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# A Review on Application of Nanotechnology in Aquaculture

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## Abstract

Application of nanotechnology truly brought advancement on different fields, including electronics, energy, environment, health sectors, agriculture and allied fields. Breakthrough on the application of nanotechnology in agriculture has revolutionized the plant production, plant protection, processing, and packaging transportation of agricultural products. Today, nanotechnology is widely utilized in the field of fisheries, including fish nutrition, fish health and detection, and water management. It has showed significant effect in improving the specificity and sensitivity on detecting opportunistic pathogens that attacked aquaculture species; development of efficient and effective nanovaccines and supplements; enhance the quality, absorption properties, bioavailability, and blending properties of the feed which significantly affect the growth rate of aquaculture species; and also showed excellent result in the purification of water resources including the elimination of unwanted contaminants. In this regard, this review aims to explore the different research and current trends, including issues and concerns on the application of nanotechnology in aquaculture.

**Keywords**: Aquaculture, Nanotechnology, Fish Nutrition, Fish Health, Water management

## Introduction

Nanotechnology is an emerging science involving the fields of life science, material science and information technology (Rajendran, 2013). It is an array of technology that is used in manipulating matter at the molecular level producing materials, devices and structures having a dimension of 1 to 100 nanometer (nm) (Ramsden, 2015). Throughout the development of nanotechnology, it has touched the fields of electronics, energy, environment and health sectors revolutionizing the processes and products, which conventional and traditional systems would be unable to achieve (Subramanian & Tarafdar, 2011; Rajendran, 2013). Continuous advancement in nanotechnology has produced a variety of nanostructures that use today, the following are: organic and inorganic nanomaterials, nanometer scale, nanorods or nanotubes, nanowires, nanoemulsions, nanoclusters, nanocomposites, nanofibers and nanoplates (Pathakoti, Manubolu, & Hwang, 2017).

Recent studies on application of nanotechnology in agriculture and allied fields has reached the interest of researchers in exploring its use in developing new tools and products focusing on agriculture, water treatment, drug delivery, antimicrobial and waste management. Studies showed that nanotechnology has great potential to make agriculture more efficient by using nanosensors, nanoagricultural chemicals, and nanocarriers for pesticides (Cicek & Nadaroglu, 2015). Nanotechnology has been used in agriculture to produce slow-release nanofertilizers for fertilizer use by plants; nanoparticles encapsulated pesticides for controlled and on-demand release; site-specific drug and nutrient delivery in fisheries and livestock; nanoparticles, nanobrushes, and nanomembranes for treatment of water and soil; cleaning and maintenance of fishponds; and nanosensors for assessing plant health and soil quality (Pramanik, Krishnan, Maity, Mridha, Mukherjee & Rai, 2020). Nanotechnology has also touched the field of fisheries including fish biotechnology, fish genetics, fish reproduction, fish growth, and fish health (Rather et al., 2011). This review aims to explore the different research and current trends, including issues and concerns on the application of nanotechnology in aquaculture such as its effect in the culture species and the environment and the requirement of huge capital investment in the initial stage of developing and employing research.

## Problems and Issues in Aquaculture Operation

**Fish Health and Detection**

Aquaculture continuously develops and expands for the last decades, contributing to a large percentage of the global fish production. However, the industry faces huge losses on production because of many reasons. Among these reasons, disease occurrence in culture species is the most serious threat as it causes damage to the livelihood of farmers, loss of jobs, reduced incomes, and food security (Assefa and Abunna, 2018). Fish diseases arise from an interplay of three key factors namely poor environment, presence of a virulent pathogen, and a susceptible host (Opiyo et al., 2020) (Figure 1).

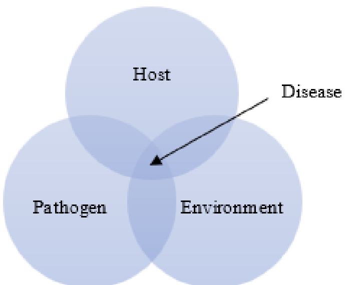


**Figure 1.** Interaction between the host, pathogen and environment (Opiyo et al., 2020)

The continuous advancement in aquaculture industry has resulted in degradation of water quality causing stress and lowers immunity of culture species, which increases their susceptibility to illnesses (Naylor et al., 2000). Water quality is a critical factor affecting fish health in aquaculture systems – health of culture species such as crustaceans and fish is highly dependent on the water quality (Vanderzwalmen et al., 2021). In aquaculture, early detection of diseasecausing pathogens and identification aids in mitigating potential outbreak, and thus to avoid any financial losses (Nayan, Mozumder, Saha, Mahmud & Aza, 2021). Disease caused by pathogens such as bacteria, parasites, fungi, and virus in culture species like fish and crustaceans significantly affect the quality and volume of production (Adams & Thompson, 2021; Hill, 2005). Conventional diagnosis of disease-causing pathogen is considered best in pathogen identification, which involves interpretation of clinical and histological signs, cultivation of pathogen sample on suitable medium, and analysis of morphological, phenotypic, and biochemical characteristics of the presumptive pathogen (Frans, Lievens, Heusdens & Willems, 2008). However, these methods are comparatively time consuming and labor intensive. Moreover, accuracy and reliability of diagnosis is highly dependent on the competency and expertise of the person (Nematollahi, Decostere, Pasmans & Haesebrouck, 2003; Van Trappen, Mergaert & Swings, 2003; Frans et al., 2008). Despite of having excellent health management, culture species are still contracting diseases due to continuous increase in farming intensity, making it impossible to eliminate disease outbreaks and poses serious problems in fish and crustacean culture (Mugimba, Byarugaba, Mutoloki, Evensen & Munang'andu, 2021; Francis-Floyd

& Wellborn, 1991). Emerging diseases in finfish and crustacean industry is attributed from several factors including; (1) wild reservoirs, (2) migratory species, (3) anthropogenic activities, (4) limitations in diagnostic tools and expertise, (5) transportation of virus contaminated ballast water, and (6) international trade – these factors contribute to the proliferation of opportunistic pathogens in the natural environment, making it impossible to eradicate them (Mugimba et al., 2021; Yadava & Banchhod, 2021). Therefore, effective fish health and detection in aquaculture is crucial in fish health management and must include an up-to-date knowledge of the health status of the fish and crustaceans; identifying and managing risks to fish health; reducing exposure to or the spread of pathogens; and managing the use of drugs or chemicals (Hill, 2005).

**Fish Nutrition**

In aquaculture, nutrition is critical because it represents 50 percent of the overall production cost (Craig, Helfrich, Kuhn and Schwarz, 2017). According to Masagounder, Ramos, Reimann and Channarayapatna (2016), the quality of feed is a key factor in determining the quality of the fish production in culture operations. According to Jobling (2016), fish nutrition greatly influences the ability of cultured organisms such as fish and crustacean to resist any environmental stressors and mount an immune response in any opportunistic pathogen. Generally, natural environment can satisfy the nutrient requirement of cultured species, however, continuous intensification in production systems, addition of variety of feed additives is an alternative way to ensure that the essential nutrients that culture species need are met so that normal physiological functions of the fish is in normal state (Encarnação, 2016). In order to promote growth and prevent signs of nutrient deficiency in culture species, the diet of fish must consist of essential nutrients such as amino acids, fatty acids, vitamins, minerals and energy-yielding macronutrients like protein, lipid and carbohydrate (NRC, 2011).

According to NRC (2011), the most important factor of the dietary compounds in feed is its digestibility because it affects the aquaculture production and efficiency and impacts the environment. These affect the quantity and quality of the waste excreted by fish as it is dependent on intake, digestion and metabolism of dietary compounds (Bureau & Hua, 2010). In an aquaculture operation, feed which is the source of nutrition is considered the main source of waste and is responsible for most of the environmental impact of aquaculture (d'Orbcastel, Blancheton & Aubin, 2009). According to Schneider, Amirkolaie, Vera-Cartas, Eding, Schrama & Verreth (2004), uneaten feeds due to excessive feeding results in immediate eutrophication of the culture environment, whereas eaten feed converts to metabolic processes, such as ammonia, phosphorus and carbon dioxide (Schneider, Amirkolaie, VeraCartas, Eding, Schrama & Verreth, 2004).

Moreover, degraded feed waste sinks and disperses, resulting in environmental toxicity and anoxia (Piedecausa, Aguado-Giménez, Cerezo Valverde, Hernandez Llorente & García- García, 2012). Piedecausa et al. (2012) pointed out that excessive feed waste has a direct impact on marine benthic habitats in open water culture, reducing sediments, hypoxia in the water overlying the sediment, increased sulphate reduction and changes in benthic fauna composition specifically species number, diversity, abundance and biomass (Piedecausa et al., 2012). Thus, proper nutrition plays a vital role in maintaining normal growth and health of culture species as it aids in mitigating the effects of stress, decreasing the susceptibility to disease, and boosting the immune system (Hixon, 2014).

**Water Quality**

Water is an essential requirement in aquaculture operations as fish and other aquatic organisms thrive and live in water, thus determining a suitable quality and quantity of water is a must (Summerfelt, 2000). According to Piper (1982), water quality determines to a great extent the success or failure of a fish culture operation.

The expansion and development of the aquaculture industry has resulted in degradation of water quality, which is a crucial factor in an aquaculture operation (Naylor et al, 2000; Summerfelt, 2000). Not only that but the increased urbanization of coastal areas across the continents due to growing global population has also contributed to challenges that the aquaculture industry is facing (Trottet, George, Drillet & Lauro, 2021). Water quality significantly influenced health, survival, and overall production of culture species (Boyd &

Tucker, 2012; Curtis & Stanley, 2016). Therefore, water quality of water source should be considered at all stages of an aquaculture production before stocking and during grow-out (Boyd, 2017). Degraded water quality in aquaculture operations may result to the following; low quality products, health risk for humans, low profit, and affect the growth, development, reproduction, and mortality of cultured species, which significantly affect the overall production (Giacomazzo, Bertolo, Brodeur, Massicotte, Goyette & Magnan, 2020).

Poor or degraded water quality greatly influences the proliferation of unwanted and opportunistic pathogens that cause diseases to culture species (Opiyo et al., 2020; Vanderzwalmen et al., 2021). In addition, continuous intensification, reliance on international trade, importance for livelihoods and food security of aquaculture industry, particularly in resource-limited countries, has contributed to the spread of diseases from a culture operation to another (Trottet, George, Drillet & Lauro, 2021). According to FAMA (2017), approximately 15– 17% of the overall pond aquaculture is reportedly affected by diseases caused by poor water quality each year, which results in a total yield loss of about 4–6%.

Not only that, but the reducing numbers of experienced farmers and uncontrolled expansion of small-scale subsistence farmers also contribute to aquaculture problems (Eze, Halse & Ajmal 2021). Farmers that lack knowledge, experience and absence of spatial planning may be exposed to the risks and uncertainties within the aquaculture industry (Rahman, Nielsen, Khan & Ahsan, 2021).

Proper water-quality management in aquaculture is essential for promoting good aquatic animal health required for efficient production (Boyd, 2017). In this regard, regular checking of water quality parameters such as dissolved oxygen, pH, temperature, salinity, nitrates, nitrites, and total dissolved solids should be done to prevent any adverse effect on the aquaculture operation (Eze, Halse & Ajmal 2021). Any fluctuation or slight changes in these parameters may lead to physiological stress on culture species, which can impact their feeding, breeding and increases susceptibility to diseases (Hu, Zhang, Zhao, Xie, Zhong, Tu & Liu, 2019; Eze & Ajmal, 2020).

## Current Research Works and Application on the use of Nanotechnology in Aquaculture Industry

### Current Application of Nanotechnology in Fish Heath Detection

Development of an effective vaccine against infectious diseases in the aquaculture industry is difficult to achieve but vaccination is a vital aspect in controlling and preventing the spread of diseases (Brudeseth, et al, 2013; Nagaraju, 2019). However, through the application of nanotechnology, nanovaccines are being developed (Nagaraju, 2019) (Figure 2).

Vaccines are enhanced through the use of nanoparticles formulated with antigens that are either encapsulated within or adsorbed onto the surface producing nanovaccines. (Gregory, Williamson & Titball, 2013; Zaman, Good & Toth, 2013). According to Nagaraju (2019), nanoparticles in vaccine development can be distinguished according to their action, either as an efficient mode of delivery system or an adjuvant. Hølvold, Fredriksen, Bøgwald & Dalmo, (2013); Tafalla, Bøgwald, & Dalmo (2013) stated that nanoparticles which function as delivery systems will deliver the antigen to the targeted immune cells while protecting it whereas immune potentiating adjuvant nanoparticles will activate a specific pathway which helps in efficient antigen uptake and processing. Nanoparticles can be classified as biodegradable or non-biodegradable based on their properties to get decomposed in a biological system (Nagaraju, 2019). Gregory et al. (2013); Zhao, Seth, Wibowo, Zhao, Mitter and Middelberg (2014); Shaalan, Saleh, El-Mahdy and El-Matbouli (2016), other forms of nanoparticles used in developing vaccine include the following; virus-like particles (VPL's), nanoliposomes, immunostimulating complexes (ISCOMs), nanoemulsions and metal nanoparticle.

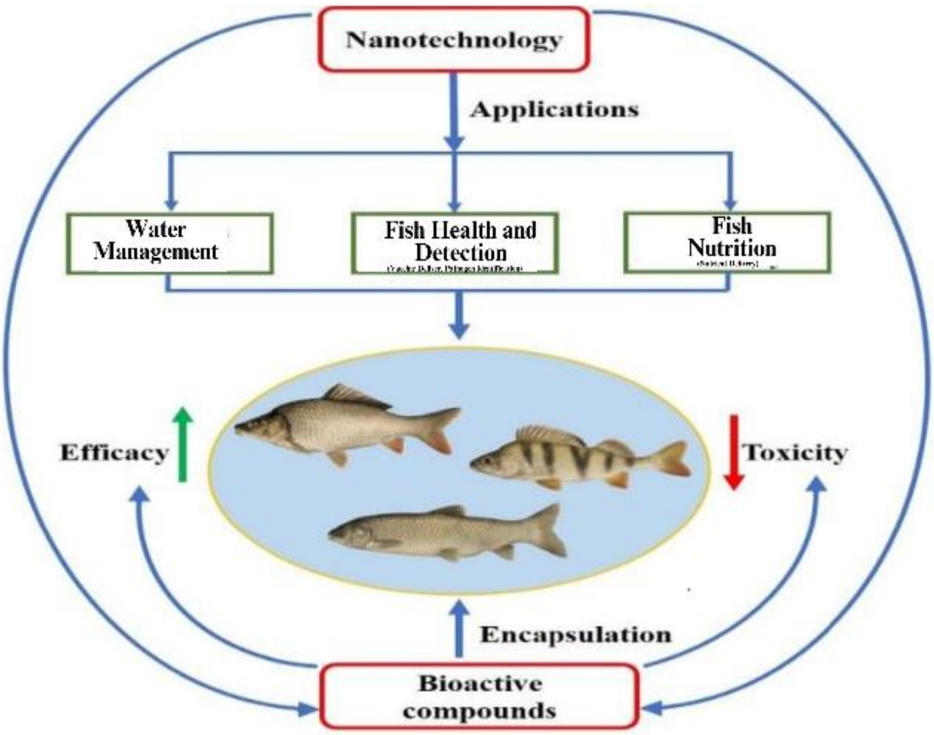


**Figure 2**. Application of nanotechnology in fish health and detection, fish nutrition and water management (Modified from Munawar, 2021).

Advantages of nanotechnology enhanced vaccines or nanovaccines include protection of antigens by encapsulation from degradation, site specific delivery of antigens, enhanced bioavailability and reduced side effects (Zolnik, González-Fernández, Sadrieh & Dobrovolskaia, 2010; Gregory et al., 2013; Zaman et al., 2013).

Nanotechnology is also being utilized in the advancement of disease detection as it significantly increased sensitivity and specificity of detection kits (Sabo-Attwood et al., 2021). Gold nanoparticles, for example, has the ability to self-aggregate, which can control color changes associated with complexed DNA probes that are amplified by loop-mediated isothermal amplification (LAMP) technology which can produce signals that are visible to the naked eye (Sabo-Attwood et al., 2021; Hash, Martinez-Viedma, Fung, Han, Yang, Wong and Lightner, 2019; Zhou, Xiao, Ma, Wang and Zhang, 2018).

de Guia et al. (2020), utilized gold nanoparticles (AuNPs) coupled with specific thiol probe in the detection of *pir*A$^{vp}$ toxin gene causing acute hepatopancreatic necrosis disease (AHPND) in shrimp culture. AHPND is caused by pathogens belonging to *Vibrio* species, causing lethargic and anorexic effect on infected shrimps. de Guia et al. and his colleagues (2020) used gold nanoparticles together with colorimetric assay developing Deoxyribonucleic acid (DNA)-based AuNPs, resulted in the highly sensitive and highly specific detection of *pir*A$^{vp}$ toxin gene at concentration level of 20 fg/ul of shrimp genomic DNA.

Hash et al. (2019) improved the Nuclear Magnetic Resonance (NMR)-based detection system which can be used to detect pathogenic levels of *Vibrio parahaemolyticus* ($10^5$ CFU/ml) with Molecular Mirroring utilizing iron nanoparticles coated with target-specific biomarkers capable of binding to DNA of the target microorganism. The NMR system generates a signal in just milliseconds by measuring NMR spin–spin relaxation time, which correlates with the amount of microorganism DNA. Hast et al (2019) and her colleagues found out that the NMR biosensor system is capable of detecting wide range of microorganism DNAs in different matrices in a short span of time.

Similar study conducted by Zhou et al. (2018) using gold nanoparticles (AuNPs). Zhou et al. (2018), established a colorimetric biosensor using gold nanoparticles (AuNPs) labeled with dual functional probes and along with loop-mediated isothermal amplification (LAMP) assay (LAMP-AuNPs). Compared with the polymerase chain reaction (PCR) method, the colorimetric biosensor using gold nanoparticles (AuNPs) is highly sensitive in detecting *Streptococcus iniae*.

**Current Application of Nanotechnology in Fish Nutrition**

Traditionally, fish feeding has relied on providing fish food in the form of formulated diets, which is generally based on the daily nutritional requirements of fish (Dar, Rashid, Majid, Hussain & Dar, 2020). According to Handy (2012), utilization of nanotechnology is being employed in formulating dietary feed or aquafeeds for aquaculture species by increasing the proportion of nutrients required by aquaculture species that pass across the gut tissue and into these species, rather than passing directly through the species digestive system unused. Moreover, this new approach and technique will significantly affect the economic and environmental sustainability (Dar et al., 2020).

Recent advances in the field of nanotechnology is the utilization of nanoparticles as feed additives to effectively deliver micronutrients and promote growth of culture species like fish. According to Chatterjee and Judeh (2016); Ji, Torrealba, Ruyra, and Roher (2015), chitosan nanoparticles can be used as an encapsulating agent for nutrients that can easily degrade when in contact with water. Utilization of chitosan nanoparticles is widely used on human and animal feed production because of its low immunogenicity, low toxicity, and antimicrobial properties. Use of chitosan nanoparticles in delivering unstable and hydro soluble micronutrients during the early stages of fish significantly affect its development, particularly promoting its growth (Khosravi-Katuli et al., 2017). In addition, other studies involving the use of chitosan nanoparticles together with SWCNTs (single-walled carbon nanotubes), C60 (fullerene), and nTiO2 (Titanium dioxide nanoparticles) in formulating feed pellet of fathead minnows and rainbow trout improved the physical property of the pellet making it more compact preventing nutrient leaching and subsequent waste in fishpond.

In a study conducted by Konkol and Wojnarowski (2018), they found out that use of nanostructure nanominerals in animal feeds particularly those of nano-selenium, nano-chromium, or nano-zinc can improve the animal production parameters, their healthiness, and the quality of products obtained from them. Moreover, nanotechnology was also employed in delivering nutraceutical to fish and shellfish. According to Ogunkalu (2019), nutraceuticals that are commonly supplied to fish and shellfish were made into nanomaterials which improves the health managements, stress reduction, and value addition of these aquatic organisms. In addition, application of nanotechnology to nutraceuticals has influenced its delivery system which improved the transportation of functional ingredients and also enhanced feed attributes such as taste, texture and shelf life.

Dar et al. (2020) pointed out that absorptive properties of nanosized minerals, making the assimilation of the nutrients fast when fed on aquaculture species. Additionally, Dar et al. (2020) also stated that it significantly reduces the environmental impact of the fish feeding process. Moreover, Rather et al. (2011), nanosized minerals and nutrients significantly increased the growth rate of aquaculture species, particularly carp and sturgeon of about 24%-30%.

Furthermore, application and utilization of nanotechnology results to effective delivery of dietary supplements and nutraceuticals in aquaculture species as it is capable in enhancing the bioavailability, bio accessibility and efficiency of the nutrients by improving their solubility and protection from harsh environment of the gut of aquaculture species (Munawar, 2021).

**Current Application of Nanotechnology in Water Quality**

Studies in utilizing nanotechnology for treating and disinfecting water in fishpond significantly increased the water quality, increasing yields and survival of aquaculture species such as fish and prawn (Huang, Wang, Liu, Hou & Li, 2015). Furthermore, Can et al (2011) stated that use of nanotechnology improved dietary feed in aquaculture operations not only helps in fast growth rate of aquaculture species but also prevent pollution and proliferation of opportunistic pathogens, reducing the cost of water treatment.

Generally, water source from inland waters like reservoirs, rivers, and stream are used in aquaculture operation without any previous treatment, thus it may be polluted or may have contaminants and opportunistic pathogens (Wang, Lee & Melching, 2015; Tavares & Santeiro, 2013). However, current methods in treating and disinfecting water are no longer sustainable as it heavily depends on conveyance and centralized systems (Qu, Brame, Li & Alvarez, 2013). Qu et al., (2013) stated that, advancement and development of new methods in treating and disinfecting water in aquaculture operations is leaning towards the application of nanotechnology due to its efficient, modular and multifunctional processes, which provides affordable and high-performance treatment and disinfection. According to Kumar, Bhanjana, Heydarifard, Nazhad and Dilbaghi (2014); Bora and Dutta (2014), nanotechnology-based water treatments such as nano-adsorption and biosorption for contaminant removal, nanophotocatalysis for contaminant chemical degradation, nanosensors for contaminant detection, various membrane technologies including nanofiltration, reverse osmosis, and photocatalysis are use in; reuse of wastewater, improving sea and saline water desalination, decontamination and disinfection of water.

Today, manufactured nanomaterials or MNMs are widely used in treating and disinfecting water in aquaculture operations. It has been employed in Lake Biwa, Japan, some areas of Shanghai, Suzhou which achieved a significant result as it purifies the water, eliminated the water body odor, and dropped NH3–N content from, without water change, no oxygen, no side effects, and no secondary pollution (Cao, Yang & Zhou, 2015)**.**

## Conclusion

Application of nanotechnology in fisheries particularly in aquaculture clearly brought significant advancement in the field, specifically in fish health and detection of pathogen, fish nutrition, and improving of water quality in aquaculture operation.

Throughout the application of nanotechnology, it has significantly improved the specificity and sensitivity on detecting opportunistic pathogens that attacked aquaculture species such as fish and crustacean. In terms of fish nutrition, employment of nanotechnology improved and enhanced the quality, absorption properties, bioavailability, and blending properties of the feed itself but also it significantly affects the growth rate of aquaculture species. Treatment and disinfection of water sources to reach the optimum water quality that can withstand and hold aquaculture species was also improved through the application of nanotechnology. The purifying, eliminating, and adsorption properties of nanoparticles exhibited good results.

Although the application of nanotechnology in the fisheries industry specifically in aquaculture showed successful and positive response. There are still questions regarding the stability and degradation of nanomaterials as it can greatly affect not only the animal health but also the humanity and environment. There are still gaps that need to be filled between nanotechnology and aquaculture. In this regard, there should be further research on the biological behavior particularly on its long-term effect on the organisms, specificity on its use, scalability in terms of feasibility and cost-effectiveness for mass production and practical application of nanotechnology in aquaculture.

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