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Biochar in Aquaculture: A Sustainable Solution for Environmental Management and Climate Mitigation

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SUMMARY

Aquaculture is a rapidly growing industry that significantly contributes to global seafood production. However, intensive aquaculture practices have led to serious environmental concerns, including eutrophication, coastal deforestation, groundwater contamination, and soil degradation. Biochar, a carbon-rich material derived from the pyrolysis of organic biomass, has gained attention as a sustainable solution to mitigate these issues. This review explores the applications of biochar in aquaculture, highlighting its role in improving water quality, enhancing soil and sediment properties, serving as a feed additive, treating wastewater, and contributing to carbon sequestration and climate change mitigation. Despite its numerous advantages, challenges such as variations in biochar properties, potential contamination risks, and the need for regulatory frameworks hinder its widespread adoption. Further research and interdisciplinary collaboration are necessary to optimize biochar production and ensure its safe and effective use in aquaculture. With continued advancements, biochar holds great promise in promoting environmental sustainability and enhancing productivity in aquaculture systems.

INTRODUCTION

The aquaculture sector is expanding quickly and contributes significantly to the world's seafood supply. However, extensive aquaculture methods, which are promoted by the need for increased profits, lead to environmental issues such as eutrophication, salinization, coastal deforestation, groundwater contamination, harm to agricultural land, etc. These issues are exacerbated by the use of extrinsic chemical compounds, endangering the system's environmental sustainability. Biochar, which has been extensively utilized in agriculture for productivity increase, may also be used for aquaculture for similar goals. Biochar has become a viable option for enhancing aquaculture output and environmental well-being in recent years. A carbon-rich substance produced by pyrolyzing organic biomass, biochar has several uses in aquaculture, such as improving fish health, enhancing soil, and purifying water.

What is Biochar?

Biochar is a fine-grained, carbon-rich, porous material made by pyrolyzing waste from industry, agriculture, cities, and animals at temperatures between 350 and 600°C without oxygen. The two main determinants of biochar's physicochemical characteristics and nutritional content are biomass and temperature. Because of its unique physicochemical characteristics, including its large surface area to volume ratio, functional groups, trace elements, and absorption property, among others, it has a greater potential for application in aquaculture.

Figure 1: Properties of biochar

Applications of Biochar in Aquaculture

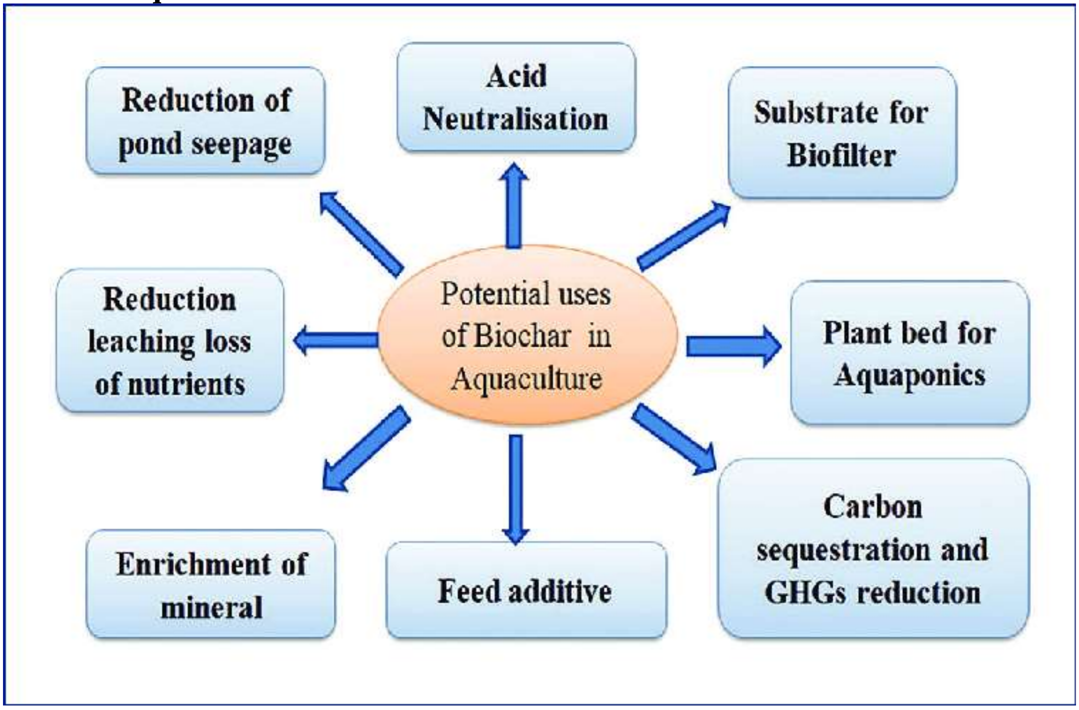

Figure 2: Potential uses of biochar in aquaculture

1. Water Quality Enhancement

Biochar plays a crucial role in water amendment in aquaculture due to its extensive pore structure, modifiability, and cost-effectiveness in pollutant removal. It efficiently adsorbs heavy metals, ammonia, and persistent organic pollutants (POPs) through physical and chemical interactions, such as van der Waals forces and electrostatic attraction. Additionally, biochar enhances microbial degradation by providing a habitat for pollutant-tolerant microorganisms, reducing contaminants like pesticides and antibiotics. Studies demonstrate its effectiveness in aquaculture filtration systems, improving water quality and fish health. Thus, biochar presents a sustainable solution for cleaner aquaculture and reduced environmental impact.

2. Soil and Sediment Improvement

Pond soil management benefits from the use of biochar, especially in inland saline aquaculture. It improves nutrient retention, neutralizes acidic soils, and stops vital minerals from leaching. According to studies, adding biochar to aquaculture ponds boosts microbial diversity, which is essential for the breakdown of organic matter and the cycling of nutrients. Adding biochar to the soil has a beneficial effect on soil fertility. It improves root development by raising the soil's air content and water-holding capacity. Additionally, by increasing the pH of the soil, biochar aids in the release of nutrients. It functions as an organic fertilizer when combined with organic waste materials like ash, molasses, wool, slurry, and pomace. Additionally, biochar keeps vital nutrients from leaching, guaranteeing that they are still accessible for plant absorption.

3. Biochar as feed additive

Research on using biochar in fish diets is still limited, but existing studies suggest significant benefits. Biochar, particularly bamboo and rice husk-based types, has been shown to improve fish growth performance, feed conversion ratio (FCR), and protein efficiency ratio (PER). Studies on various fish species, including Japanese flounder, brown trout, and striped catfish, indicate that biochar supplementation enhances weight gain, specific growth rate (SGR), and survival rates. The optimal biochar levels vary among species, with doses ranging from 0.2% to 4% in diets yielding positive results.Biochar binds harmful toxins and pathogens in the gastrointestinal tract, reducing the incidence of diseases and improving overall fish health.

4. Wastewater treatment

The cost-effectiveness of incorporating biochar into conventional granular media filters for water treatment will be determined by its sorption efficiency as well as, its ease of regeneration or replacement and reuse. The specific properties of biochar including large specific surface area, porous structure, enriched surface functional groups and mineral components make it possible to be used as a proper adsorbent to remove pollutants from aqueous solutions. As an adsorbent, biochar has a porous structure similar to activated carbon, which is the most commonly employed and efficient sorbent for the removal of diverse pollutants from water throughout the world.Aquaculture generates significant amounts of organic waste, including uneaten feed, fish excreta, and dead biomass. Converting this waste into biochar through pyrolysis not only reduces environmental pollution but also provides a valuable resource for improving water and soil quality.

5. **Carbon Sequestration and Climate Change Mitigation**

Biochar has the potential to act as a long-term carbon sink, reducing greenhouse gas emissions from aquaculture operations. It plays a crucial role in carbon sequestration by storing carbon in a stable form in the soil for hundreds to thousands of years, reducing the release of CO_2 and other greenhouse gases into the atmosphere. This process helps slow down climate change by preventing the rapid return of photosynthetically fixed carbon to the air.It sequesters carbon that would otherwise be released into the atmosphere through the decomposition of organic matter. This makes it a promising solution for sustainable aquaculture practices.

Challenges and Future Prospects

Biochar presents significant opportunities for sustainable aquaculture, yet several challenges must be addressed for its effective application. One of the key opportunities lies in its potential to enhance water quality, improve sediment conditions, and manage pollutants, making it a promising tool for environmentally responsible aquaculture. Research has demonstrated its ability to promote fish growth and health while also playing a role in nutrient management and pollutant removal. However, the widespread use of biochar in aquaculture is still limited due to gaps in research, particularly regarding its long-term ecological impact and interactions with aquatic organisms. There is a need for comprehensive studies on the effects of biochar-treated water and sediments, especially concerning heavy metal and organic pollutant exposure. Additionally, variations in biochar properties due to differences in feedstock and pyrolysis conditions raise concerns about potential toxic contaminants, such as dioxins and polycyclic aromatic hydrocarbons (PAHs), which could pose risks to aquatic life and human health. Ensuring the quality and safety of biochar before its commercial application remains a significant challenge. Moreover, regulatory frameworks and global guidelines for its use in aquaculture are currently lacking, necessitating collaboration between researchers, policymakers, and industry stakeholders. Despite these challenges, the potential benefits of biochar warrant further exploration, particularly through optimising production methods, conducting long-term impact studies, and raising awareness among aquaculture practitioners. Addressing these gaps through interdisciplinary research and regulatory development will be crucial in unlocking biochar’s full potential as a sustainable solution for aquaculture.

CONCLUSION

Biochar has emerged as a promising tool for sustainable aquaculture, offering multiple benefits such as water purification, soil enhancement, improved fish health, wastewater treatment, and carbon sequestration. Its ability to adsorb pollutants, enhance microbial activity, and improve feed efficiency makes it a valuable addition to aquaculture systems. Moreover, its role in carbon sequestration and climate change mitigation further highlights its environmental significance.However, despite its potential, challenges remain in terms of long-term ecological impact, variations in biochar properties, and potential contamination risks. Further research is needed to establish standardized guidelines, ensure biochar quality, and assess its long-term effects on aquatic ecosystems. With continued scientific investigation, policy support, and industry collaboration, biochar could become a key component in making aquaculture more sustainable and environmentally friendly.

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