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Current Advancements and Innovations in Aquaculture

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ABSTRACT

The practice of rearing commercially important aquatic species in regulated settings, such as shellfish and fish along with the commercially important plants, is known as aquaculture. It is an important industry for producing seafood, offering a sustainable alternative to wildcaught fishes and ensuring global food security. Aquaculture offers a constant and sustainable protein source to feed the growing population of the world, gives millions of individuals jobs worldwide in agriculture, trade and processing. Additionally, helps to combat overfishing by supplementing natural fisheries with farmed fish and shellfish. Despite all of these advantages, a number of environmental, social, and economic issues are causing major changes in the sector. Advancements in aquaculture are thus absolutely essential to satisfy the growing global need for seafood. Because of this, several cutting-edge technologies have been created in recent years. This paper emphasizes on the latest innovations in aquaculture that have been developed in recent years. Biofloc technology, aquamimicry, triploidy, polyploidy, vaccines, utilizing black soldier flies (BSF) as an extra source of protein, probiotics, and prebiotics in aquaculture operations, the use of effective microorganisms (EM) to regulate water quality, are some of the innovations, which were developed recently in order to achieve sustainable aquaculture production, minimize disease outbreaks, increase crop yields and promote environmental friendly advancements.

Keywords: *Aquaculture, Innovations, Technologies, Advancement, Sustainable, Food security.*

Introduction:

Raising aquatic animals with human help during breeding in order to raise output in various fields such as feeding, storage, reproduction and predator protection is known as aquaculture. (Araujo and Silva, 2022). Fish farming is quickly emerging as one of the most important areas of the global agricultural economy. Growing human population and the need for high-quality, beneficial animal protein, particularly with its beneficial fats at affordable prices is the main factors fueling the aquaculture sector's steady growth (Sudhakar and Dathu, 2025). About half of fisheries products for human consumption come from aquaculture, which grew to 52.5 million metric tons in 2008 from six hundred thousand metric tons in 1950 (FAO, 2010). The creation of new agricultural techniques and the growth of culture volume have been responsible for the majority of this increase. In order to achieve the desired outcomes, modern methods based upon scientific, ecological, technological, and economic principles must be employed (Sudhakar and Dathu, 2025). In addition, aquaculture has significant obstacles such as disease outbreaks, environmental contamination,

and labour shortages, making new technologies essential to boosting fish and aquaculture production and ensuring sustainability (Yue and Shen, 2021). Aquaculture has developed quickly as a result of scientific applications or the arrival of new technologies (Brunell and Allan, 2009). Example, advancement in reproductive technology, have made it easier to manipulate different phases of species' life, hence allowing species diversification in the industry. By using live feeds like zooplankton, worms, shrimp, artemis, microalgae, and copepods in breeding facilities, successfully has overcomed the obstacles arises during culturing of various marine species. Using quantitative genetics to guide selective breeding has considerably improved commercially valuable traits in over more than 61 aquaculture species (Gjedrem and Robinson, 2014). By enabling intrafamily selection in mass-crosses, molecular parentage has decreased the risk of inbreeding. Selection of phenotypes governed by a few essential genes or individual genes has been made achievable by marker-aided selection as well as the Qualitative trait loci (QTL) mapping. Lower food expenses and higher feed rate of conversion (FCR) are the outcomes of improved feed formulations that consider the dietary demands of certain fish species. Diversification of species, live and prepared feeds, disease control, water management, molecular parentage, selective breeding, sex control, and closing cycle of reproduction, the prevalence of illnesses in aquaculture has decreased thanks to disease management technologies (Yue and Shen, 2021). Robotics, detectors, artificial neural networks, blockchain, additive reality (AR), drones, immersive reality, and 3D printing are some of the advanced technologies connected to farms through satellites, smartphones, and the Internet of Things (IoT) (Ruby and Ahilan, 2023).

Aquaculture Importance and Advancements:

Aquaculture has a wider range of species, aquafeeds, production methods, products, business models, and marketing strategies than the majority of other food producing industries. Nearly every facet of aquaculture has profited from development, expansion, and advancement in science and technology. Aquaculture has multiple economic benefits, in farming, processing, and distribution, by generating employment. Additionally, it helps local companies that provide transportation and equipment facilities. Aquaculture minimizes dependency on imports by producing fish locally. The home economy is strengthened as a result. It also offers a sustainable food supply, increasing food security and export possibilities (Ruby and Ahilan, 2023). Despite of all these benefits, aquaculture faces significant obstacles such as disease outbreaks, environmental contamination, and a need for a large workforce, to overcome these issues and for improve sustainability, new technologies are essential. The biotechnology industry is developing more quickly in the fields of fisheries and aquaculture, where it has been found to aid in raising fisheries production (Lakra and Ayyappan, 2003). The aquaculture sector therefore adopts new technology and procedures in response to the demand for seafood on a global scale and the requirement for efficient, sustainable production (Brunell and Allan, 2009). Artificial intelligence (AI), computerized models and geographical information systems (GIS) are some of the examples of technology-related innovations that are used to improve aquaculture facility management as the component of regional planning for aquaculture development. Due to the rapid development of new technology and advancement in our understanding about the fish biology, aquaculture production experienced a tremendous increase in the initial decades of the twenty-first century. Meanwhile, developments in biotechnology have transformed the aquaculture industry and made a substantial contribution to the preservation of biodiversity. These developments include molecular biology, polyploidy, monosex culture, and the use of artificial hormone in fish breeding. Increasing

growth rates is the main goal of gene biotechnology's application in aquaculture, but it also targets improving disease resistance, creating sterile stocks, and physiologically tolerating harsh environmental conditions (Manan et al., 2023).

Major Aquaculture Techniques:

Aquaculture practices are being used to improve production and management through the use of beneficial microbes for the productivity and the disease control, implementation of aquamimicry, microbial biotechnology and the addition of soldier fly as an extra protein feed, as well as the use of prebiotics, triploidy, polyploidy, medications, probiotics, and incorporation of internet for tracking the quality of water in aquaculture operations (Manan et al., 2023). Aquaculture productivity and profitability are increased through scientific applications and the introduction of new technology, which serves to improve the aquaculture sector and support sustainable aquaculture output in the near future as well as the sustainable development objective.

Innovations in aquaculture

Soldier fly: *Hermatia illucens*, is the scientific name of this fly, its larvae are being utilized more and more in aquaculture as a sustainable substitute for fishmeal. They provide a high-protein feed source that can be made from organic waste, enhancing fish health and environmental sustainability (Manan et al.,2023).

Vaccines: In aquaculture, vaccines are essential for preventing disease. Common forms of vaccines include inactivated, live-attenuated, and recombinant vaccines, which can be given orally, by injection, or by immersion (Mondal and Thomas, 2022).

Aquamimicry: According to Manan et al. (2023), it is a novel system that necessitates the integration of the biological carbon without specifying the particular carbon to nitrogen ratio. Additionally, this process does not require the adjustment of the carbon to nitrogen ratio because it solely depends on the incorporation of the metabolized source of carbon.

Biofloc technology: It is an innovative technology that supports aquaculture production by boosting shrimp yield, replacing animal feed, promoting bioremediation and biodegradation processes. The diverse range of microorganisms that comprise biofloc includes worms, protozoa, fungi, algae, heterotrophic bacteria, and detritus. Together, these microbes preserve the water's purity and encourages the dense shrimp farming (Manan et al., 2023).

Triploidy and polyploidy: Chromosome manipulation and hybridization are two efficient techniques for enhancing aquaculture genetic makeup. The method of hybridization is needed for the biological evolution, maintenance of gene variability among individuals, and biological adaptability (Manan et al., 2023).

Aquaculture applications of pro-biotics and pre-biotics: Both pro and pre- biotics are commonly utilized as a food supplements in the aquaculture field. It has been suggested that both of them helps the host by fighting off illnesses, which immediately enhances growth by making the host larger and more substantial. In certain situations, they also function as substitute antibacterial substances and boost the immune system (Manan et al., 2023).

Integrating fish farming: Fish aquaculture combined with livestock husbandry or rural elements is recognized as a sustainable farming method. Therefore, integrated fish farming increases the use of available natural resources, which helps to produce food over time (Sankhla and Kumar, 2020).

Aquaculture technologies

Technologies includes sensors, 3D printing, blockchain, robots, drones and artificial intelligence are widely used in aquaculture for

increased production and real-time monitoring of growth of aquatic organisms and water quality. These automations are linked to aquafarms via cell phones, satellites, and the internet of things (IoT) giving real-time data.

Robotics: Robots can be used for vaccination injections, fish disease removal, pond net cleaning, and feeding. Additionally, robots have been employed to monitor and stop farmed fish from escaping, as well as to assess the health of the fish (Ruby and Ahilan, 2023).

AI (Artificial Intelligence): In aquaculture, artificial intelligence helps with water quality monitoring, assessing community condition in cages, ponds, and hatcheries, figuring out when and how much feed to give to cultured species, lowering the amount of food supply to cultured systems, and increasing labour efficiency by automating culture systems (Kim, 2021).

Sensors: Sensors are crucial to modern aquaculture because they permit continuous monitoring and control of various physiochemical parameters of water, maximize aquatic life development, and reduce potential issues such as fish kills (Lopes et al., 2024).

Drones: In aquaculture, drones are being utilized more and more for a variety of functions, including for tracking the health and behaviour of fish, evaluating the quality of the water, distributing feed optimally, and even transporting live fish, which increases productivity and lowers personnel costs (Ubina and Cheng 2021).

3D printing: Specialized tools for planting, harvesting, and other aquaculture chores can be made using 3D printing to meet specific requirements (Kim, 2021).

Block chain: By allowing the tracking of fish products from farm to consumer, blockchain technology has tremendous potential for increasing traceability and transparency in the aquaculture sector, hence combating fraud and ensuring food safety (Ruby and Ahilan, 2023).

Conclusion:

Currently, aquaculture has many obstacles, such as disease outbreaks, brood stock enhancement, deteriorating water quality, and a shortage of available land area. Therefore, aquaculture technical developments are necessary to improve aquaculture production. Presently, researchers and scientists are actively developing innovative technologies in the aquaculture domain to enable aquaculture communities to achieve higher production levels and foster environmentally sustainable practices for future production. By embracing innovation and technology the aquaculture industry can improve efficiency, sustainability and animal welfare while meeting the growing demand for seafood.

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