

Nano-Aquaculture: Potential Applications of Nanotechnology in Fish Health and Growth Enhancement

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Introduction

Aquaculture plays a crucial role in global food security, but it faces challenges such as disease outbreaks, poor feed utilization, and water quality management. Nanotechnology has emerged as a promising tool to enhance fish health, improve growth performance, and ensure sustainable aquaculture practices. This article explores the applications of nano-based feed supplements, nanomedicine for disease control, water purification using nanomaterials, and nanotechnology-assisted vaccine delivery. The integration of nanotechnology in aquaculture holds immense potential, but concerns related to toxicity, environmental impact, and regulatory frameworks must be addressed to ensure its safe and effective implementation.

Keywords: Nano-aquaculture, Fish health, Growth enhancement, Nanotechnology, Applications, Challenges.

Introduction:

Aquaculture, a rapidly growing food production sector, faces challenges such as nutritional deficiencies, disease outbreaks, and poor water quality. Traditional methods of disease control, feed supplementation, and water treatment

often have limitations in efficiency and sustainability. Nanotechnology, which involves manipulating materials at the nanoscale (1-100 nm), offers innovative solutions by improving bioavailability, targeted delivery, and antimicrobial properties. Nano and biotechnology are two of the 21st century's most promising technologies. Nanotechnology involves designing, developing, and applying materials and devices with minimal functional make-up on a nanometer scale, while biotechnology deals with metabolic and physiological developments of biological subjects, including microorganisms. These microbial processes have opened up new opportunities for exploring novel applications, such as the biosynthesis of metal nanomaterials. Nanobiotechnology offers a wide range of uses in medicine, agriculture, and the environment, with many diseases that do not have cures today potentially being cured by nanotechnology in the future. However, the use of nanotechnology in medical therapeutics requires adequate evaluation of risk and safety factors. While some scientists support advancement in nanotechnology, testing should



be carried out to ensure its safety in humans. If everything proceeds as expected, nanobiotechnology may become an inevitable part of everyday life and save many lives.

Applications of Nanotechnology:

a) Dietary enhancement through nanotechnology:

Aquaculture is a rapidly growing food sector that requires continuous innovation for sustainability. Traditional feed additives are used to enhance nutritional value, but nanotechnology has shown potential to improve feed formulation and reduce environmental impacts. It examines the use of nanoparticles in fish feed formulation for enhanced sustainability, focusing on nutrient availability, feeding efficiency, growth performance, and health. Results show that nano-enhanced diets improve fish growth, health, and environmental sustainability by enhancing nutrient efficiency and minimizing waste.

b) Silver Nanoparticles:

The fisheries and aquaculture industry can be significantly impacted by nanotechnology, offering tools for rapid disease detection and enhancing fish's ability to absorb drugs. The global nanotechnology industry is predicted to reach USD one trillion by 2015, with potential applications in electronic and materials science, humans, animal food, and agriculture. Silver nanoparticles are effective in antimicrobial activity, reducing fish disease and environmental problems caused by antibiotics. Nanopackaging can increase fresh fish's shelf life by using nanopolymers and coatings, while

nano silver can reduce bacteria build-up in aquaculture systems. Nano-biosensors can be used for microbe control, with sensitized carbon nanotubes-based biosensors detecting microbes from water and food sources. Nano colloidal silver is a beneficial product of nanotechnology, acting as a catalyst against a wide spectrum of bacteria, fungi, parasites, and viruses. DNA nano-vaccinations can provide high levels of protection against bacterial diseases and certain viral diseases with vaccine-induced side effects.

c) Treatment of Aquaculture effluents using nanotechnology:

The application of nanotechnology in aquaculture has recently garnered attention due to its advantageous implications for both humans and the ecosystem. Relevant literature was sourced and systematically compiled from academic databases, followed by a thorough analysis in this investigation. It offers the diverse aquatic parameters influencing aquaculture, the incorporation of nanotechnology in the treatment of aquaculture effluents, and the toxicity associated with these nanoparticles (NPs) to both fish and other aquatic organisms, which may inform future research endeavors. Existing studies suggest that nanotechnology proves to be highly effective in the remediation of aquaculture effluents by normalizing physiochemical parameters, eliminating heavy metals such as lead, and removing organic contaminants including Polychlorinated Biphenyls, Polycyclic Aromatic Hydrocarbons, and



pesticides. Furthermore, it plays a role in diminishing the microbial load of pathogens such as Salmonella, Escherichia coli, Campylobacter, and Vibrio in effluents. Despite these favorable outcomes, the nanoparticles utilized in the treatment of these effluents may also exert negative effects on aquatic organisms and result in heightened salinity within the environment. However, the use of both plain and fluorescently labeled NPs, as well as the coating of NPs with tyrosine, holds promise for mitigating toxicity.

d) Nanoparticles and Emulsion-Based Systems:

Pickering emulsions, stabilized by solid particles instead of surfactants, are advantageous over conventional surfactant-stabilized emulsions due to their low toxicity, enhanced resistance to coalescence, good reproducibility, scalable productivity, and improved biocompatibility. These emulsions ensure sustained and controlled release of encapsulated-bioactive compounds throughout the gut course. Numerous colloidal particles have been employed as stabilizing agents in the fabrication of Pickering emulsions. Marku and colleagues prepared starch-based Pickering emulsions as topical drug delivery vehicles with good stability during storage for 8 weeks and against mild centrifugation. Cossu et al. used this system for the encapsulation and delivery of antifungal natural phenolic compound thymol and amphotericin B., concluding that starch-based emulsions could be a potential approach for the delivery of

hydrophobic antifungal compounds in treating oral candidiasis. Cyclodextrins-based Pickering emulsions were synthesized for topical delivery of antifungal azole derivatives, and heat-treated soy glycinin stabilized gel-like Pickering emulsions were prepared for the delivery of β -carotene. In vitro studies simulating intestinal digestion, conditions found that all tested emulsions well protected the encapsulated β -carotene against degradation and ensured its sustained release.

e) Nano-Selenium:

Selenium is a crucial trace element for body functions and animal metabolism, playing a significant role in fish physiology by enhancing their physiological status and immune systems. It prevents cell damage, promotes growth, fertility, and immune functions, and protects against oxygen-free radicals. Selenium supplementation increases immunity by enhancing lysozyme activity and red blood cell count, which can be enhanced with an appropriate diet in tilapia. The nano form of selenium is more effective due to its high bioavailability and lower toxicity. The biological properties of nano-selenium (Nano-Se) depend on their size, with smaller particles having greater activity. Nano-Se has low toxicity and excellent bioavailability, but is unstable and can be stabilized by encapsulation with chitosan.

f) Removal of Heavy Metals:

Ligand-based nanocoatings are effective for heavy metal removal due to their high absorption propensity and cost-effectiveness.



These nanoparticles, including ferric oxides, aluminum oxides, manganese oxides, cerium oxides, magnesium oxides, and titanium oxides, have a high surface area and specific aqueous system affinity for heavy metal adsorption. New technologies for synthesizing metal oxide nanoparticles and practical applications, such as composite materials or granular oxides, are being developed. Research on the effects of humic acid and fulvic acid on heavy metal removal by various nanomaterials from aqueous solutions has been conducted. Chitosan nanoparticles have been used as adsorbents for heavy metal removal from clays like kaolinite, bentonite, and montmorillonite. Recent studies have focused on nano chitosan-clay composites for metal ion removal and chitosan-magnetite nanocomposites for heavy metal removal from aqueous solutions.

g) Nanobiosensor:

Nanobiosensor systems are being developed to detect low concentrations of parasites, bacteria, viruses, and polluting elements in water, particularly in commercial aquaculture systems. Nanotechnology holds the potential to overcome the challenge of early detection and eradication of pathogens. Nanosensors can detect a wide range of pathogenic agents, such as electrical nanosensors for single virus particles and immuno-targeted gold nanoparticles for specific biomolecules. They are also used for fishpond cleaning and stock scrutiny. Tracking-nanosensors, with locators relaying data about geo-localization and fish health status, allow control of individual fish or

intelligent cage systems. Nano-barcode systems, coupled with synthetic DNA tagged with color coded probes, can be used to identify pathogens, monitor leakages, temperature changes, and other parameters, enhancing product quality.

h) Usage in Seafood Processing:

Nanotechnology is being utilized in aquaculture and seafood marketing to extend product shelf-life and preserve freshness. Research in food packaging has intensified due to the potential properties of nanomaterials, such as oxygen depletion, reduced enzyme activity, antimicrobial and antifungal activities, and detection of pathogens and toxins. Nanostructures like nanoemulsion, nanofibers, and nanoparticles can slow down degradation, maintaining product color and flavor. Essential oils encapsulated in diverse nanostructures, such as cyclic oligosaccharides, nanotubes, polymeric nanoparticles, solid lipid nanoparticles, zein nanoparticles, and biodegradable nanoparticles, are also being used. Nanoparticles impregnated with ice can be used for various food packaging applications, such as reducing microbial load on the flathead grey mullet surface. Organic methods are being focused on producing silver nanoparticles for seafood preservation. Animals like oysters, prawns, and fishes also possess bioactive compounds with potential ethnobotanical functions.

i) Usage In Packaging Industry:

Nanotechnology is being used in seafood preservation to delay spoilage and ensure food



security. Products with antimicrobial activity, such as silver nanoparticles, are becoming popular. Nanocomposites films, derived from natural biopolymers, are increasingly used as a replacement for plastics produced by petrochemical sources. Chitosan nanoparticles, with their poly cationic form, have been investigated for their antimicrobial properties. Nanocomposite films with chitosan nanoparticles and gelatin, with oregano essential oil, show high antimicrobial activity against common food pathogens. Chitosan is also considered an efficient antimicrobial agent due to its poly cationic form. Other nanomaterials, such as carbon nanotubes, fullerene, graphene, and graphene oxide, also show good antimicrobial properties. These nanomaterials could have significant potential for developing new nanocomposite materials for the seafood packaging industry.

j) Nano-vaccine:

Nanotechnology's convergence with biotechnology has led to advancements in biomedicine and the development of nanovaccinology, a new science field that focuses on vaccines designed with antigens or nanoparticles. Nanovaccines target the body's infection site using the immune system to inhibit disease spread. The production of vaccines has shifted from using whole pathogens to protein and peptide antigens to reduce side effects. Nanoparticles are used as carriers and adjuvants to enhance the immunogenicity of vaccines, resulting in triggered cellular and humoral immunity

responses. Nanovaccines offer advantages such as enhanced blood flow stability, increased immune system activation, no need for booster doses, and active targeting. However, concerns exist about environmental and health risks associated with nanoparticle delivery. In aquaculture, vaccination has significantly impacted disease management and prevention, particularly in salmon aquaculture, where pathogens are highly transmitted.

k) Gold Nanoparticles:

Au nanoparticles (AuNPs) have been found to increase cell membrane permeability, allowing for better nutrient uptake and growth rates. They have also been found to mitigate hepatic damage in Asian carp exposed to environmental pollutants. AuNPs have been shown to reduce oxidative stress markers, improve liver function, and enhance survival rates. They also have detoxification capabilities, as demonstrated by Muralisankar et al. (2016) and Sharif et al. (2017). In addition, AuNPs have been found to increase antioxidant enzyme activities in common carp. These nanoparticles are likely to enhance oxidative stress markers, decrease hepatic ions, metabolic enzymes, hepatotoxic markers, and alter tissue enzymes.

l) Green Synthesis Production of Nanoparticles:

Green synthesis is an eco-friendly and sustainable method for producing nanoparticles for feed formulas. This approach uses microorganisms like bacteria, fungi, yeast, and algae to produce various compounds. These



microorganisms possess lipid-based amphipathic membranes, allowing them to interact with their environment and trigger coupled oxidation-reduction processes. Green synthesis has successfully produced metal nanoparticles like silver, gold, cadmium, selenium, palladium, barium titanate, and titanium. These nanoparticles are nontoxic to cells and offer a substitute antibacterial therapy against pathogens. The biosynthesis of ZnO nanoparticles is in its infancy, but nano Zn was successfully prepared using *Parthenium hysterophorus* leaves. The green synthesis approach is straightforward, cost-effective, and less time-consuming, making it a highly efficient and sustainable option for nanoparticle production. However, it has some drawbacks, such as the need to maintain specific cultures and their conditions, resource-intensive culture media, prolonged nanoparticle formation time, and challenging product recovery.

Challenges and Risks of Nanotechnology:

Nano-enhanced aquafeeds pose significant challenges, including nanoparticle toxicity, environmental risks, and public skepticism. Nanoparticles can penetrate cell membranes, causing genotoxicity, oxidative stress, and DNA damage. Zinc oxide nanoparticles (ZnONPs) can induce oxidative stress and inflammation more readily than bulk zinc additives, while SeNPs may negatively impact sperm quality and increase oxidative stress at non-optimal doses. The long-term effects of nanoparticles in fish tissues and their release into aquatic environments remain unclear,

raising concerns about ecosystem disruption and biodiversity loss. Overuse of nanoparticles at high concentrations can lead to oxidative stress, cellular damage, and bioaccumulation in aquatic organisms. Limited research on long-term impacts on fish health and human consumers complicates regulatory approval processes. Environmental risks include N runoff from aquaculture systems, contaminating nearby water bodies and contributing to environmental pollution. High costs of NP synthesis, specialized equipment, and lack of standardized guidelines for NP safety assessment further complicate regulatory approval processes. Regulatory hurdles arise from public skepticism and technological advancements.

Conclusion:

Nanotechnology offers a promising advancement in aquaculture, providing innovative solutions to improve fish health, nutrition, and overall growth performance. Through the use of nanomaterials in feed formulation, water purification, and disease management, the aquaculture sector can enhance efficiency, sustainability, and productivity. Nanoparticles enhance nutrient bioavailability, bolster immune responses, and facilitate targeted drug delivery, thereby decreasing environmental waste and reducing antibiotic overuse. Nevertheless, additional research is necessary to evaluate the long-term ecological effects and safety of nanomaterials in aquatic ecosystems. With careful implementation and regulatory oversight,



nanotechnology has the potential to transform modern aquaculture into a more resilient and sustainable industry.

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