increasing its fertility and, consequently, reducing the need for the application of chemical fertilizers to crops (Anjos et al., 2017). These technologies demonstrate benefits and emphasize the fundamental role of reuse of water as a basis for the circular economy in aquaculture, transforming a waste product into a valuable and useful resource.

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Non-Antibiotic Antimicrobials: A Barrier to Residue Contamination

The implementation of non-antibiotic antimicrobials represents a fundamental strategy to prevent contamination by antibiotic residues in aquaculture. By replacing the conventional antibiotics with alternatives such as bacteriocins (e.g. nisin) (Bondadÿ Reantaso et al., 2023; Cotter et al., 2013; Li et al., 2020; Sudagidan et al., 2012), oils essential oils from aromatic plants (Reverter et al., 2014), probiotics and prebiotics (Bondad-Reantaso et al., 2023), the risk of persistent residues with the potential to induce resistance is significantly lower. Furthermore, several antimicrobial alternatives do not antibiotics have targeted modes of action and break down more easily in the environment, which minimizes the risk of them accumulating in ponds and effluents. Additionally, the effect of these compounds on the environmental microbiota is generally less severe compared to that of broad-spectrum antibiotics. Comparative studies on the effectiveness and advantage of non-antibiotic antimicrobials over antibiotics traditional methods in shrimp farming are fundamental for sustainable use (Bondad-Reantaso et al., 2023).

Strategic Integration: Water Reuse and Non-Antibiotic Antimicrobials in Waste Mitigation

The strategic combination of water reuse and non-antibiotic antimicrobials is a measure collaborative to combat antibiotic residues in shrimp farming. Reuse limits the dispersion of substances, and non-antibiotics reduce contamination by residues persistent and resistance-inducing. In reuse systems, the use of non-antibiotics that do not accumulate and are easily degraded maintains water quality and the health of the microbiome, such as bioflocs (De Schryver et al., 2008). The effectiveness of biofloc reuse systems water in reducing contaminants has been frequently demonstrated. For example, Fedorova et al. (2022) investigated a tertiary treatment pond system developed for reuse in aquaculture. They observed a significant reduction in several compounds pharmaceutically active substances (PhACs), including antibiotics. This decrease resulted in a reduction of ecotoxicological risks and antimicrobial resistance before reuse beneficial to water. This study validates the potential of such systems for aquatic production safer and more sustainable. To ensure safety and efficiency in water reuse and non-antibiotic antimicrobials, it is essential to develop and implement strategies

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robust and sustainable water quality treatment and monitoring in shrimp farming. Hence the need for standardized protocols for monitoring residues and the validation of technologies to guarantee the health safety of products and the environment.

Relevant Works

According to the study by Jeronimo and Balbino (2012), the mangrove areas of Rio Grande do Norte have suffered significant degradation due to the accelerated and often irregular expansion of shrimp farming, threatening the ecosystem and local communities. The authors point to a critical scenario of water contamination, destruction of native vegetation and decline of species marine life, especially crabs, warning of ecological imbalance and its unpredictable consequences. The authors identify the liquid effluents from the fishing stage as one of the main responsible for environmental impacts, characterized by high concentration of decomposing organic matter and the presence of chemical agents such as antibiotics and antioxidants. In order to mitigate the problems arising from the disposal inadequate treatment of these effluents, the work of Jeronimo and Balbino (2012) proposes the investigation and adaptation of physical, chemical and microbiological treatment processes to reduce environmental impacts and align shrimp farming activities with legal standards for disposal industrial effluents. Although this study contributes to the understanding of the impacts environmental, it does not address in detail the role of non-antibiotic antimicrobials in reducing of the pollutant load and water reuse.

Souza (2022) investigated the efficiency of the halophytic plant *Salicornia ambigua* in the treatment of effluent from shrimp farming in a biofloc system (BFT) over 270 days, aiming to reduce nitrogen levels in water, optimize its reuse and avoid soil and groundwater contamination water table, with the potential to improve the cost-benefit of production. The study used a Nutrient Film Technique (NFT) hydroponic system with the plant roots in contact with the effluent discharged from the clarifiers. The results demonstrated a reduction in the levels of ammonia and satisfactory plant development, indicating adequate plant production.

Souza (2022) concluded that the reuse of shrimp farming effluent in aquaponics is efficient both for water treatment and for vegetable production, representing a sustainable approach to shrimp farming, which has grown significantly since the 1990s.

2000, reaching 55% of the world's crustacean production, and where water reuse is essential for environmental and economic sustainability. Despite demonstrating the potential for reuse, this study does not evaluate the impact of the presence of antibiotic residues in the treated effluent and how the adoption of non-antibiotic antimicrobials could influence water quality for reuse.

According to studies conducted by Anjos et al. (2017), the potential of the effluent from shrimp farming as a source of irrigation for rice *(Oryza sativa* L.), with the aim of reducing the use of fertilizers and promote water reuse. Through an experiment with different dilutions of the effluent, the authors observed that, although the public water supply has favored the greater growth of rice, the effluent from shrimp farming increased the matter organic matter of the soil without damaging its chemical characteristics. The research concluded that the shrimp farming effluent represents a promising alternative for agriculture, especially in regions with water scarcity such as the Brazilian Northeast, by allowing fertilizer savings and water reuse, avoiding eutrophication. However, research does not address the microbiological safety of irrigation water and the potential impact of residues of antibiotics present in the effluent in the soil and crops.

A relevant study for the approach to water reuse in shrimp farming is that of Leitão et al. (2011), published in the Brazilian Journal of Agricultural and Environmental Engineering. This work had with the aim of evaluating the reuse of fishing water from shrimp ponds in own activity, seeking to mitigate the significant environmental impacts caused by the high water demand and effluent disposal. The experiments showed that, although the rate survival rate of the shrimp *Litopenaeus vannamei* in fishing waters has been 42.1%, the highest mortality occurred in the first week of the fattening cycle. However, the authors suggest that a change in production strategy, such as an increase in density initial settlement, can compensate for this loss and also take advantage of accelerated growth of shrimp (reaching cutting weight in 68 days compared to 116 days with river water). Conclu-
It is known that reusing fishing water is a viable alternative, with the potential to reduce water and energy costs, reduce pollution load and increase farm productivity of shrimp.

In Brazil, a more recent scenario described by Silva et al. (2025), who carried out an analysis bibliometric analysis of the socio-environmental impacts of shrimp farming between 1993 and 2023. From 56 reviewed studies highlighted key environmental concerns such as the alteration of areas of mangroves, water quality contamination and the presence of the patch syndrome white. In addition to social and economic impacts, such as changes in local ways of life and job creation. Although fundamental to understanding the scale of the impacts, work de Silva et al. (2025) does not delve into water reuse solutions or strategies for mitigate contamination by chemical residues, including antibiotics.

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In this context of urgency for effective solutions in the management of effluents in shrimp farming, present review, by exploring the potential of non-antibiotic antimicrobials to decrease the use of antibiotics and their residues in effluents, aims to contribute to facilitating not only the treatment of these effluents, with the reduction of antibiotics in the environment, but also to enable water reuse, essential for sustainability and future responsibility of the activity. The literature review shows that there is a need for research that addresses the use of non-antibiotic antimicrobials to facilitate the safe reuse of water in shrimp farming.

Regulation and the Path to the Future

Regarding water reuse, Brazil still lacks specific technical standards for reuse systems (Moura et al., 2020). Standards are often used international reference standards or technical guidelines prepared by private entities. This lack of specific legislation and regulations has hindered the implementation of this practice in the country, making the work of professionals in the field difficult. Furthermore, the lack of technical guidance for the installation of wastewater reuse systems and the consequent inadequate monitoring of these systems can compromise the health of the population (Moura et al., 2020). Water reuse legislation in European countries (Belgium, the Netherlands and Spain), highlights the importance of clear laws for the effective and safe implementation of this practice (Hoffmans et al., 2025), an indispensable point for the development of shrimp farming sustainable in Brazil.

In this context, the analysis of the literature reveals an urgent need for development and implementation of specific regulations for water reuse in aquaculture in Brazil, considering the aspects of environmental and health safety (Cunha et al., 2012; Fagundes et al., 2020). The standardization of these regulations at a global level and effective enforcement are still represent significant challenges (Cunha et al., 2012). Furthermore, public policies that encourage the adoption of sustainable practices are crucial to driving the transition to a more responsible shrimp farming (Costa-Pierce, 2021), such as water reuse and the use of non-antibiotic antimicrobials.

The future of sustainable shrimp farming involves adopting practices that minimize the use of antibiotics and improve water use. This requires investment in research and development of effective alternatives, such as non-antibiotic antimicrobials, and in accessible and efficient water reuse technologies. Awareness among producers, support government and consumer demand for safe and sustainable products as well will play a crucial role in this transition. Future work should focus on feasibility of large-scale implementation of interconnected processes, as well as in impacts on aquatic ecosystems and product quality (Diana et al., 2013).

Conclusions

Prioritizing the implementation of water reuse systems is essential to ensure environmental and economic sustainability of shrimp farming, optimizing the use of each resource increasingly scarce and reducing water pollution. On the other hand, the need to replace traditional antibiotics with non-antibiotic alternatives becomes evident to mitigate the spread of antimicrobial resistance and contamination by residues, protecting health human and aquatic ecosystems.

The joint adoption of these strategies, in accordance with the Development Goals Sustainable Development Goals (SDGs) of the UN, represents the most favorable path towards more sustainable shrimp farming. responsible and healthy. This review demonstrates that integrating water reuse with use of non-antibiotic antimicrobials offers significant potential for sustainability of shrimp farming. However, the success of this transition depends on continuous investments in research, development of accessible technologies, as well as well-defined regulations and development of public policies, with the purpose of contribute to global health and environmental preservation by aligning the production of food with a more sustainable future.

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