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Strategies for Reducing the Carbon Footprint in Aquaculture: Sustainable Approaches for a Greener Future

Parpanathan Ajith[1], Panneerselvam Dheeran[2], Anbazhagan Anusuya[1], Gurusamy Pradeepa[1] and Tamil Prakash S.[1]

[1]College of Fisheries, Mangalore

[2]ICAR-Central Institute of Fisheries Education, Mumbai (M.S.)

SUMMARY

Aquaculture is increasingly recognized as a crucial component of sustainable food production, offering a viable alternative to traditional livestock farming with a lower carbon footprint. As global food demand continues to rise, aquaculture has the potential to enhance food security while minimizing environmental degradation. However, ensuring its long-term sustainability requires continuous advancements in breeding techniques, disease management, water quality control, and alternative feed sources. Effective waste management strategies and ecosystem-based farming approaches are essential to mitigate pollution and habitat destruction. This article examines the role of scientific innovation, responsible consumer behaviour, and industry collaboration in promoting sustainable aquaculture practices. Furthermore, it emphasizes the need for policy reforms, stricter environmental regulations, and global cooperation to facilitate the green transformation of the sector. By integrating cutting-edge technologies, responsible governance, and stakeholder engagement, aquaculture can contribute significantly to reducing the environmental impact of global food systems while ensuring economic viability and food security for future generations.

INTRODUCTION

As the global population grows, the demand for sustainable food production has never been more urgent. Aquaculture, farming fish and other aquatic organisms has emerged as a crucial solution for meeting this demand while minimizing environmental impact. Aquaculture, unlike traditional livestock farming, has a lower carbon footprint, making it a key player in the transition toward greener food systems. However, ensuring its long-term sustainability requires continuous scientific research, technological innovation, and informed consumer choices. Furthermore, collective action, advancements in breeding techniques, and strategic policy reforms are essential to drive the sector toward an environmentally responsible future. This paper explores the role of aquaculture in reducing global food production emissions and the necessary steps for its sustainable transformation.

Carbon footprint

Carbon footprint is the total amount of greenhouse gases (GHGs) generated during the life cycle of a person, business, or product. Metric tons of carbon dioxide equivalent (CO_2 eq) is commonly used to quantify the carbon footprint. But it's important to remember that other GHGs, such as nitrous oxide (N_2O) and methane (CH_4), contribute significantly to climate change. The GHG emissions generated throughout the aquaculture process, which are mostly caused by the production and consumption of energy, are represented by the carbon footprint of aquaculture. The production and delivery of feed, the processing and refrigeration of aquaculture products, and the operation of water pumps, aerators, and other equipment for preserving water quality and circulation are examples of these energy-intensive operations. In addition, producing and transporting artificial feed, water quality treatment, water level management, and the processing of aquatic products all contribute to emissions by releasing GHGs. The aquaculture industry's high energy demands have made its GHG emissions a major environmental concern. As a result, calculating aquaculture's carbon footprint involves considering both the wider societal ramifications and the environmental impact.

Carbon footprint implications

Aquaculture carbon footprint research is essential for quantitative assessments and for creating mitigation plans for environmental effects. Advanced big data analytics make customised probability models possible, which improve environmental controls and lower emissions by evaluating important parameters like temperature, salinity, and dissolved oxygen. Targeted enhancements, including effective feed strategies, stringent emission requirements, and thorough waste treatment, are informed by identifying emission patterns. Biofloc Technology (BFT), Integrated Multi-Trophic Aquaculture (IMTA), and Recirculating Aquaculture Systems (RAS) are examples of sustainable practices that are investigated; IMTA provides efficient fertilizer recycling. Development in feed management, species domestication, and farming techniques have been implemented to lessen aquaculture's carbon footprint. Emissions can be further reduced by optimizing oxygen levels, feed conversion ratios, and monitoring systems.

Carbon footprint emissions profile of fish culture

Aquaculture produces about 3271 kg of CO2eq for every ton of fish raised. However, this emission rate is much lower when seaweed or shellfish are cultivated. The feed supply chain, which includes crop cultivation, the capture of wild fish for the manufacture of fish meal and oil, and the processing and transportation of the feed, is the primary source of greenhouse gas emissions in fish farming. Due to fuel and energy use, infrastructure development, and maintenance, industrial fish farming systems such as closed or recirculating systems have greater emissions. Additionally, fish farming can lead to water eutrophication and the buildup of leftover feed, which can deteriorate benthic habitats and increase GHG emissions.

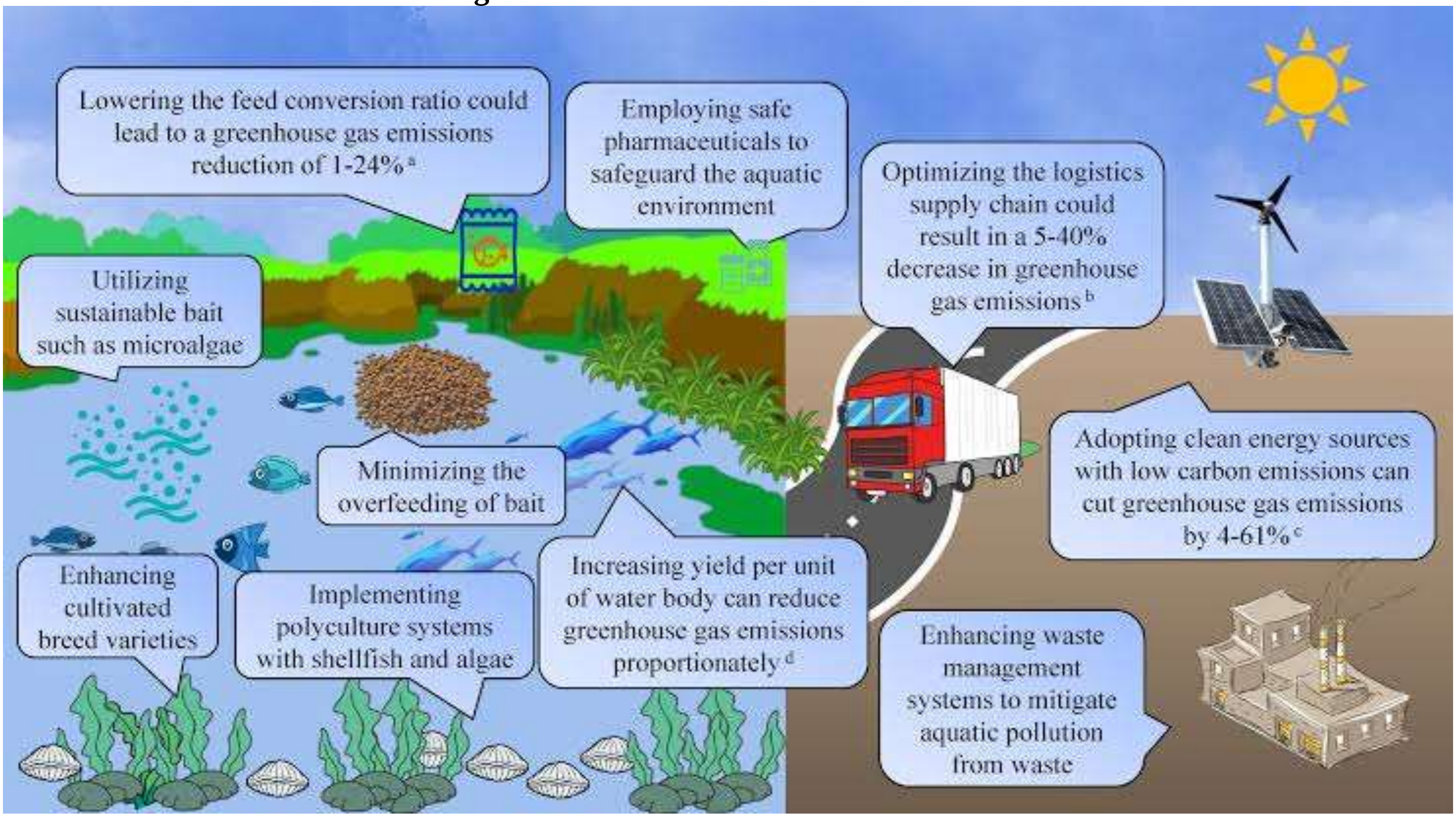
Factors affecting carbon footprint in aquaculture production

Aquaculture is essential to satisfy the demand for aquatic products worldwide. The production and use of feed cause a sizeable portion of GHG emissions during cultivation. Aquaculture sites' fuel and energy consumption are also major sources of emissions. To reduce emissions, technological and financial constraints are associated with the treatment and transportation of waste, including excrement.

Primary measures for emission reduction

According to research, aquaculture's environmental effects can be considerably reduced by lowering the feed conversion ratio (FCR). Implementing sustainable feeds, improving their composition, and controlling feeding procedures are essential to reducing aquaculture's environmental impact. Feed consumption and related carbon emissions can be reduced using appropriate feed formulations and eliminating excess. A low-cost and environmentally friendly feed substitute, microalgae are nutrient-dense for aquatic animals' growth and well-being and need little cultural resources. Precise feeding, waste reduction, and pollution reduction depend on accurate aquaculture management, which includes monitoring water temperature, quality, flow, and pressure.

Other GHG emission control strategies



Other viable strategies for carbon footprint emissions in aquaculture include,

Low-carbon energy adoption:

To lessen its environmental influence, the aquaculture industry should switch from conventional energy to renewable sources such as solar, wind, and hydropower.

Logistics optimization:

To improve product delivery efficiency and reduce logistics' carbon footprint, it is essential to streamline transportation routes and pool transportation and storage resources.

Water resource management:

Aquaculture systems' water quality may be improved, contamination risk can be decreased, and dependency on natural water bodies can be lessened by promoting and regulating safe, low-impact treatments.

Waste treatment enhancement:

Aquatic pollution can be considerably reduced by funding research and implementing cutting-edge waste treatment techniques, including biological filtration, reverse osmosis, and algae cultivation.

Eco-friendly product development:

By creating green aquaculture goods, the industry is urged to make a commitment to marine conservation and sustainable production. This approach can decrease wasteful practices, boost market appeal and demand, and lessen the production's negative environmental effects.

Studies determined that the following four broad technology strategies can be used to lessen aquaculture's negative environmental effects.

(1) Breeding and Genetics

(2) Disease control

(3) Nutrition and feeding

(4) Low-impact production system.

Aquaponics

In this hybrid aquaculture and hydroponics system, in which the plant and fish farming units continue operating independently or as integrated systems, Lettuce, spinach, and other leafy greens can be grown using feed-efficient fish waste from tilapia and pangasius. This makes it possible to create better high-yield production methods without causing environmental damage. Through the sequestration of plant biomass, high-density fish aquaculture reduces greenhouse gas emissions by producing nutrient-rich effluent for plant development.

Integrated Algae Farming

Algae farming are acknowledged as a climate change adaptation and mitigation technique. Establishing seaweed farms with the minimal capital needed is a wise move, particularly for poor nations along the shore. Protect marine and coastal ecosystems from the effects of climate change, such as oxygen depletion and ocean acidification, by helping to mitigate them. About 1,500 tCO_2 km^2/yr is algae farms' possible CO_2 storage intensity, which is 10% more than the 12,500 tCO_2 km^2/yr avoidable CO_2 emissions of offshore wind farms.

Sustainable Development Certification and Standards

Promoting ethical aquaculture methods requires a sustainability certification system. Eco-friendly efforts are encouraged by tightening industry control and environmental legislation. Reducing food waste and promoting ecologically friendly packaging are two benefits of educating consumers about sustainable seafood options. Diversifying seafood options and lowering dependency on conventional species require market impact. Industry organisations should lead by example by incorporating sustainable technologies and upholding environmental and health norms.

Shifting Consumer Preferences Toward Low-Carbon Aquatic Products

The industry's green transition is supported when customers are encouraged to select low-carbon aquatic products. As a sustainable substitute for terrestrial proteins, unfed aquatic organisms have a small environmental impact. Important minerals like iron, zinc, vitamin B12, and omega-3 fatty acids are found in "blue foods". Better environmental impact evaluation and comparison are made possible by establishing standardized carbon footprint benchmarks. Long-term industry sustainability is ensured by controlling emissions through policy recommendations and technology developments.

CONCLUSION

Aquaculture holds significant potential for reducing the carbon footprint of global food production, offering a more sustainable alternative to traditional livestock farming. However, achieving long-term sustainability in the sector requires a multifaceted approach that includes scientific research, technological innovation, and responsible consumer choices. Additionally, collective efforts to improve breeding techniques, implement eco-friendly practices, and enact policy reforms are essential for fostering a green transformation. By prioritizing sustainability in aquaculture, stakeholders can contribute to a more resilient and environmentally responsible global food system.

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