Chapter 8
Applications of Nanoparticles in Aquaculture

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8.1 Introduction

Protein demand is increasing as the world's population and economy grow at a rapid pace. Aquatic protein resources are widely valued due to positive health impacts and key food composition aspects, and as a result, global aquaculture has risen at an astonishing rate recently. Aquaculture currently provides 50% of the world's fish for human consumption. Global fish production increased by approximately 171 million tonnes in 2016, with a total first-sale value of US$ 362 billion for fisheries and aquaculture industry. Food fish consumption per capita increased from 9.0 kg in 1961 to 20.2 kg in 2015, an average yearly increase of around 1.5%, and was expected to increase to almost 20.3 and 20.5 kg in 2016 and 2017, respectively (FAO 2018). Nonetheless, as the sector develops, there is still a question mark over its long-term viability, as the effect of ever-increasing aquaculture waste has a negative influence on both productivity within aquaculture systems and the ambient aquatic ecology. There is a significant gap in technological advancement for drug use, treatment approaches, water quality management, the development of tailored fish for good health, productivity driven by epigenetic as well as nutrigenomic interactions, better breeding success through efficient delivery of maturation as well as spawning inducing agents, nutraceutical delivery for fast growth promotion, and reduced culture time. To address these obstacles, a combination approach of

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comprehending, integrating, engaging, and deploying new science and technological techniques in order to sustain desirable aquaculture is required (Aklakur et al. 2016).

Nanotechnology is being used to deliver nutrients, vaccines, and other biological elements to various fish systems (Shaw and Handy 2011; Handy et al. 2008a). Nanoparticles have been used in a variety of medical applications, including diagnostics, immunisation, and medication and gene delivery. There are a variety of nanoparticles that are less harmful to the various cells in the fish immune system. When it comes to transmitting biological components, nanoparticles are less expensive than other materials. As a result, nanoparticles can be utilised in large-scale experiments in animal systems to research various aspects of food intake via various carriers (Hosseini et al. 2016; Vimal et al. 2012).

Because some biological materials have low specificity, they can't strongly bind to pathogens and thus can't be employed as a primary target for viruses and bacteria (Yue et al. 2017). It leads to breakthroughs in nanotechnology, which has transformed the generation of biological materials. In aquaculture, nanomaterials have piqued interest as a particular and sensitive method for diagnosing bacterial, fungal, and viral infections (Sarkar et al. 2015). Cu-based nanoparticles, Ag nanoparticles, metal oxide nanoparticles such as ZnO and TiO_2 NPs, and composites of various metals are all examples of nanoparticles (Khan et al. 2015). These NPs are less harmful than their biological materials in comparison to nutrients and drug delivery in fish, although metal toxicity in fish can be examined in a better method to compare and contrast the effects of nonmetals on the different cells of fish. These various types of NPs can be engineered to serve an important role in disease diagnosis and fish treatment. Each nanoparticle has its own distinct properties that are developed for medication delivery and other medical applications. Silver-based nanoparticles are the most prevalent type of nanoparticle used in illness detection in fish and other animals (George et al. 2012).

Disease is a major factor in fish mortality, especially in young fish. Pathogenic illnesses and nonpathogenic diseases are the two types of fish diseases based on their infectiousness. Noninfectious diseases include gas bubble diseases caused by increased aeration, nutritional illnesses caused by a lack of certain nutrients (such as vitamins and minerals), pollution-related disorders (industrial and agricultural), and neoplastic and hereditary abnormalities, which refer to abnormal cell growth in any organ that causes the organ to start losing its function and structure. The infectious disease, on the other hand, is regarded as a particularly deadly condition since it is transmitted from one fish to another and results in massive mortality. Infectious diseases are divided into three categories: bacterial, fungal, and parasitic (Ali et al. 2014, 2018). Control initiatives have been adopted over the years for a large number of chemicals that are presently being utilised in the establishment of the aquaculture industry. Hormones, vitamins, antibiotics, and a few other compounds were tested in aquaculture systems for various cures. Although they have favourable advantages, they cannot be recommended due to their long-term and other negative effects. Synthetic therapies include disinfectants (e.g. hydrogen peroxide and green malachite), antibiotics (e.g. sulfonamides and tetracyclines), and anthelmintics (e.g.

pyrethroid insecticides and avermectins); neutral remedies include probiotics and essential oils (Citarasu 2010; Rawn et al. 2009). Nanotechnology is thought to offer a solution for preventing and monitoring illnesses and infections, as well as multiplying the benefits of aquaculture. Antibacterial and antifungal surfaces made utilising porous nanostructures, nanosensors in aquaculture environments for pathogen detection in water, and nanodelivery of veterinarian goods and fish medicines via fish meals are some of the fish health applications of nanotechnology. Nano-trace element usage is up to 100 times greater than standard inorganic trace element usage, which is often extremely limited because the former enters the animal body by direct penetration (Nasr-Eldahan et al. 2021; Shah and Mraz 2020).

Because nanomaterials work on the very same level as a particle-infecting virus or diseases, controlling viruses, bacteria, and fungi would require early detection and removal of pathogens (Nasr-Eldahan et al. 2021; Shah and Mraz 2020; Luis et al. 2019). Because nanoencapsulated materials are robust and can withstand high temperatures or acidity, chitosan-based wrapping around vaccinations as a nanoencapsulation carrier for effective therapy of bacteria and viruses causing fish sickness has been documented. These nanomaterials are proving to be highly advantageous in the growth of pathogen-free fish seedlings and shrimp or prawn post-larvae in agriculture (Nasr-Eldahan et al. 2021).

8.2 Nanoparticles

Materials with one or more dimensions in the nanometre (1–100 nm) range are called nanoparticles. Materials in the nanoscale range have been linked to unique features and applications that are distinct from their respective bulk counterparts. Nanoparticles have a large exposed surface area per unit volume due to their small size, which increases their chemical reactivity. It's also said to be particularly stable in high-temperature and high-pressure environments. These are easily absorbed by animals' gastrointestinal tracts, making them more effective at lower doses than bulk materials (Chris et al. 2018). They also interact more efficiently with organic and inorganic compounds within animal bodies, and they can cross the small intestine to reach the blood, brain, liver, and other organs (Hillyer and Albrecht 2001). For particle size homogeneity and eco-friendliness, nanomaterials for feeding animals are best synthesised via chemical or biological techniques (Iravani and Zolfaghari 2013). Nanometals (e.g. silver nanoparticles (NPs)), metal oxides (e.g. TiO2 NPs), carbon-based materials such as carbon nanotubes (CNTs), and carbon spheres (e.g. C60 fullerenes, dubbed "buckyballs" by the media), and composites made of several substances such as nanoceramics and quantum dots have all been produced in various chemical forms (Boxall et al. 2007; Stone et al. 2010). Combinations of known hazardous metals, such as ZnS and CdSe, employed in quantum dots for novel light-emitting diodes can be used in the latter (Bae et al. 2009). NMs, on the other hand, have the possibility of an unlimited number of chemistries. Hydroxyl groups, carboxylic acid groups, sulphate moieties, and other functional groups can be applied to the surface of NMs. Compounds on the NM's surfaces can be covalently bounded and so fundamentally part of the material's composition, or they can be a loosely attached surface coating (e.g. citrate-coated metal NPs). "Second-generation" NMs are beginning to appear, with sophisticated three-dimensional structures and/or several chemical components. For very specialised purposes, NMs are already being made with highly functionalised surfaces (e.g. functionalised CNT) (Handy et al. 2008b; Ju-Nam and Lead 2008).

Nanoparticles can be made in a variety of ways, including chemical, biological, and physical techniques. The biological method is one of the most important strategies for drug delivery and other biological material supplementation across the cell membrane. Because of the low cost and great efficiency of the synthesis of nanoparticles, this technology has a significant advantage over chemical and physical methods. The attention of other materials and their incorporation in different portions of the cell are increased by the green creation of nanoparticles. Traditional methods, on the other hand, are unreliable for the preparation of NPs because they require a huge number of reagents and chemicals for the large-scale production of nanoparticles, both at the industrial and commercial levels. As a result, old methods are no longer viable due to low demand and expensive costs when compared to technological advancements in nanotechnology. Nanoparticles can undergo several modifications during synthesis and modification before being transformed into their final form, whereas other materials, other than nanoparticles, require a large number of raw components and are time-demanding (Munawar 2021).

Fish are heterotrophic organisms with numerous organs and tissues. Fish can ingest algae or other heterotrophs, depending on the species. Various nanoparticles can be employed or carried to the various cells of the fish in order to provide the appropriate treatment at the appropriate location. Because of its unique action, once the nanoparticle reaches its designated location, it will begin to perform its activities at the cellular and molecular levels. The gill allows for gas exchange between both the organism's internal and external aqueous environments. Other chemicals, such as metal nanoparticles and organic compounds, can interact with fish gill cells and eventually get into the bloodstream during this exchange process (Kok et al. 2020).

Supplementing fish diets with nanoparticles of elements such as selenium, iron, and other sources could help them develop faster. The method can be used to lower the cost of water treatment in aquariums and commercial fish ponds. Nanotechnologies, according to researchers, have the potential to create disease-free and pollution-free fishponds. Another potential application for nanotechnologies is the use of various conservation and packaging techniques to ensure seafood safety by preventing mildew and microbial decomposition (Can et al. 2011).

Nanoparticles also revealed that various cells have distinct reactions to changes in the rate of fish death. Many nanoparticles can penetrate antigen-presenting cells via various routes and elicit suitable immune responses to the antigen. It also depends on the quality of each nanoparticle that is designed to execute a certain role in a cell. Biodegradable polymers, nanoliposomes, carbon nanotubes, calcium phosphate, and immunostimulating complexes (ISCOMs) are among the nanoparticles utilised in fish vaccine administration. Poly (lactic-co-glycolic acid) and chitosan are the most investigated forms of nanoparticles to date (Pandey and Prajapati 2018; Kumar et al. 2018; Dawood et al. 2020).

8.3 Action of Nanoparticles

Concerns about nanosafety still exist, and they must be addressed before full-scale implementation. Nanoparticle toxicity is determined by a complex interaction of particle parameters such as diameter, form, surface charge, concentration, time of exposure, nature of the nanoparticles, medium composition, route of particle administration, and the immune system of the target species. Despite the current data, various criticisms obstruct a complete knowledge of the safety of nanoparticles in aquaculture. To begin with, the manner in which nanoparticles are administered in aquaculture might vary greatly: they can be added to food, water media, or aquaculture infrastructure. Nonetheless, present aquatic toxicology studies are insufficient to meet the demand for nanoparticle safety in aquaculture, such as administration route, concentration, and exposure time. Concentrations are sometimes lower or greater than those used in aquaculture or expected to be used, resulting in unrealistic outcomes. As a result, inferring the potential negative impacts on the final consumer is impossible. It is vital to investigate the safety of nano-based aquaculture, taking into account not only relatively short treatment periods (less than 40 days) but also the entire cultured product life cycle, including water quality, from the egg/larva to the table. Second, because aquatic organisms are maintained in diverse conditions, nano-based goods can behave quite differently in terms of the generated consequences; hence, it might be interesting to investigate how environmental parameters such as pH, salinity, and temperature influence nanosafety (Khosravi-Katuli et al. 2017).

8.3.1 Selenium (Se)

Selenium is a trace element that is necessary for normal bodily processes and animal metabolism (Prashanth et al. 2015). It has a substantial impact on the physiology of fish by improving the animal’s physiological and immunological systems. Selenium supplementation protects cells from harm and is important for fish development, fertilisation, and immunological function. It also protects the organism from oxygen-free radicals, which are formed in stressful situations or when an animal is exposed to certain types of toxicity (Khurana et al. 2019). As per Le et al. (2014), selenium supplementation improves fish immunity by increasing lysozyme activity as well as fish red blood cell (RBC) count, with RBC and hematocrit proportions in tilapia being improved with the right diet (El-Hammady et al. 2007). The nano form of selenium has the most favourable effect, as it is more effective than the bulky version. The nano form of selenium is a unique type that draws more interest than inorganic and organic forms, wherein inorganic compounds are more poisonous than organic compounds, owing to their large bioavailability and lower toxicity (Khurana et al. 2019; Shi et al. 2011). The biological features of selenium nanoparticles (SeNPs) are dependent on their size: tiny particles have more activity (Torres et al. 2012). In comparison to other organic and inorganic oxidation states, nano-selenium (nano-Se) advantages from the capacity to utilise selenium at zero oxidation (Se^0), which has low toxicity and excellent bioavailability (Torres et al. 2012). It's highly unstable, and it can readily revert to a dormant state. Encapsulation with chitosan, on the other hand, can help to stabilise it (Zhai et al. 2017).

The impact of dietary nano-selenium (nano-Se) with vitamin C on the growth of mahseer fish (*Tor putitora*) has recently been investigated (Khan et al. 2017). According to reports, nano-Se supplementation in feed up at the expense of 0.68 mg n-Se/kg dry feed greatly improved ($p < 0.05$) percent weight gain (percent WG), feed conversion efficiency (FCE percent), and specific growth rate (SGR) of fish when compared to fish fed a basal diet; however, the feed conversion ratio (FCR) was substantially lower ($p < 0.05$) in fish fed a supplemented diet when contrasted to fish fed a basal diet. In addition, a study on common carp (*Cyprinus carpio*) fed diets supplemented with nano-Selenium at 1 $mgkg^{-1}$ dry feed level reportedly significantly improved growth performance (in terms of final weight and weight gain) along with higher selenium contents in liver and muscle in fish fed nano-Selenium at 1 $mgkg^{-1}$ dry feed level compared to the control (Ashouri et al. 2015). Total protein and globulin levels were significantly greater ($p < 0.05$), but albumin levels were decreased for supplemented levels of 2 mg kg^{-1} dry feed. In comparison to diets containing higher or lower amounts of nano-Se supplementation, antioxidant activities in fish given 1 and 2 $mgkg^{-1}$ dry feed were generally considerably ($p < 0.05$) improved.

8.3.2 Iron (Fe)

Iron has a vital part in the physiological processes of oxygen transport, cell respiration, lipid oxidation reactions, immune system function, and infection defence in fish (Beisel 1982; Hilty et al. 2011; Tahri et al. 2016). Because most natural bulk iron sources have limited solubility and bioavailability, dietary iron supplementation for fish is required to meet dietary needs (Hilty et al. 2011). The effects of iron oxide nanoparticles (nFe_2O_3) on growth in freshwater shrimp (*Macrobranchium rosenbergii*) post-larvae were investigated in comparison to a control diet. The fish fed supplemental doses of 10–20 mg nFe_2O_3 Kg^{-1} dry feed had significantly better survival, growth, digestive enzyme activities, body biochemical composition, and some haematological parameters than those fed basal feed ($p < 0.05$) (Tahri et al. 2016). However, negative responses were recorded at greater supplemented amounts, such as 30–50 mg nFe_2O_3 Kg^{-1} dry feed. Previously, researchers compared the performance of Indian major carp (*Labeo rohita*) on a base diet and two other diets (basal feed supplemented with 0.54 mg nFe_2O_3 Kg^{-1}feed and 0.55 mg

$FeSO.7H_2O$ Kg^{-1}feed, respectively) (Behera et al. 2014). They found that fish fed a nano-iron supplemented diet had significantly better survivability, growth, and haematological parameters than fish fed a control diet, but there was no significant difference in performance between fish fed diets containing 0.54 mg nFe_2O_3 Kg^{-1}feed and 0.55 mg $FeSO.7H_2O$ Kg^{-1}feed. When freshwater fish, *Oreochromis niloticus*, were exposed to biologically generated Fe_2O_3 NPs at concentrations of 0.5, 5, and 10 g/ml, some haematological parameters (RBC, WBC, Hb, and HCT) were reported to be considerably negatively affected (Chris et al. 2018). When an Indian major carp (Labeo rohita) was exposed to an environment (water) containing 500 mg of nFe_2O_3/litre of water for 25 days, blood parameters were impacted differentially. Throughout the duration, fish in the control had greater white blood cell (WBC) counts but lower red blood cell (RBC) counts than those in the treated water (Remya et al. 2015). The mean corpuscular haemoglobin concentration (MCHC) levels in both the treatment and control groups were relatively consistent throughout the trial duration. Other blood parameters, such as mean corpuscular volume (MCV), mean corpuscular haemoglobin (MCH), and haematocrit (Hct), were greater in the treatment for the first few days but then dropped in favour of the control. (Saravanan et al. 2015) obtained similar results after exposing Indian major carp (*Labeo rohita*) to different doses (1 and 25 mg/l) of nFe_2O_3 for 96 h. The control and the two treatments reacted differentially to various haematological parameters.

8.3.3 Silver (Ag)

Silver nanoparticles (AgNPs) are very well-known nanoparticles for their commercialization worldwide, owing to their unique biological properties, and are frequently used in medicine. Despite AgNPs' biological activities and a vast range of applications, there is a paucity of research on their effects on health and the environment. The widespread usage of AgNPs around the world, as well as their release into the aquatic ecosystem, has sparked fears of a negative influence on aquatic life. Silver nanoparticles have a critical role in the cleaning of water in which fish habitat systems are preserved due to the natural environment. Silver nanoparticles (AgNPs) are the most extensively studied multi-mechanism nano-based antibacterials. These nanoparticles contain specialised surfaces that attach to receptors in living cells, allowing them to cure and diagnose specific diseases. Silver ions (Ag^+) are released and bind to bacterial cell membrane proteins, causing cell membrane rupture and death. The antibacterial activity of chitosan-Ag nanocomposites (CAgNCs) against the fish disease *Aliivibrio salmonicida* has been examined. Previous research has shown that silver-based nanoparticles reduced *A. salmonicida* growth at 50 and 100 mg/L, respectively, indicating a minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) (Dananjaya et al. 2016).

Different nanoparticles have been created specifically for testing their action at the cellular level. When compared to other nanoparticles, silver nanoparticles are securely bound to the majority of bacteria, resulting in antibacterial activity. Furthermore, multiple studies have demonstrated that AgNPs are efficient against pathogenic organisms such as *B. subtilis*, *Vibrio cholerae*, and *Escherichia coli*, and that higher surface areas of AgNPs enable better contact with bacteria (Zinjarde 2012). Plants such as *Carica papaya* and *Musa paradisiacal* (banana) have been designed and tested to combat *Aeromonas hydrophila* (Munawar 2021). In juvenile *Feneropenaeus indicus*, biogenic Ag-NP made from tea leaf extract (*Camellia sinensis*) showed bactericidal efficacy against *Vibrio harveyi*, but only at high dosages of the nanoparticles (Onitsuka et al. 2019). Synthesised nanoparticles containing *Carica papaya* (papaya) have antibacterial action at a concentration of 153.6 g mL^{-1}. Biogenic CuO NPs were evaluated against *Aeromonas hydrophila, Pseudomonas fluorescens*, and *Flavobacterium branchiophilum* in 2015 and showed improved antibacterial activity against all fish pathogens even at lower doses, i.e. above 20 μ g/mL (Kumar et al. 2015).

8.3.4 Zinc (Zn)

Zinc is required for the growth and health of all higher animals, including fish. Zinc helps animals grow, functions as an antibiotic, and regulates their immune and reproductive systems. Zn cannot be stored in the body of an animal, and a lack of it can cause repeated infections, a lack of appetite, and issues with taste and smell. Zinc supplementation is consequently required on a regular basis (Zalewski et al. 2005; Case and Carlson 2002). The effects of nano zinc oxide (nZnO) on grass carp (*Ctepharyngodon idella*) growth and haematological parameters have been studied in comparison to ZnO and $ZnSO_4$ as dietary zinc supplements in basal feed (Faiz et al. 2015). For each treatment, two amounts of supplementation (30 (level 1) and 60 (level 2) mg Kg^{-1}) were evaluated. Fish fed level 1 of nZnO supplemented diets had significantly higher percent weight gain (percent WG), specific growth rate (SGR), and feed conversion ratio (FCR) than fish fed level 2 of nZnO supplemented diets ($p < 0.05$). Growth was slowed in fish fed both levels of $ZnSO_4$ and level 2 of ZnO, according to the findings. Supplementing with $ZnSO_4$ and ZnO at both levels, as well as nZnO level 2, reduced haematological parameters including red blood cells (RBCs) and white blood cells (WBCs). This implies that the best dietary supplementation level of nZnO for *C. idella* is 30 mg/kg feed (Haghtalab et al. 2015; Akhtar et al. 2012).

8.4 Nanoparticle Applications in Fisheries and Aquaculture

Nanotechnology is already being used in the food business, with researchers interested in how NMs may affect food structure, texture, and quality, as well as technical applications in food production, processing, storage, transportation, and traceability (Chaudhry et al. 2008; Tiede et al. 2008). In the realm of fish and shellfish farming, there is a slew of possibilities. Fresh fish's perishability has long been a source of concern; therefore, any packaging that might extend its shelf life would be beneficial. This can be accomplished in a variety of ways. First, nanopolymers and coatings for packaging reinforcement are available, which may lower the occurrence of bruising or mechanical damage to packed fish fillets (De Azeredo 2009). Nanopackaging, unlike most of the conventional plastics, can be manufactured from natural nanoscale materials such as cellulose, starch, or chitosan and is thus expected to be biodegradable (De Azeredo 2009; Thompson et al. 2004). It has also been proposed that the meat sector use strong and light nanopackaging (Lee 2010). Microbial activity causes fresh fish items to spoil. Antimicrobial and antifungal surfaces can be used in packaging, and nanosilver is known for its antibacterial qualities (De Azeredo 2009; Moraru et al. 2003). Silver nanoparticles (AgNPs), zinc oxide (ZnO), as well as magnesium oxide (MgO), nano-silica (nS), aluminium oxide (Al_2O_3), titanium dioxide (TiO_2), and copper oxide (CuO) aid in a variety of bioactivities and biomodifications, and thus have a broad array of applications in agriculture, fisheries, food preservation and packaging, natural fibre strengthening, and the removal of contaminants from soil and water bodies, among others (Muthiah et al. 2019) (Fig. 8.1).

8.4.1 Water Treatment

One of the most critical pillars for long-term aquaculture is water treatment. In recent years, water contamination has been identified as the world's most serious health threat, and it is steadily increasing as a result of waste dumping from cities, businesses, and agriculture, as well as the misuse of antibiotics and other synthetic substances in fisheries. The degradation of waters in this way has a direct impact on human health by reducing the availability of clean groundwater, but it also has an indirect impact on aquatic creatures, whose ingestion can result in a variety of foodborne illnesses. Apart from that, the fishery industry suffers a significant financial loss as a result of microorganisms and heavy metals in these waters, which induce growth retardation and fish death. Nanotechnology has important applications in aquaculture, such as water treatment to offer a favourable and safe environment for fish spawning. In this light, the scientific community supports adsorption and photocatalysis as the most efficient and cost-effective methods of water purification.

To eliminate pollutants from water, ultrathin nano-scale particles have also been utilised. Trichloroethane, carbon tetra chloride, and polychlorinated biphenyl, for

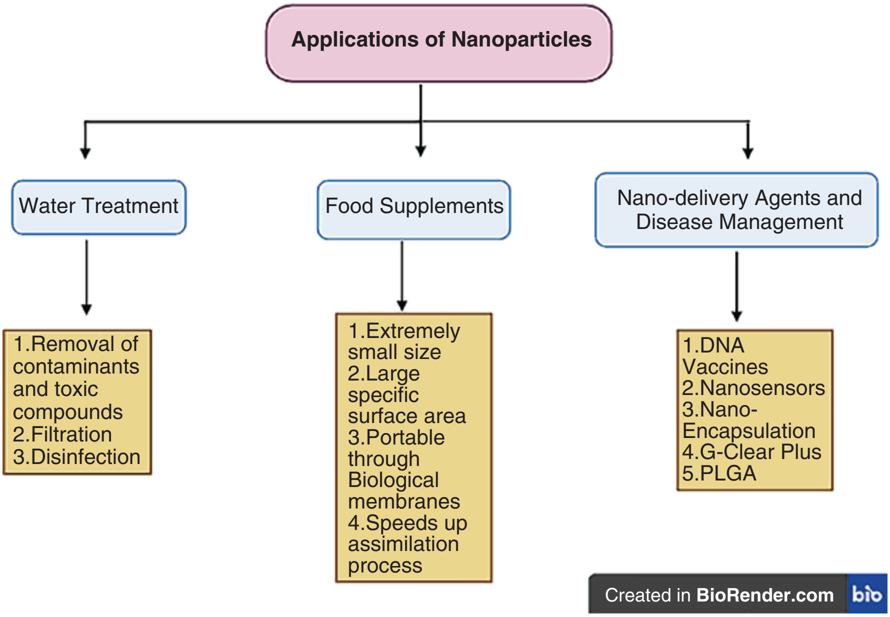

Fig. 8.1 Different types of nanoparticles applications in the field of aquaculture. (Created with BioRender.com)

example, can be effectively removed from the environment using iron-derived ultra-thin nanopowder (Wang et al. 2018). Researchers created and effectively implemented nanocrystalline zinc oxide film for photocatalytic water degradation and purification (Aal et al. 2009), as well as titanium oxide nanoparticles for coating ceramic or stone, which can remove moss and bacteria from fish bowls used for fish rearing (Van Doorslaer et al. 2012). Similarly, due to the improved stability of the nanoparticles on the foam, which aids in the controlled release of the material to the environment when desired, low-cost silver nanoparticles coated on polyurethane foam have been proposed for the effective killing of bacteria or providing an antibacterial filter for water treatment (Jain and Pradeep 2005). As a result, silver nanoparticles can be termed “new-generation antimicrobials” (Rai et al. 2009). The use of nanosilver-coated zeolite to reduce fungal development during commercial fish raising and the use of a 0.5% nanosilver filter to prevent fungal infections greatly reduced fungal infections (Johari et al. 2016). The different types of nanoparticles used in the current application of nanomaterials for water purification and filtration can be expressed. Multiwall nanotubes, single-wall nanotubes, metals and metal oxides, silica polymers, and composites are examples of nanoparticles (Aitken et al. 2006). Nano-check, a cleaning substance based on nanotechnology, has been successfully used to clean fish ponds and swimming pools. Nano-check is made up of nanoparticles (40 nm) of a lanthanum-based compound that absorbs phosphorus from water and prevents algae growth, reducing nutrient enrichment in water bodies (Rivas-Aravena et al. 2015). As a result, excessive algae growth in the pond can be controlled by limiting phosphorus availability, extending the pond's life. Furthermore, nanoscale-based weedicides have already been created and can aid in specifically targeting the tissues of the pest, as well as improved product delivery, which has been found to be very effective for large water bodies (Can et al. 2011). Iron oxide nanoparticles, according to (Karnik et al. 2005), can be used to improve ultra-filtration technology. The use of iron oxide nanoparticles for cleaning water for consumption has been proposed; additionally, the mode of action is primarily enhanced disinfection, which could be an effective strategy for most water supply providers. "Nano-863" is another novel material used in water management. Nano-863 has been used successfully for antibacterial effects, algal growth prevention, disease control, and pollution control (Shiwen et al. 2015). Furthermore, chitosan and chitosan-based nanoparticles were shown to have a number of positive effects on water management (Udo et al. 2018) (Table 8.1).

Magnetic konjac glucomannan (KGM) aerogels were produced by one of the study groups to cleanse water from arsenite (Ye et al. 2016). The pH-dependent capacity of the planned system was discovered, along with green step characteristics. However, graphene oxide and graphene nanosheets (GNs) have received a lot of interest in recent years because of their important function in eliminating various pollutants from water (Liu et al. 2016; Kuang et al. 2017; Motamedi et al. 2014). It has been particularly concentrated on the fabrication of hybrid GO-TiO2 for various environmental and energy applications, such as adsorption, and evacuating heavy metal ions and organic dyes from wastewater (Hu et al. 2013; Atchudan et al. 2017). Thanks to the research community for taking an interest in this topic of water treatment and contamination removal. Because, if left unattended, their higher concentrations can have negative, even life-threatening effects on human health by accumulating in the tissues of aquatic animals, particularly fish at the bottom of the aquatic food chain, whose consumption is highly recommended to combat cardiovascular diseases (CVDs) and cancer (Sioen et al. 2007). Fish are the most vulnerable and exposed aquatic creatures since they feed and live in an aquatic environment. They have no protection from the harmful effects of these contaminants (Saleh and Marie 2015; Mahboob et al. 2014). According to certain research, natural processes (e.g. volcanic activity) or anthropogenic acts cause increased levels of heavy metal (Hg, Cd, and Pb) buildup in the tissues of marine aquatic creatures (Dugo et al. 2006). Similarly, F^{-1} toxicity was revealed to be responsible for the experimental fish's enzyme activities, gastrointestinal function, and immune system failure

Table 8.1 Water pollutant removal methods based on nanoparticles

System	Target	References
AgNP-coated polyurethane foam	*Escherichia coli*	Jain and Pradeep (2005)
IAO/GO	F^{-1}	Liu et al. (2016)
3-D RGO hydrogel	Hg and F^{-1}	Wu et al. (2016)
NCC	NO^{-3}	Azadbakht et al. (2016)
FeOOH-GO nanocomposites	F^{-1}	Kuang et al. (2017)
TiO_2 and TiO_2–SiO_2	F^{-1}	Zheng et al. (2016)

(Manna et al. 2007), as well as the freshwater snail *Physella acuta's* habitat degradation and destruction (Camargo and Alonso 2017). Wu et al. used a 3D RGO (three-dimensional reduced graphene oxide) hydrogel produced by a hydrothermal technique for Hg^{+2} and F^{-1} removal from aqueous solutions in this study (Wu et al. 2016). Their findings revealed that the aerogel has a significant capacity for the adsorption of Hg^{+2} and F^{-1}, with 185 and 31.3 mg g^{-1}, respectively. They recommended the method as a good way to regulate pollutants in the environment. Azadbakht and colleagues created nanocrystalline cellulose (NCC) to remove NO_3 from aqueous solutions (Azadbakht et al. 2016). They found that bagasse-based NNC could be a useful strategy for removing nitrate from both water and wastewater reservoirs after obtaining a peak level removal of 25% at pH 6. Liu et al. developed a selective adsorbent based on magnetic iron–aluminium oxide/graphene oxide (IAO/GO) NPs for water purification from F^{-1} (Liu et al. 2016). The absorbent was found to exhibit improved F^{-1} selective adsorption performance, stability in an acid-base environment, and super para-magnetism properties. As a result, they speculated that IAO/GO-based adsorbents could be useful for F^{-1} in natural water resources. For the elimination of F^{-1} from the aqueous solution, another study group used TiO_2 and TiO_2–SiO_2 nanocomposite. The manufactured adsorbents had very high levels of F^{-1} adsorption, with TiO_2 adsorption reaching 94.3 mg g^{-1}. Liu et al. tested several nanosystems and found that nano net was one of the best, ensuring a 100% increase in fish survival rate. They also discovered a significant reduction in water nitrite and nitrate levels, as well as better pH and water quality.

8.4.2 Food Supplements

Nanotechnology is a new technique for increasing aquaculture productivity by developing and applying innovative nanoparticles, nanocomposites, and other substances. Nanomaterials used as supplements in fish feed have a significant impact on fish growth performance. Because of their extremely small size and large specific surface area, they can easily pass through most biological membranes without causing distortion, assisting in effective absorption. Dietary minerals of a nanoscale size can move through cells faster than bulk particles, speeding up the assimilation process and improving not only the fish‘s growth but also their overall health (Onuegbu et al. 2018). Iron nanoparticle addition in fish diets, for example, increased the growth of sturgeon and carp by 30 and 24%, respectively. Similarly, adding nano-selenium and selenomethionine nanoparticles to a fish meal at a dose-dependent dosage increased *C. auratus'* growth, muscle development, and antioxidant status (Srinivasan et al. 2016). Further research has demonstrated that supplementing the diet with elemental nanoparticles such as selenium, iron, zinc, and silver can boost overall fish development performance (Can et al. 2011; Shiwen et al. 2015). Nano-863 is another new substance that has recently become popular in China for improving aquaculture. Nano-863 is made by combining nanoparticles with strong light-absorbing capabilities and sintering them with a ceramic carrier at high temperatures. It has a variety of uses in aquaculture, including increasing fish activity and energy, increasing shrimp appetite, and promoting aquatic creature growth and development (Shiwen et al. 2015). The emergence and application of nanotechnology in their manufacturing and production are being re-engineered to get maximum benefit in improving the physical, chemical, and nutritional quality of feed and their respective constituents (Navrotsky 2003). Nanoparticles made up of various compounds are now being researched as growth promoters. Nanoparticles will improve fish feed by boosting the proportion of fish meal ingredients that pass through the gut tissue, facilitating efficient digestion, rather than passing directly through the fish digestive system, according to Onuegbu et al. (2018). Many aquaculture professionals are looking into feed supplementation as a way to improve fish productivity by enhancing the physical, chemical, and nutritional quality of the feed. Fish production has shown a considerable increase in survivorship and growth performance when supplied with dietary nanoparticles (Onuegbu et al. 2018) like iron and zinc in the case of sturgeon and carp (Srinivasan et al. 2016) and copper (20 mg/kg) in the case of *M. rosenbergii* (Muralisankar et al. 2016) as compared to control feed administration. Selenium is another key fish feed additive for increased development and reproduction, with studies showing that selenium nanoparticles promote body weight gain and improve antioxidant properties in a variety of fish species. In comparison to the basal diet, nano-selenium supplementation up to 0.68 mg/kg of dry fish feed significantly improved % weight gain, feed conversion efficiency, and specific growth rate of fish ($p < 0.05$). In a similar study, nano-selenium supplementation at 1 mg/kg of dry fish feed resulted in enhanced growth and greater selenium levels in the liver and muscle of *C. carpio* compared to the control (Ashouri et al. 2015). Additional benefits of selenium nanoparticles in fish production have been demonstrated directly through improved growth performance and indirectly through stress resilience and health enhancement, such as improved growth performance in Crucian carp (*Carassius auratus gibelio*) (Nastova et al. 2014; Zhou et al. 2009); enhanced growth performance and reduced oxidative stress in juvenile Grass carp (*Ctenopharyngodon idellus*) (Johari et al. 2016); enhanced growth performance, muscle composure, and reduced oxidative stress in juvenile Grass carp (*Ctenopharyngodon idellus*) (Sarkar et al. 2015); enhanced growth performance, and glutathione peroxidase activity in Barramundi (*Lates calcarifer Block*) (Fotedar and Munilkumar 2016). In addition, selenium functions as a chemopreventive agent in fish (Rajendran 2013) and helps to maintain the integrity of the gill membrane (Halver 2007). Furthermore, the synergistic effects of selenium supplementation on blood enzyme activities, antioxidant response, and assimilation in *B. barbus* (Kouba et al. 2014), as well as the improved nutritional value of tilapia (*Oreochromis niloticus*) (Molnár et al. 2012) and the growth performance and yield of tilapia fortified with vitamins C and E (Fonseca et al. 2013), have been noted. In addition to promoting fish growth, selenium has also been shown to lower carp mortality. In comparison to the control group (17.5%), low mortality of carps in the ponds was seen (0.7%) when a selenium-enhanced diet was added, suggesting the importance of selenium in boosting survivorship (Nastova et al. 2014). According to recent studies, food supplementation with nano zinc and copper resulted in improved survival and growth in *M. rosenbergii (*Srinivasan et al. 2016*)*. Metallic nanoparticles, including iron, iron oxide, selenium, zinc, copper, silver, and magnesium oxide, are among the many additional nutrients that have been used in aquaculture development. The optimal level of such nanoparticles for feed supplementation can be proposed based on such investigations (Table 8.2).

Supplementing gilthead seabream (*Sparus aurata*) with selenium (Se), zinc (Zn), and manganese (Mn) NPs in their early weaning meals increased stress resistance and bone mineralization (Izquierdo et al. 2017). A formulation of solid lipid (SL) NP-encapsulated 6-COUM showed enhanced uptake of the compound by two gilthead seabream (*Sparus aurata L.*) cell types, namely an established cell line (SAF-1 cells) and primary cultures of head-kidney cells, when compared to a competitor's 6-coumarin loaded pectin microparticles (MPs) (HK). As a result, SLNPs can be used as nanocarriers to transport biologically active compounds to fish (Trapani et al. 2015). In rainbow trout, a meal supplemented with iron NPs and *Lactobacillus casei* as a probiotic considerably enhanced growth parameters (Mohammadi and Tukmechi 2015), whereas a diet supplemented with 16 mg kg^{-1} MnO NPs significantly increased growth and the antioxidant defence system of freshwater prawns (*Macrobrachium rosenbergii*) (Asaikkutti et al. 2016). In the same way, copper (Cu) NP supplementation at 20 mg kg^{-1} significantly increased the growth and biochemical constituents of freshwater prawn (*Macrobrachium rosenbergii*) post-larvae (Muralisankar et al. 2016) and red sea bream *(Pagrus major*) (El Basuini et al. 2017). In a freshwater common carp fish, Kunjiappan et al. (Kunjiappan et al. 2015) investigated the hepatoprotective and antioxidant properties of *Azolla microphylla*-based gold NPs (GNPs) against acetaminophen (APAP)-induced toxicity (*Cyprinus carpio L.*). GNPs improved metabolic enzymes, hepatotoxic indicators, oxidative stress markers, altered tissue enzymes, reduced hepatic ions, aberrant liver histology, and other factors. As a result, phytochemically produced GNaP from *Azolla microphylla* was indicated as an effective protector against acetaminophen-induced liver damage in freshwater common carp fish (Kunjiappan et al. 2015). Sharif Rohani and colleagues investigated the effects of three different amounts of aloe vera NPs (0.5%, 1%, and 1.5% of the diet) on Siberian sturgeon growth, survival, and body composition (*Acipenser baerii*). Their findings revealed that a diet supplemented with 1% aloe vera NPs considerably improved Siberian sturgeon growth indicators when compared to controls (Sharif Rohani et al. 2017). Another study looked at the effects of ginger (GN) and GNNPs on performance, cognition, immunity, and the prevention of motile *Aeromonas septicaemia* (MAS) in *Cyprinus carpio* fingerlings in the same year. Fish fed 1 and 0.5 g GNNPs per kg feed had 100% relative percentage survival (RPS), whereas fish fed 0.5 g GN per kg feed had a 20% mortality rate and a 71% RPS. These findings demonstrated that GNNPs, rather than GN, are a successful formulation for preventing MAS (Korni and Khalil 2017). AgNPs made from *Azadirachta indica* (neem) were created to test their immunomodulatory function in *Cirrhinus mrigala* fingerlings challenged with *Aeromonas hydrophila*. It was found that these NPs have potential immunomodulatory and antibacterial action after dramatically increasing the functional activity of immunological markers in fish treated with them (Rather et al. 2017). Erdem and his colleagues

Table 8.2 Studies regarding supplement delivery using nanoparticles in aquatic animals

Nanoparticle	Mode of administration	Target	Experimental design	Observations	References
Se NP (+/-Vit E)	Extruded into pellets	Juvenile Mahseer fish	Vitamin C doses of 100, 200, and 300 mg kg^{-1} were combined with a nano se dosage of 0.68 mg kg^{-1} to examine if they had any synergistic effects on growth, feeding, or physiological measures	Blood physicochemical properties such as Hb, WBC, RBC count enhanced, and liver and muscle protein content rose when vitamin C300 + nano se 0.68 mg kg1 was used	Khan et al. (2017)
Se NP	Extruded feed was added and air dried	Juvenile common carp	The growth performance of fish was evaluated at three different doses of SeNP (0.5, 1, and 2 mg/kg dry food)	Carp development was enhanced by 1 mg nano-se per kg feed, while 2 mg/kg caused toxicity	Ashouri et al. (2015)
Fe_3O_4 NP	Aloe vera leaf extract was used to make AgNP, which was combined with normal feed	Rainbow trout, *Labeo rohita*	Hematological parameters, respiratory burst activity, and serum bactericidal activity were assessed using 0.5 mg of Fe_3O_4 NP (T1) and Fe_2SO_4 (T2) per kg dry diet	Control had a lower Fe content in muscle than T1 and T2, whereas Fe_3O_4 NP had the greatest Fe level. In FeNP-treated diets, RBCs and haemoglobin levels, immunological parameters, bactericidal activity, and myeloperoxidase activity were all increased	Behera et al. (2014)
CuNP	The dough containing ZnNP was baked at 105 °C, chilled, and then pelletised using egg albumin and cod liver oil	*Macrobrachium rosenbergii*	Cu-NPs were added to the baseline meals at 0, 10, 20, 40, 60, and 80 mg kg^{-1}. *M. rosenbergii* PL was given these cu-NPs supplemented meals for 90 days	Survival, growth, digestive enzyme activities, biochemical constituent concentrations, and total and differential haemocyte count of prawns fed 20 mg (200 nm) cu-NPs kg^{-1} supplemented feed exhibited significant ($P < 0.05$) improvements, whereas 40–80 mg cu-NPs kg^{-1} supplemented feed showed negative performance	Muralisankar et al. (2016)

(continued)

Table 8.2 (continued)

Nanoparticle	Mode of administration	Target	Experimental design	Observations	References
SeNP	In a drum mixer, se sources were slowly combined with the diet ingredients part by part, then extruded and air-dried at room temperature	*Carassius auratus gibelio*	T-1- (se NP), T-2, selenomethionine, and control were the three treatments. The relative growth rate as well as the final weight were calculated	In comparison to T-1 and T-2, the control had lower se content in muscle, while se NP had the greatest se content in muscle. Dietary interventions had no effect on survival rate or feed conversion ratio	Zhou et al. (2009)
Se, Zn and Mn NPs	Microdiets made by pelletizing, drying, grinding, and sieving squid powder with water-soluble components, vitamins, and gelatin	Seabream larvae	Larvae were fed one of the experimental diets (with no minerals, organic and inorganic form of the mineral, and nano forms of the mineral) every 45 minutes for 24 days after being fed rotifers supplemented with DHA protein. Image analysis was used to evaluate diet acceptability	Inorganic versions of these minerals were shown to be less efficient than organic forms. In compared to a non-supplemented diet, minerals improve larval weight and bone mineralization. Furthermore, the larvae were less stress tolerant, and the fish had more bone abnormalities in the pre-hemal area. Nanometal additions of Zn, Mn, and se had little effect on growth. However, stress resistance and bone mineralization have improved	Izquierdo et al. (2017)
Mn_3O_4 NP	Added to pelletised feed and dried at 40 °C	*Macrobrachium rosenbergii*	Seven groups of *M. rosenbergii* PL (1.42 ± 0.35 cm length; 0.18 ± 0.02 g weight) were studied with different levels of Mn NP for 90 days	The results of the trial showed that prawns fed a meal supplemented with 3–18 mg Mn-oxide NPs/kg had improved growth performance, final weight, and FCR ($P < 0.05$)	Asaikkutti et al. (2016)

(continued)

recently synthesised AgNPs from *Aeromonas sobria* to test their antibacterial efficacy against a variety of fish infections (*H. alvei, P. rettgeri*, *M. morganii subsp. sibonii*, *C. braakii*, *E. hermannii*, *A. hydrophila*, *E. cloacae*, and *E. coli*). These NPs were thought to be a promising candidate for use as a disinfectant or antibacterial agent for better fish health management due to their great efficacy against *A. hydrophila* (Erdem et al. 2019).

Dietary iron oxide and copper nanoparticles (20 mg/kg) have been suggested for improving *M. rosenbergii* growth and health (Srinivasan et al. 2016; Muralisankar et al. 2016). When compared to the basal diet given to the African catfish, *Clarias gariepinus*, chitosan-derived nanoparticles (5 mg/kg) produced improved growth and feed utilisation (Udo et al. 2018). In addition to using dietary nanoparticles as fish feed supplements, there are several commercially patented goods that are employed as well. One such feed addition is “nano PUFA,” which is intended to boost daily weight gain in fish and shrimp. Nano PUFA is made up of colloidal polyunsaturated fatty acid particles embedded in amino acid matrices and then bioencapsulated for use in fish and shrimp nutrition. It also contains essential enzymes, extracts from a variety of helpful herbs, and feed-grade polymers (Moges et al. 2020).

8.4.3 Nanodelivery Agents and Disease Management

Nanomedicines include nanodiagnostics, nanovaccines, nanotherapeutics, and nanotoxicological compounds. Nanotechnologies enable new ways for strong fish health diagnostics, even down to the single virus level, as well as delivery mechanisms, particularly for heat-sensitive or labile medications. Various laboratories have researched the effects of silver and zinc oxide nanoparticles as promising antibacterial and antifungal agents against fish pathogens (bacteria, fungi, viruses, etc.) and diagnostic and therapeutic agents. Aquaculture is one of the most disease-prone systems, resulting in insecure development and long-term viability. It is also vulnerable to novel infections that can cause huge damage. As a result, focused vaccine/drug administration is critical for sustaining aquatic creature health. Several antibiotics are commonly employed as therapeutic medicines in aquaculture, either through feed or injection. The primary stumbling block is the drug’s bioavailability, which makes it difficult for it to reach the fish underwater (Plant and Lapatra 2011). Because of the fish’s low immune response, the traditional technique of drug/vaccine delivery to them has several drawbacks. Certain carriers, like oil/water emulsions, have been employed to improve the efficiency of medications, vaccinations, and nutrients; however, this strategy has resulted in numerous side effects. Nanoencapsulation is a revolutionary strategy for boosting aquaculture productivity by mitigating the negative impacts of oil emulsions. A vaccination or medicine is encapsulated inside another chemical that acts as a nanoscale protective shell in this approach. Nanoencapsulated complexes are extremely durable, able to withstand extreme temperatures and variations in water acidity, and hence are advantageous to use (Dominguez 2014).

Nanomaterial-based technologies could successfully prevent and manage illnesses and infections, boosting aquaculture productivity by a factor of ten. Nanomaterial-based technologies could help aquaculture grow by preventing and controlling illnesses and infections. Some of the fish health uses of nanotechnology include antibacterial or antifungal surfaces created utilising porous nanostructures, nanosensors in aquaculture systems for detecting infections in water, and the nanodelivery of veterinary products and fish pharmaceuticals through fish meals. Nano-trace elements have a far higher utilisation rate, up to 100%, than typical inorganic trace elements, which is normally extremely limited because the latter might enter the animal body by direct penetration. Epizootic Ulcerative Syndrome (EUS) (Kuan et al. 2013) and vibriosis in fish, as well as white spot syndrome (WSS) in shrimp species (Rajeshkumar et al. 2009), are some of the most frequent diseases caused by viruses, bacteria, and fungi. Because nanomaterials act at the same scale as viruses or disease-infecting particles, controlling these diseases would necessitate early detection and elimination of pathogens. Since nanoencapsulated materials are robust and can survive high temperatures or acidity, chitosan-based wrap-around vaccines as nanoencapsulation carriers for effective treatment delivery against bacteria and viruses that cause fish ailments have been described. Such nanomaterials can be used to produce pathogen-free fish seedlings as well as shrimp or prawn post-larvae for commercial farming.

Nanomedicine is a fast-expanding area of nanotechnology, and there is potential to employ these advancements to monitor and enhance fish health (Freitas Jr 2005). Due to the poor stability of pharmaceuticals in natural water, many fish treatments must be administered through food, or it must be accepted that much of any aqueous treatment will be washed away. NMs have been used to develop new medication delivery methods for people, and they could potentially be employed to develop veterinary medicines for fish. Solid core drug delivery systems (SCDDS) include coating a solid NP with a fatty acid shell to keep the medication of interest contained. This approach is particularly beneficial for heat-sensitive or labile medicines since it operates at low temperatures and pressures (Trivedi et al. 2014). Drug distribution can also be accomplished using porous NMs. Mesoporous silica particles, for example, can be utilised to release chemicals in a controlled manner (Strømme et al. 2009). This latter approach could be used to deliver fish vaccinations, for example. Pathogen detection nanosensors are also becoming available. Electrical nanosensors can already detect single virus particles, indicating that nanosensors will play a significant role in illness detection in the near future (Patolsky et al. 2004).

Because of their bactericidal properties, silver nanoparticles have been used in disease control (Gong et al. 2007). One of the most difficult difficulties in aquaculture was infection and disease control caused by viruses, bacteria, fungi, and parasites. Antimicrobials have traditionally been used in aquaculture to combat bacterial illnesses. Excessive use of these substances, on the other hand, resulted in resistant strains, making the therapies ineffective (Pelgrift and Friedman 2013). In a previous investigation of resistance strains in fish producers in 25 nations, it was discovered that tetracycline was the most commonly used antibiotic. In addition, several isolated bacteria from tilapia demonstrate a broad antibiotic range. *Aeromonas* *salmonicida*, *Photobacterium damselae*, *Yersinia ruckeri*, *Listeria* sp., *Vibrio* sp., *Pseudomonas* sp., and *Edwardsiella* sp. were among the resistant strains (Tuševljak et al. 2013). Some researchers researched the silver nanoparticle effect for various approaches to managing significant pathogens from fishes, mollusks, and crustaceans to explore other choices to avoid different ailments in aquatic organisms (Swain et al. 2014; Seil and Webster 2012). Silver nanoparticles were tested for antibacterial activity against two fish infections, *Lactococcus garvieae* and *Streptococcus iniae*, in a recent study (Raissy and Ansari 2011). It was determined what the minimum inhibitory concentration (MIC) and minimum bactericide concentration (BC) were. According to the findings, the MIC ranges from 1.12 to 5 g mL^{-1} for *L. garvieae* and 1.2 to 2.5 g mL^{-1} for isolated *S. iniae*. For *L. garvieae* and *S. iniae*, the mean MIC was 2.59 and 2.1, respectively. The strain *S. iniae* was shown to be more sensitive to silver nanoparticles than the strain *L. garvieae*. In another study (Saleh et al. 2017), the antiparasitic impact of AgNPs was assessed against *Ichthyophthirius multifiliis*, a parasite that causes white spot in freshwater fishes, and it was discovered that 10 and 5 ngL^{-1} of AgNPS have antiparasitic effects in vitro and in vivo investigations.

The application of AgNPs synthetised from natural products to *Vibrio harveyi* control in infected *Feneropenaeus indicus* organisms yielded positive results (Vaseeharan et al. 2010), for example, when AgNPs were synthesised by *Camellia sinensis* to control *Vibrio harveyi* in infected *Feneropenaeus indi*cus organisms. In vivo experiments revealed that a dose of 10 g mL^{-1} suppressed bacterial growth in 70% of cases. In another work (Sivaramasamy et al. 2016), *Bacillus subtilis*, a non-pathogenic bacteria, was utilised to synthesise a nano molecule, which was then tested for antimicrobial activity against *V. parahaemolyticus* and *V. harveyi* in *Litopenaeus vannamei*-infected mice. The survival rate in the control group was 1%, but it was 90% in the nano compound group. It was also discovered that when bacteria and plant extracts were employed, no physiological changes or harmful effects on the shrimps were seen. It was observed that AgNPs encapsulated with starch and applied through immersion baths (20 min) with 10 ng of nanoparticle concentrations had antiparasitic and antifungal effects in *Carassius auratus* infected with *Ichthyophthirius multifiliis* and *Aphanomyces invadans*. The findings revealed that fish recovered after 3 days without becoming harmful as a result of the AgNPs treatment (Barakat et al. 2016). In vitro, some researchers tested AgNPs encapsulated with chitosan (75 g mL^{-1}) for antibacterial activity against *Vibrio tapetis* (Dananjaya et al. 2014). The lowest inhibitory concentration of one nano compound comprising chitosan and AgNPs was determined in 2017 to evaluate the antifungal efficacy in vitro against *Fusarium oxysporum* (Dananjaya et al. 2017). Later, in vivo studies were performed on fungus-infected zebrafish. In vitro experiments revealed that a concentration of 250 g mL^{-1} of nano compound had a minimum inhibitory concentration of 38.69%, while in vivo tests revealed fungal mycelium degradation storage in fish backs, confirming that fungus was damaged by nano compound contact.

Nanoparticles encapsulating the medicine will improve the specificity of the target region while also assisting in better drug absorption. Researchers have recently had some success creating nanoencapsulated vaccinations against the bacteria *L.anguillarum* in Asian carp and the white spot syndrome virus in shrimp (Rajesh Kumar et al. 2008, 2009). Furthermore, particular medicines such as antibiotics, vaccines, probiotics, and nutraceuticals can be tagged on nanoparticles in a controlled time way. G-Clear Plus is a brand-new probiotic supplement designed to improve probiotic delivery in fish (Moges et al. 2020). It's a collection of probiotic strains that help fight the nasty gut sickness caused by several *Vibrio* bacteria. G-Clear Plus works in principle by selectively eliminating infections while simultaneously colonising the probiotic strains used in G-Clear Plus. G-Clear Plus is organic in nature because it does not contain antibiotics or powerful chemicals. Nanoparticles such as chitosan and poly-lactide glycolipid acid (PLGA) can also be employed to create nanovaccines (Dubey et al. 2016). Because of their mild inflammatory response in fish and shrimps, these chemicals can be employed to effectively remove bacteria as well as destroy viral infections. Nanocapsules containing nanoparticles can efficiently be utilised to retain bioavailability for a longer period of time in the event of mass vaccination, where vaccine delivery is a critical component. In addition, chitosan nanoparticles have been employed in the production of vaccines, such as the inactive virus vaccine against infectious salmon anaemia virus (ISAV), which uses the ISAV gene sequences as an adjuvant (Rivas-Aravena et al. 2015). This vaccine provided up to 77% protection against the ISAV virus. Rajesh Kumar et al. (2008) have shown that chitosan nanoparticles may be used to successfully deliver DNA vaccination to fish (Rajesh Kumar et al. 2008). In addition, using chitosan and chitosan/tripolyphosphate nanoparticles, the same group developed an oral DNA vaccine against *Vibrio anguillarum* in Asian sea bass (*Lates calcarifer*); the results showed that sea bass orally vaccinated with the chitosan-DNA (pVAOMP38) complex showed moderate (46%) protection against experimental *V. anguillarum* infection (Rajesh Kumar et al. 2008). Furthermore, an oral vaccine against the reddish body iridovirus, which infects the turbot *Scophthalmus maximus*, has been created and proven to be efficacious (Zheng et al. 2016). Feed supply is another challenge in aquaculture that necessitates efficient distribution. Because water is the medium through which fish reproduce, feed, and prosper, keeping the integrity and quality of feed in water is difficult due to its high liquidity. Because some nanoparticles can modify the physical qualities of feed, such as buoyancy and hardness, using nano-capsulation technology to preserve fat-soluble vitamins, minerals, and fatty acids in water may be helpful. The use of nanoencapsulation technology in the application of carotenoids, trace minerals, vitamins, and fatty acids has been proposed, with the primary purpose of enhancing bioavailability (Khot et al. 2012). Nutrients, medicines, food antimicrobials, and food additives can all be carried in them (Reza Mozafari et al. 2008). Nanoparticles have also been employed for enhanced and rapid diagnosis of fish disease, in addition to drug/vaccine development. Gold nanoparticles have played a crucial role in this regard. For the rapid diagnosis of furnaculosis infection in fish, gold nanoparticles coupled with *Aeromonas salmonicida* antibodies were utilised (Saleh et al. 2015). Early detection of yellow head virus in shrimp (Khunthong et al. 2013) and spring viremia of carp virus (Saleh et al. 2012) has also been achieved utilising specific colorimetric tests based on gold nanoparticles. Nanoparticles are also utilised in delivery methods, such as anaesthesia and oil emulsifiers (Kheawfu et al. 2017). When compared to current conventional approaches to blending, such advanced techniques of nano-based delivery systems have several advantages, including a broader application for nutraceuticals, less chance of leakage into the water, a conservative amount, protection against oxidation, superior efficiency of antioxidants and preservatives, high bioavailability of compounds, and thermal and pH stability (Aklakur et al. 2016).

8.5 Challenges and Limitations

Despite its many uses, nanotechnology's usage in aquaculture is currently limited and has not been fully commercialised to the extent that it has been in other industrial sectors. Academics bear the brunt of nanotechnology research breakthroughs, while industries are limited to patent ownership. Furthermore, the size of scientific patents has grown significantly, necessitating the inclusion of broad claims when filing in order to ensure future freedom to operate in the face of changing economic conditions. Another disadvantage of nanotech goods is the high initial capital investment required due to the usage of advanced equipment and services, which can be overcome if the job is done on a large scale. Start-ups and small businesses may become demotivated as a result of this. There are, however, specific financing bodies that can help start-ups establish their setting by providing a seed fund to demonstrate the principle of scale-up. Furthermore, most metal-based nanoparticles are nonbiodegradable and have the ability to increase biomagnification. Several metal-based nanoparticles, including silver, gold, titanium, and magnesium, have been shown to have dose-dependent harmful effects on animal development and to cause developmental defects in young animals (Hegde et al. 2016; Iswarya et al. 2019; McGillicuddy et al. 2017; Verma et al. 2018). Metal nanoparticles can also interact with organisms' essential enzymes, causing negative biological effects. In this context, zinc oxide nanoparticles were shown to have specific clinical manifestations such as a pulmonary inflammatory response in mice at high doses (>1 mg/mL) (Sayes et al. 2007), as well as severe symptoms of lethargy, anorexia, vomiting, diarrhoea, body weight loss, and even death when gastrointestinally administered, whereas such effects were mitigated in bulk-sized zinc particles at equal doses (Wang et al. 2006). As a result, increased use of such nanoparticles may eventually be hazardous to living organisms. In this context, the use of organic or carbon-based nanoparticles appears promising and has the potential to mitigate the harmful effects of metal nanoparticles, thereby reducing environmental impact. Carbon-dots, graphene nanoparticles, metal nanoparticles encapsulated in graphene/silica, and carbon-metal-nano-conjugates are examples of possible nanotechnology advancements that could help enhance agriculture while minimising environmental effects. Despite these drawbacks, the introduction of nanotech goods to the market will yield significant benefits due to their cost effectiveness, specificity, stability, mobility, and variety of applications. Risk assessment using in vitro and in vivo models,

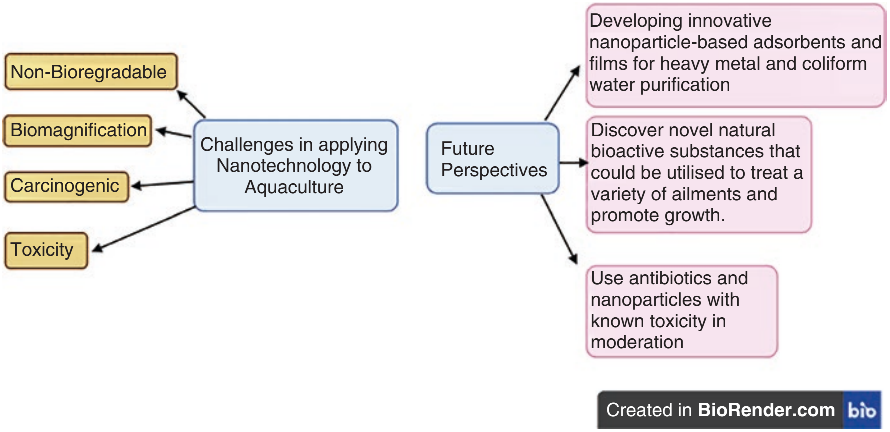

Fig. 8.2 Challenges and limitations in the application of nanoparticles in aquaculture and its future perspectives. (Created with BioRender.com)

appropriate dose determination for field application with minimal environmental impact, shifting to organic and environmentally friendly nanoparticles, and evaluating the use of nanoparticles in controlled clinical trials using appropriate models are all possible approaches for mitigating deleterious effects and selecting environmentally friendly nanoparticles. As a result, advances in nanoscience will have far-reaching implications for aquaculture; nevertheless, producing next-generation fish with nanotechnology will be difficult, necessitating additional research into biological behaviour, specificity, scalability, and practical application (Fig. 8.2).

8.6 Conclusion

Nanotechnology undoubtedly plays an important role in the growth and long-term viability of aquaculture. Various nanotechnology-based solutions have been used to enhance the major pillars of aquaculture and fishing up to this point. Despite their enormous potential, the use of watershed management ideas and methods, as well as nanotechnology in fisheries and aquaculture, is still limited. In comparison to consumer goods and human healthcare, nanotechnological uses in fisheries, agriculture, and water management as a whole are significantly less prevalent. Only a small number of nano-products or nanotechnologies are now accessible in the fisheries subsector, despite their enormous potential. This position opens up a lot of possibilities for allocating more money to nanotechnology research and implementation in the subsector.

However, there is rising worry in this field concerning the toxicity of NPs, as well as the overuse of antibiotics and other synthetic substances. As a result, the use of safe and environmentally friendly methods is unavoidable. Based on this knowledge, we highly suggest that future research in aquaculture and fisheries be focused on:

(i) Developing innovative nanoparticle-based adsorbents and films for heavy metal and coliform water purification.
(ii) Using antibiotics and nanoparticles with known toxicity in moderation.
(iii) Discovering novel natural bioactive substances that could be utilised to treat a variety of ailments and promote growth.

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