Chapter 6 Sustainable Aquaculture, what should we consider?

Capítulo 6 Acuicultura sustentable, ¿Qué debemos considerar?

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DOI: 10.35429/H.2023.14.1.40.48

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I. Martínez, Y. Osorio, F. Martínez and K. Aguilar. (VV. AA.) Sustainability in agricultural production and natural resource management T-I Biotechnology and Agricultural Sciences. Handbooks-©ECORFAN-México, Hidalgo, 2023.

Abstract

In recent decades, aquaculture has played a crucial role in global food security by meeting the increasing demand for high-quality animal protein. Mexico engages in aquaculture across 23 of its 32 states, producing 351,002 tons of aquaculture products in 2021. However, disparities exist between large and small producers due to financial constraints, technological limitations, and the impact of climate change. Despite aquaculture's contribution to meeting protein demands, sustainability concerns persist. The constant increase in aquaculture demand, coupled with the generation of waste and negative public perceptions, presents challenges. Key issues include parasites in farms, antibiotic use, sourcing aquaculture feed, nutrient release, waste accumulation, and the impact on wild populations and introduction of non-native species. The article proposes solutions for sustainable aquaculture, focusing on recent advancements. Various approaches are discussed, including integrated control programs involving chemical, biological, and mechanical methods, proper antibiotic management, exploration of alternative protein sources, and the reduction of excess nutrient release and waste in natural ecosystems through integrated approaches like agroaquaculture and integrated multitrophic aquaculture. The aim is to minimize the impact on wild populations and prevent the introduction of non-native species. Strategies such as diversifying cultivated species and prioritizing regional suitability are also recommended. In conclusion, achieving sustainability in aquaculture involves minimizing waste, promoting local production, and adopting practices that consider ecological balance. The adoption of sustainable practices, such as species diversification and integrated multitrophic aquaculture, along with effective parasite and disease management, is crucial for the long-term viability of the aquaculture industry. Public awareness and education are also essential to garner societal acceptance and support for sustainable aquaculture practices.

Sustainable aquaculture, Integral aquaculture, Multi-trophic aquaculture, Agro-aquaculture

Resumen

En las últimas décadas, la acuicultura ha desempeñado un papel crucial en la seguridad alimentaria global al satisfacer la creciente demanda de proteína animal de alta calidad. México participa en la acuicultura en 23 de sus 32 estados, produciendo 351,002 toneladas de productos acuícolas en 2021. Sin embargo, existen disparidades entre los grandes y pequeños productores debido a limitaciones financieras, restricciones tecnológicas y el impacto del cambio climático. A pesar de la contribución de la acuicultura para satisfacer las demandas de proteínas, persisten preocupaciones sobre la sostenibilidad de esta. El constante aumento en la demanda de productos acuícolas, junto con la generación de residuos y las percepciones negativas del público, presentan un gran desafío. Problemas clave incluyen la presencia de parásitos en las granjas, el uso de antibióticos, la obtención de alimentos para la acuicultura, la liberación de nutrientes, la acumulación de residuos y el impacto en poblaciones silvestres e introducción de especies no autóctonas. El artículo propone soluciones para la acuicultura sostenible centradas en avances recientes. Se discuten diversas estrategias, tales como programas ide control integrados que involucran métodos químicos, biológicos y mecánicos, manejo adecuado de antibióticos, exploración de fuentes alternativas de proteínas y reducción de la liberación excesiva de nutrientes y residuos en ecosistemas naturales mediante enfoques integrales como la agroacuicultura y la acuicultura multitrófica integrada. El objetivo es minimizar el impacto en poblaciones silvestres y prevenir la introducción de especies no autóctonas. También se recomiendan estrategias como la diversificación de las especies cultivadas y la priorización de la producción localizada. En conclusión, lograr la sostenibilidad en la acuicultura implica minimizar residuos, promover la producción local y adoptar prácticas que consideren el equilibrio ecológico. La adopción de prácticas sostenibles, como la diversificación de especies y la acuicultura multitrófica integrada, junto con un manejo efectivo de parásitos y enfermedades, es crucial para la viabilidad a largo plazo de la industria acuícola. La conciencia pública y la educación son también esenciales para obtener aceptación y apoyo social para lograr una producción acuícola sostenible.

Acuicultura sustentable, Acuicultura integral, Acuicultura multitrófica, Agroacuicultura

6 Introduction

In recent decades, aquaculture has played a key role in global food security by meeting the growing demand for high-quality animal protein. In addition to providing protein, aquaculture provides other essential nutrients, such as fatty acids, amino acids, vitamins and elements such as iodine and selenium, which are often scarce in other crops or meats (Kwasek et al., 2020; Nasr-Eldahan et al., 2021).

In Mexico, aquaculture is present in 23 of the country's 32 states, producing 351,002 tonnes of aquaculture products in 2021. During that year, shrimp led the production with 214,546 tonnes, with a value of $15,330 million pesos. It was followed by mojarra with 96,977 tonnes and a value of $2,588 million pesos, and oyster with 15,602 tonnes and a value of $141 million pesos (CONAPESCA, 2021). It should be noted that these data come from the 4,845 registered production units, but it is estimated that most production systems are small and are not registered, which could distort the statistics (Ortega-Mejía et al., 2023).

In general, aquaculture production is concentrated among a small number of large producers, who account for more than 70% of production, while small producers cover less than 30% (Hasimuna et al., 2023). This disparity is attributed to lack of financial resources among small-scale producers, as well as poor technology implementation, poor management of material resources, limited access to adequate markets and the effects of climate change (Hasimuna et al., 2023; Maulu et al., 2021; Ortega-Mejía et al., 2023).

The aquaculture sector faces constant uncertainty regarding its sustainability, as demand for aquaculture products continues to increase, with per capita consumption exceeding 20 kg. This has led aquaculture to contribute 56% of the production of aquatic organisms for human consumption (FAO, 2022). The growth in production also leads to an increase in waste generation, which affects both the productivity of aquaculture systems and natural aquatic ecosystems (Nasr-Eldahan et al., 2021). Despite increasing demand, aquaculture production is often perceived negatively by society (Correia et al., 2020), which hinders the implementation of sustainable production systems. Therefore, it is essential to address the main problems associated with aquaculture, which have been identified in previous studies (Correia et al., 2020; Hasimuna et al., 2023; Mangano et al., 2019; Ortega-Mejía et al., 2023; van Osch et al., 2017):

- The presence of parasites in aquaculture farms and the use of antibiotics to increase productivity and prevent diseases.
- The supply of feed for aquaculture.
- The excessive release of nutrients into natural ecosystems and the accumulation of aquaculture waste in natural water bodies.
- The impact of aquaculture on wild populations and the introduction of non-native species.

Each of these problems has specific contexts, and this paper will provide a general introduction to them, summarising the main proposals for addressing the challenges that stand in the way of achieving sustainable aquaculture. The main purpose of the paper is to encourage new proposals for solutions that promote true sustainability in aquaculture.

6.1 Methodology to be developed

Sustainability in aquaculture has become an issue of great relevance in recent years. Numerous studies have been carried out to propose methodologies to reduce the environmental impact of aquaculture and improve its resource efficiency. However, there has been less research focused on the dissemination of production alternatives that promote more sustainable aquaculture with less impact on aquatic ecosystems. Therefore, this article is based on a focused literature review, using search tools and browsers such as Google Scholar to obtain a wide range of results. The most recent studies were prioritised, and search terms included "integrated aquaculture", "sustainable aquaculture", "multi-trophic aquaculture", "agro-aquaculture", "polyculture", among others.

The content of the articles was reviewed for direct or indirect relevance to this paper, and relevant references found in some of the reviewed studies were also included. Some studies were not included if they did not meet adequate standards of project design or data management, in order to avoid introducing biased information.

6.2 Results

In order to address the main issues in aquaculture, multiple solutions have been proposed and investigated both theoretically and experimentally. In this paper, only the most recent and most interesting solution proposals for the specialised community will be presented, providing a brief context of the problem in question.

6.2.1 The presence of parasites in aquaculture farms and the use of antibiotics to increase productivity and prevent diseases

One of the predominant challenges in any type of aquaculture culture is the presence of parasites associated with the species. In their natural habitat, organisms harbour a number of parasites, but the problem is that some of these tend to spread rapidly under aquaculture culture conditions (Buchmann, 2022). This accelerated spread not only reduces productivity, but also poses the risk of transmitting diseases to organisms in the production system and to wild species in the environment (Bouwmeester et al., 2021). Due to their high adaptability, the main approach to control parasites is the implementation of integrated control programmes encompassing chemical treatments, medication, biological and mechanical systems. This is done to reduce the risk of developing resistance, as to date no specific method has been documented that can completely control parasite proliferation (Buchmann, 2022; Buchmann et al., 2022).

On the other hand, in the same context, antibiotics are widely used to prevent bacterial infections and improve growth and productivity (Mo et al., 2017; Noor et al., 2023). However, due to inadequate waste management in the environment, resistance has been induced in the microbial community in the environment (Noor et al., 2023). To address this problem, some countries have implemented restrictions on the use of chemotherapeutic agents (Correia et al., 2020). Proposals have also been developed to degrade antibiotics using various methodologies (Gong et al., 2023; Noor et al., 2023; Silva et al., 2021). Considering the quest for sustainable aquaculture, the preventive rather than the corrective approach should be prioritised. Therefore, proper use and management of antibiotics represents the best alternative to control this problem.

6.2.2 The aquaculture feed source

One of the main concerns regarding the sustainability of aquaculture lies in its reliance on fishmeal as the main source of protein in the feed of aquaculture organisms to achieve the desired productivity (Kari et al., 2022). Despite decades of research on the use of alternative protein sources, a viable alternative has so far not been found due to its practicality and feasibility (Kari et al., 2022; Wang et al., 2023).

To address this problem, the main focus is on reducing the use of fishmeal and fish oils in aquaculture feed production (Gatlin III et al., 2007; Idenyi et al., 2022; Moutinho et al., 2017). This has been achieved by exploring alternative feeds, including algae, microorganisms, insects and agricultural wastes, among others (Eroldoğan et al., 2023; Howieson et al., 2023; Kari et al., 2022; Ratti et al., 2023; Wang et al., 2023). In addition, research and the use of additives to improve growth and feed efficiency, as well as to strengthen the immune system and increase resistance to disease (Azeredo et al., 2017; Magalhães et al., 2016) has been promoted, which could lead to a direct reduction in feed consumption. Importantly, further research into alternative protein sources for aquafeeds is needed to achieve long-term sustainability of aquaculture production systems.

6.2.3 Excess nutrients released into natural ecosystems and the accumulation of aquaculture waste in natural water bodies

Despite efforts to find technological solutions to improve the sustainability of aquaculture, intensive production systems release high levels of nutrients and organic wastes that can cause eutrophication of natural aquatic systems (Sarà et al., 2018). Only about 20-40% of the nitrogen and less than 50% of the calories consumed are retained by the farmed species (Correia et al., 2020; Peres and Oliva-Teles, 2005; Teles et al., 2020). The generation of waste represents one of the main problems that cause uncertainty and consumer rejection of aquaculture production (Hasimuna et al., 2023). There are various proposals to reduce nutrient accumulation, including integrated production in its various forms. These include agro-aquaculture systems, crop-livestock-fish farming systems and multi-trophic or polyculture systems (Buck et al., 2018; Hasimuna et al., 2023; Thomas et al., 2021; Waktola et al., 2016).

Agro-aquaculture systems are characterised by interdependence between their components, allowing them to meet human requirements while reducing their impact on the environment (Hasimuna et al., 2023). These systems can be configured in different ways: aquafeed grown in combination with plants, livestock or other animals in the same production system, or the independent cultivation of each system within the same farm, using waste from one as input for the other. This provides a portion of the requirements for quality food production at low cost, in addition to generating employment and a source of household income (Hasimuna et al., 2023). This production model allows smallholders to generate steady income from different production systems within their farm (Hasimuna et al., 2023). As this model represents one of the best alternatives to increase the income of small-scale farmers, it should be encouraged (Ibrahim et al., 2023).

Integrated multi-trophic aquaculture (AMTI) is a strategy that seeks to integrate the production of aquaculture species at different trophic levels under a circular economy approach. It aims to minimise energy losses and reduce environmental degradation (Buck et al., 2018; Correia et al., 2020). In this production system, uneaten food and waste from one species is recaptured and converted into food, fertiliser and energy for other species. AMTI has the potential to promote sustainability in aquaculture with environmental, economic and social advantages (Correia et al., 2020; Khanjani et al., 2022). This is achieved through nutrient recirculation, which increases economic resilience by improving productivity, diversifying products and the possibility of accessing markets willing to pay a better price due to the commitment to the environment. (Correia *et al*., 2020; van Osch *et al*., 2017).

AMTI can be implemented in various configurations, including vertebrate, invertebrate and algal production. In this system, organisms that are fed and species that extract organic and inorganic substances from the water are included (Khanjani et al., 2022). In freshwater aquaculture systems, rearing species may include, for example, tilapia (Klahan et al., 2023), while species that feed on organic waste, such as uneaten food and faeces, may be species such as freshwater prawns or catfish (Nuswantoro et al., 2023). In addition, microalgae, which capture dissolved nutrients, also play a role in this system (Idenyi et al., 2022).

Ecological processes in polyculture systems also involve associated biodiversity, which includes wild fish, plants, invertebrates, microorganisms and terrestrial animals (Thomas et al., 2021). AMTI systems encourage more sustainable aquaculture by considering different species as valuable products rather than problems, which optimises resource use, promotes economic diversification and improves social acceptance through better management.

6.2.4 The impact of aquaculture on wild populations and the introduction of non-native species is a major issue in the management of these systems.

Aquaculture has been identified as a significant mechanism for the introduction of non-native species into freshwater aquaculture ecosystems (Gu et al., 2022). Although many of the species of commercial interest have failed to establish in new environments, aquaculture has been directly or indirectly linked to the introduction of non-native species with the potential to become invasive (Sandilyan, 2023). These non-native species that manage to establish in the natural environment due to escapes or poor aquaculture farm management represent a direct threat to regional biodiversity due to competition for resources with native species (Kang et al., 2023; Peña-Herrejón et al., 2016; Thomas et al., 2021).

A viable alternative to reduce the risk that aquaculture poses to biodiversity is the diversification of cultivable species (Bernery et al., 2023; Thomas et al., 2021). This strategy involves prioritising the use of regional species that can be cultivated in aquaculture systems, thus promoting localised production. By focusing on species that already have a potential to thrive in the environment, the likelihood of introducing non-native species into natural ecosystems is reduced, which contributes to the conservation of local biodiversity (Hasimuna et al., 2023; Peña-Herrejón et al., 2016).

In summary, diversification of cultivable species and a focus on regional species are key strategies to minimise the impact of aquaculture on wild populations and reduce the risk of introducing non-native species into freshwater aquaculture ecosystems. These measures are essential to preserve biodiversity and ensure the long-term sustainability of aquaculture.

6.3 Acknowledgement

To the knowledge development fund FONDEC-UAQ 2019 (FIN202008).

6.4 Conclusions

In the quest for sustainability in aquaculture, it is imperative to focus on minimising waste and promoting local production. The adoption of more sustainable aquaculture practices not only reduces social opposition to intensive aquaculture, but also promotes the conservation of natural resources and community welfare. In order to achieve sustainable aquaculture, it is essential to convey clear and accessible information about the advantages and opportunities offered by this form of production (Buck et al., 2018; Correia et al., 2020).

In short, sustainability in aquaculture is not only a desirable goal, but a necessity. The adoption of sustainable practices, such as the diversification of farmable species, the implementation of AMTI systems and the proper management of parasites and diseases, is essential to ensure the health of aquaculture ecosystems and the long-term viability of the industry. In addition, promotion of local production and education about the benefits of sustainable aquaculture are crucial steps to ensure societal acceptance and continued support.

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