Journal of Marine Biology and Aquatic Research
Volume 3 | Issue 1

Review Article Open Access

Green Technology: A Panacea for Effective and Sustainable Fish Health and Aquaculture Management

Olugbojo Joseph Abiodun*

Department of Biological Sciences, Bells University of Technology, Ota, Ogun State, Nigeria

***Corresponding Author:** Olugbojo Joseph Abiodun, Department of Biological Sciences, Bells University of Technology, Ota, Ogun State, Nigeria, Tel.: +2349034809642, E-mail: josephgbojo2012@gmail.com

Citation: Olugbojo Joseph Abiodun (2025) Green Technology: A Panacea for Effective and Sustainable Fish Health and Aqua culture Management, J Marin Biol Aqua Res 3(1):101

Received Date: March 28, 2025 **Accepted Date:** April 25, 2025 **Published Date:** May 30, 2025

Abstract

The advent of sustainable aquaculture demands a serious need for eco-friendly technology. This is what green technology seek to offer as regards different areas of aquaculture which include: fish nutrition, fish diseases management, water quality management and pollution control, ecotoxicology, and fish breeding. To achieve sustainable aquaculture through green technology, various principles of green chemistry technology must be taken into consideration which includes environmental pollution prevention, efficient use of raw materials, lesser harzardous chemical synthesis, reduction in the toxicity of the product, safer solvent and ancillaries, renewable sources of energy, reducing derivatives and involving catalysis, biodegradability, and controlled production of hazardous wastes.

Nonetheless, aquaculture has witnessed a steady and tremendous growth in recent years as a result of green chemistry technology. Some of these includes the use of medicinal plants, microorganisms, fungi, algae, and green nanotechnology. This technology has also helped in biomonitoring, bioremediation, and bio-augmentation in aquatic pollution management, and has led to good water quality for fish production. It has also helped to improve fish production (fish breeding), nutrition, and fish health management. The advent of green nanotechnology has greatly improve the application of green chemistry technology in aquaculture, and this evolving technology has continue to create a definite impact in every aspect of fisheries and aquaculture.

Keywords: Sustainable aquaculture; Eco-friendly technology; Pollution prevention; Biodegradability; Bioremediation; Ecotoxicology

Introduction

Green technology is the design of products and processes that reduce or eliminate the use or generation of hazardous substances. Green chemistry spans across the life cycle of a chemical product, including its design, production, use, and disposal.

According to Anastas [1], if a technology reduces or remove the hazardous substance used to clean up environmental contaminants, this technology can be regarded as green technology. Green technology involves a process that deliberately remove hazardous chemical from an environment, prevent or reduce toxicity in a edible items or living cells. The use of plant or animal sources for the purpose of remediation, synthesis or processing without leading to hazardous product or by-product can be referred to as green chemistry [2]

Aquaculture is the fastest growing industry in the animal food sector. It surpasses capture fisheries and it is already recognized as an alternative, efficient and sustainable food supply [3]. In addition, the global demand for aquatic products is steadily increasing, and it is expected to improve further with the growing world population [4]. However, the traditional aquaculture system faces limitations due to a vicious cycle where the high density of farms (such as poultry, piggery, and crop production farms, and so on) pollutes the fish ponds or fish rearing environment, and the whole operation impact negatively on the living environment with direct effect on man [5]. Ideally, sustainable aquaculture if not improving on the environmental health, and benefits the resident communities, at least it should uphold the quality and condition of the environment. Moreover, the rapid advancement of aquaculture over the past few decades has raised concerns that it may lead to a serious environmental degradation and hazard. However, green (chemistry) technology offer a tremendous help for a sustainable and eco-friendly aquaculture practice. It is a sustainable technologies which integrate and exploit environmental productivity while minimizing or eliminating the ecological footprint.

Aquaculture is one of the few options of food security and economic growth that contribute significantly at the global level. All commercial varieties of fishery products, including shrimp, prawn, lobster, crab, fish, and other aquatic animals and plants, have been cultured for quite a long time in Nigeria and worldwide. Disease vulnerabilities and polluted water are the crucial factors that affect the production rates in aquaculture. In view of this, disease control has become an active field of research in aquaculture, and aquaculture practitioners identified various control measures over the years. Consequently, drugs and chemicals are often applied to treat diseases of cultured aquatic animals and improve the water quality in culture facilities. While aquaculture practices in recent years has tremendously expanded, the use of chemicals has also increased, especially in the culture systems of commercially important species such as shrimps. On the other side, chemical use in aquaculture has adversely affected both water and fish [5]. Despite various statutory regulations set on the usage of chemicals, the public health hazards related to the chemical inter-mixture in freshwater, brackish water, and coastal saline waters of culture facilities are usually ignored. However, it is important that the fish culturist, and suppliers of chemicals, government agencies, and scientists should also be at alert to the chemical inter-mixture in the aquaculture systems.

This paper mainly discusses basic concept of green chemistry technology with reference to aquaculture and fish diseases management towards ensuring a sustainable aquaculture, effective diseases management and safe environment.

Principles of Green Chemistry Technology and its relevance in Aquaculture Management and Environmental (Aquatic) pollution prevention

Green chemistry technology provides innovative scientific solution to real-world environmental challenges. This technology can be applied in every area where chemical reactions or activities occur in aquaculture. Its introduction does not lead to the generation of pollution in any form. It reduces the negative impacts of chemical processes on fish health, human health and the environment. It lessens and possibly eliminates hazards from the existing products and processes involved.

Effective Utilization of Raw Materials

In chemistry this is referred to as atom economy [6], but in aquaculture, it can be referred to as effective utilization of material with less wastes, high productivity and as much as possible no hazard in involved. This approach supports the principle of green technology such that at the end efficiency is highly maximized. Normally in fish production, feed conversion ratio is about 80% compare to poultry which is much lesser, about 60% [7]. Moreover, when it comes to chemical treatments or the use of antibiotics on ponds and fish to combat pathogens or cure diseases, in most cases chemical hazard on water, fish health and environment in general present lesser advantage with this methods, and thus the purpose is not maximized.

Lesser Hazardous Synthesis with Reduction in the Toxicity of the Product

Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment [8]. This means that the chemicals products and processes should be such that reduce intrinsic hazards. It prevent wastes and it's by product can become a new raw material for another product. The product eventually produced are non-toxic and very effective than the usual toxic and dangerous chemical products. The reactants or raw materials are safer and the reaction condition is safe to the scientist and the environment. To be safer and greener, room temperature and pressure are mostly recommended, so as to ensure increase energy efficiency. The implication of this in aquaculture is that, every chemical products that will be used either to treat pond water, fish diseases etc., should be eco-friendly and non-toxic to fish, and this have to do with preparation or processing method. While minimizing (or removing) toxicity, it must, at the same time, maintain function and efficacy. For instance nanoparticles have been employed as antimicrobial, immuno-stimulant, anti-parasitic, and anti-tumour in fish health and diseases management, and have also been used in pond water treatment, however, chemical and physical synthesis of nanoparticles involves the use of hazardous chemicals, high energy input leading to high toxicity of the end product, and low production yield, whereas when biologically synthesized (as a green chemistry approach), all these problems are removed. The product (nanoparticles) obtained will be unique, with a better advantage than what would have been obtained through chemical and physical preparation methods [9]. Nevertheless, to achieving this goal, understanding of the principles of toxicology, environmental resources management, in addition to the knowledge of chemistry and fisheries/aquaculture will be required.

Renewable Sources of Energy

Energy has become a key issue in the 21st century era. Majority of the energy that is produced is based on fossil fuel. And usually, the energy eventually obtained are minimal due to much loss during conversion and transmission. This means that, looking at the life cycle of energy production, and how much energy is actually available for useful work at the point of need, it is less than 1 or 2 percent of the energy that was originally available in the fossil fuel [8]. It is also true that most fossil fuel energy is used for transportation services of one kind or another. There are tremendous number of opportunities to change this energy use profile. Various forms of renewable energy can be deployed to enhance aquaculture practice beyond the usual fossil fuels.

Aquaculture is one of the fastest growing sector which produces fish - a cheap source of animal protein and nutrition. In the recent past, the growth of aquaculture sector was booming, due to declining catches from wild capture fisheries. However, in future, fish protein will be fully depends on aquaculture only. The annual fish production in 2016 globally was 171 million tons [4]. The cost of feed, disease treatment and prevention, electricity, wages and fuel are major recurring problems in the aquaculture sector, couple with its pollution effect in the environment (when diesel engine is used to power the farm). Normally the farmers spend exorbitant amount of fund on fuel whereas if use eco - friendly renewable energy sources, they can grossly reduce the production cost. Renewable energy is an energy that is generated from natural processes that are continuously replenished. This includes sunlight, geothermal heat, wind, tides, water and various forms of biomass. It is an excellent innovation in sustainable aquaculture. It is an eco-friendly novel technique in enhancing aquaculture without compromising natural aquatic ecosystems. This energy cannot be exhausted and is consistently renewed. Renewable energy is also called “clean energy” or “green power” because it doesn’t pollute the environment. So the use of renewable energy in aquaculture reduces the production cost and increase the sustainability. An efficiently produced energy can be used for aeration, feed dissension, water pumping, light sources, transportation and so on, there are several other ways by which renewable energy sources can be used in aquaculture.

The Use of Enzymes for Catalysis and to Reduce Derivatives

One of the key principles of green technology is to reduce the use of derivatives and protecting groups during any form of synthesis or processes. One of the best ways of doing this is the use of enzymes. Enzymes are so specific that they can often react with one site of the molecule and leave the rest of the molecule alone and hence protecting groups are often not required.

It also Involve catalysis whereby reactions are not only speed up, but it minimizes wastes. A small amount of catalyst can be enough for several reactions. The products eventually got through green chemistry are easily degradable, and thus does not accumulate to pollute the environment, especially fish rearing or capturing environment.

Enzymes are also used in bio-extraction and bio-deacetylation of chitin and chitosan respectively [10], which can then be synthesized into organic nanoparticles and nanocomposites for onward application in fish growth enhancement, improve fish production, treatment of various fish diseases, parasites, pond water purification and remediation.

Safer use of Solvents and other substances during the reaction processes

Solvents account for 50 – 80 percent of the over-all mass in a standard batch chemical operation, depending on whether one include water or not. Moreover, solvents account for about 75% of the cumulative life cycle of environmental impacts of a standard batch chemical operation. Solvents and mass separation agents are what determine the smooth running of most of the energy consumption in a process. Solvents are alternately heated, distilled, cooled, pumped, mixed, distilled under vacuum, and filtered [2].They could be recycled, and if not, they are often incinerated. Solvents are also the major contributors to the overall toxicity profile, and based on this, most of the materials of concern associated with processes depends on it. Consequently, they contribute a major concern on safety issue during production and all processes because they could be flammable, toxic, and sometimes explosive. Generally, it compel workers to use personal protective gadgets of different types. Solvents will always be needed, due to so many things involved in chemical processes. Based on this, effective optimization will be highly required. Therefore, the choice of solvent must be such that reduce the energy requirements, have the least toxicity, have the fewest life cycle environmental impacts and do not have major safety implication. It is possible to make better choices, and that is what application of this principle should promote since we are dealing with living organism (fish and fisheries products) which will eventually get back to man through food chain. This is much applicable in aquaculture as regards synthesis of several reagents and chemicals used in water treatment, antimicrobial, drugs, vaccines, etc.

Green chemistry technology is design for biodegradable. Whatever is regarded as green chemistry, it is designed to be biodegradable. Plants materials, enzymes, microorganisms, yeast etc. that are products of plants and animals are known to be degradable. It is also a real time synthesis in which production of hazardous wastes are controlled through effective monitoring. Likewise, safety must be fully assured during the laboratory processes involving synthesis to prevent explosion, especially when high heat generation in involved [8].

Application of Green Chemistry in Aquaculture Management, Fish Nutrition, Fish Health and Various Green Methods Involved

Use of medicinal plants

Compared with chemical drugs and antibiotics, medicinal plants have few side-effects, produce little drug resistance, and exhibit low toxicity to the water environment. Most medicinal plants can effectively improve the growth performance of aquatic animals. They are becoming increasingly valued and widely used in aquaculture.

Several plant extracts have been reported as appetite stimulants and growth promoters [11]. For instance, grouper (*Epinephelus tauvina*) fed with a supplemented diet of a mixture of methanolic herb extracts (Cynodondactylon, *Piper longum*, *Phyllanthus niruri, Tridax procumbens* and *Zingiber officinalis*) displayed 41% higher weight than control fish [12]. Other studies have reported that administration of plant extracts improves digestibility and availability of nutrients, resulting in increase in feed conversion and leading to higher protein synthesis [13]. Numerous studies have shown that fish treated with medicinal plants presented enhanced immune parameters, for example, Nile tilapia (*Oreochromis niloticus*) fed with a diet containing mistletoe (Viscumalbum coloratum) for a period of 80 days displayed higher lysozyme, respiratory burst, alternative complement and phagocytic activity, which resulted in 42% increased survival ability when they were challenged with the bacterial pathogen *Aeromonas hydrophila* [14]. Studies on fish haematological parameters have shown that fish treated with plants displayed higher levels of erythrocytes, lymphocytes, monocytes and haemoglobin than control fish, indicating better fish fitness [15]. *In vitro* and *in--vivo* studies have shown the potential of medicinal plants against a wide range of marine pathogens (bacteria, virus, fungus and ectoparasites) [16]. Antibacterial properties of medicinal plants are by far the best studied biological activities, with abundant in--vitro studies reporting antibacterial activity in numerous plants against both Gram-positive and Gram-negative marine bacteria [17]. *In-vivo* studies in Indian major carp (*Labeo rohita*) fed with diets enriched with prickly chaff flower (Achyrantesaspera, 0, 2%) and Indian ginseng (With an iasomnifera, 0, 5%) showed a reduction in mortality of 41% and 49% respectively when fish were challenged with *A. hydrophila* [18]. Antiviral and antifungal activities of medicinal plants are also able to prevent high mortality rates in aquaculture. Balasubramanian *et al.* [19] showed that black tiger shrimp (*Penaeus monodon*) challenged with white spot syndrome virus (WSSV) while being treated with Bermuda grass (*Cynodondactylon sp.*) displayed no mortality and no signs of disease compared to 100% mortality observed in control groups. Several studies have shown *in-vitro* anti-fungal activities of several plants like Conidinium fruit (*Conidium monnieri*), magnolia bark (*Magnolia officinalis*), aucklandia root (Aucklandialappa) and common rue (Rutagraveolens) [20]. Medicinal plants also seem to be an effective alternative for treating ectoparasites. Several studies have shown antiparasitic activities of medicinal plants when added to water or administered orally [21]. Methanol extract of bupleurum root (*Radix bupleurichinensis*), aqueous and methanol extracts of cinnamon (*Cinnamomum cassia*), methanol extract of Chinese spice bush (*Lindera aggregata*) and methanol and ethyl-acetate extracts of golden larch (*Pseudo larixkaempferi*) had 100% *in-vivo* efficacy against monogenean *Dactylog yrus intermedium* in infected goldfish (*Carassius auratus*) [22]. Harikrishnan *et al.* [15] showed 40% mortality decrease and enhanced immunity in olive flounder (*Paralichthy solivaceus*) infected by the protozoan ciliate *Miami ensisavidus* when fish were fed with a diet supplemented with Suaedamaxima.

Table 1: Some of the medicinal Plants used in aquaculture and fish diseases management

Order	Family	Species	Activities	Part used
Acorales	Acoraceae	*Acorus Calamus*	Antiviral	Root
Alismatales	Araceae	Alocasiamacrorrhizos	Not Applicable	Leaf
Alismatales	Araceae	Colocasia esculenta	Antibacterial	Root

Apiales	Apiaceae	Angelica membranaceus	Immuno-stimulant	Root
Apiales	Apiaceae	Angelica sinensis	Immuno-stimulant	Root
Apiales	Apiaceae	Angelica pubsecens	Antifungal	Root
Apiales	Apiaceae	Bupleurum chinense	Antiparasitic	Whole plant
Arecales	Arecaceae	Area catechu	Antiparasitic	Leaf
Asparagales	Amarylidaceae	Allium sativum	Antibacterial	Whole plant
Asparagales	Amarylidaceae	Allium tuberosum	Antibacterial	Leaf
Asparagales	Xanthorrhoeacea	Aloe vera	Antibacterial	Whole plant
Asterales	Asteraceae	Artemisia annua	Antiparasitic	Leaf
Asterales	Asteraceae	Artemisia capillaries	AntibacterialAnd growth promoter	Whole plant
Asterales	Asteraceae	*Artemisia cina*	Antibacterial and growth promoter	Whole plant
Brassicales	Caricaseae	Carica papaya	Antiparasitic, antibacterial and growth promoter	Leaf, seed, and peel
Caryophyllales	Amaranthaceae	Alterantherus sessilis	Growth Promoter	Leaf, fruits
Caryophyllales	Molluginaceae	Glinus oppositifolius	Antiviral	Fruits
Caryophyllales	Plumbaginaceae	Aegialitis rotundifolia	Antibacterial	Leaf and whole plant
Caryophyllales	Polygonaeceae	Polyonum hydropipper	Antiviral, antifungi	Bark
Cucurbitales	Cucurbitaceae	Mormodica cochinchinensis	Antiparasitic	Leaf
Cyatheales	Cyatheaceae	Cyathea kanchine	Antibacterial, immunostimulant.	Leaf
Dipsacales	Caprifoliaceae	Lonicera japonica	Antibacterial, antiviral, immunostimulant	leaf
Ericales	Styracoceae	Styrax japonica	Antibacterial	Stem

Source: Reverter *et al.* [23]

Advent of Nanotechnology and Application in Fish Nutrition and Diseases Management

Nanotechnology involves the synthesis, characterization, and the use of nano-sized (1-100 nm) materials for the growth of science and technology. It deals with the materials whose structures exhibit novel and improved physical, chemical, and biological features due to their very small size. Now, green nanotechnology involved the use of biological materials to reduce a precursor (the principal reactant, mostly compound from which the nanomaterials are obtained) in order to obtain the nano-size product. The biological material could be medicinal plant extract (from leaves, flower, root, bark and liquid discharge from plant), fungi, bacteria, etc. these acts as biological reducing agents instead of toxic chemical reducing agents.

Among several inorganic nanoparticles, the most commonly used one is silver nanoparticle due to its antimicrobial activities. Some of these nanoparticles that have been found useful in aquaculture for encapsulation, vaccination or targeted delivery of food and feed supplements. This includes chitosan, liposomes, and metal/metal oxide nanoparticles like gold, silver, copper, selenium, zinc oxides, and iron [24].

There are two main approaches used for nanoparticle preparation. The two techniques of nanomaterials preparation are termed “Bottom-up” and “Top-down”. The “Bottom up” technique is the most used and preferred production procedure. It includes: self-assembly, biomass reactions, crystallization, microbial synthesis, solvent extraction/ evaporation, and layer-by-layer deposition. The “Bottom-up” preparation technique helps to produce molecular structures containing more complex designs based on self-organization potential of biological compounds [25]. The “Top-down” production technique of nanoparticles is achieved by breaking down bulky-sized matter into nano-scaled particles of few nanometers in dimension through the chemical or physical procedure. Example of the “top-down” approach is the Homogenization technique which involves the use of pressure to reduce the large-sized fat globules into nano-scale size. Homogenisation is a highly sought-after industrial technique used globally in the dairy industry. Another “top-down” nanoparticle synthesis method includes the use of lasers and vaporization, followed by cooling. In general, the size and shape of the nanoparticles are the properties that largely influence its functional activities [24].

Green Nanotechnology

Green chemistry, also known as green synthesis is an evolving research method among other techniques in nanoparticle synthesis. It is currently gaining acceptance because of its eco-friendly nature. It is a bottom up method, and the reducing agents employ in the synthesis include bacteria, yeast, fungi, algae and plant [26].

Synthesis of Nanoparticles Using Microorganisms

Green synthesis of noble metal NP was initiated using bacteria cells. *Pseudomonas stutzeri* (AG259) and *Proteus mirabilis* (PTCC 1710) were cultured in high concentration of $AgNO_3$ to develop Ag (Silver) and Au (Gold) NPs [27]. Slow synthesis rate and limited number of sizes and shapes of NPs compare with chemical methods of synthesis has limited the use of bacteria mediated green synthesis.

Fungi is another route in green mediated synthesis of metallic nanoparticles. Although there are difficulties in characterizing fungi in terms of their microscopic structures and mechanistic studies for nanoparticles characterization [28], yet fungi mediated biological synthesis has been reported as a better choice in nanoparticle formation compare to bacteria mediated route. Fungi has ability to secret large quantity of extracellular protein which made it a good metal reducing and stabilizing agent of newly formed nanoparticles [29].

The bio-accumulation ability of fungi was engaged by Murali *et al.* [30] in biosynthesis of NPs. The mechanism of bio-fabrication involves the secretion of enzymes (as reducing agents) in a large quantity to reduce metal ions [31]. The NPs were eventually formed on the mycelium surface unlike chemical method where NPs are formed in solution. Moreover, extract from fungi such as mushroom can also be used for the synthesis of NPs which is similar to the approach used in chemical method.

Various green synthesis routes have helped to develop different morphologies of NPs, such as spherical, triangular, and hexagonal shape. Ahmad *et al.* [32] used *Fusarium oxyporium* to develop Fungi mediated NPs as the first person to report this, which has a benefit of non-binding to the biomass over intracellular method. Mourato *et al.* [33] also studied and successfully reported the use of yeast as a green method in NPs synthesis. Algae has also been exploited in nanoparticles production. Marine algae (*Sargassum wightii),* according to Singaravelu *et al.* [34] was used to produce a highly stable NPs. The characteristics of NPs synthesized through algae showed that they are more stable than other green route mediated NPs. Table 2 below shows different micro-organisms, the size, and shape of NPs they produced.

Table 2: Microorganisms-mediated Synthesis of Nanoparticles: sizes and shapes

Types of Microorganism	NPs produced	Sizes (nm)	Shapes
Candida utilis	Au	10-25	Not available
Rhodococcus sp	Au	Not available	Spherical
Pseudomonas aeruginosa	Au 15-30		
Escherichial coli	Ag	50	Not available
Bacillus cereus	Ag	4-5	Spherical
Aspergillus flavus	Ag	8.92±1.61	Spherical
Fusarium oxysporum	Au-Ag alloy	8-14	Spherical
Yeast cells	Fe_3O_4	Not available	Worm hole-like
Saccharomyces cerevusssae	Sb_2O_3	2-10	Spherical
Lactobacillus sp	$BaTiO_3$	8-35	Tetragonal
Multicellular procaryotes	Fe_2S_4	Not available	Not available

Source: Olugbojo [35]

Synthesis of Nanoparticle Using Plants (Plant-mediated synthesis of nanoparticles)

The development of nanoparticles (NPs) and nanostructures (NS) materials through exploration of biodiversity of plants to reduce metal ions has been adjudged as a widespread application in recent years.

Phytochemicals present in plants has been reported as the sources of reducing and capping agents, unlike the chemical synthesis which involve the use of harsh and toxic chemicals which are often absorbed in the NP surfaces and renders chemically synthesize NPs inefficient for medical applications [36].

Moreover, plant biomolecules (polyphenols, protein, carbohydrates, and essential oils) are found to contain active functional group (Aldehyde, Amine, and Carboxyl) which act as sources of reducing and capping potentials of plants for the development of NPs [37]. Moreover, the use of plant in the synthesis of NPs are found to be faster (Nucleation and on-set of growth commenced within few minutes), sustainable, and cheaper than those microbes routed and conventional approach [38]. Hence, many draw backs encountered in other nanofabricated technique are overcame when plant mediated procedure is employed. Table 3 below depicts different plants that have been used to synthesize nanoparticles, showing different particle sizes and shapes, while Table 4 gives examples of green synthesized Nanoparticles and their benefits in fish Health and Nutrition.

Table 3: Plant mediated synthesis of Nanoparticles: sizes and shapes

Plant	Part(s) used	Metal/Alloy	Size and Shape
Azadirachta indica	leaves	Ag+	20 nearly spherical shape
Cinnammum camphora	leaves	Ag+, Au3+	55-80 Triangular or spherical
Cinnamon zeylanicum	bark	Ag+	31 and 40 Quasi-spherical and small, rod-shaped
Aloe vera	Leaves	Au3+	Spherical
Aloe vera	Pulp	Ag+	25 spherical
Aloe vera	Leaves	In_2O_3	5-50 nm

Ipomoea aquatica, Enhydra fluctuans Ludwigia adscendens	Leaves		100 – 400 spherical and cubic
Azadirachta indica	Leaves	Ag core–Au shell	Polydisperse, flat, plate-like, spherical, peculiar core shell structure
Carica papaya	Leave	Ag+	20-69 nm
Brassica juncea	Leaves	Ag+, Au3+, Cu2+	5–35 50–100
Medicago sativa	Leaves	Au3+	4–10 twinned, crystal

Source: Olugbojo [35]

Table 4: Green synthesized Nanoparticles and their benefits in fish Health and Nutrition

Nanoparticles	Green sources	Particle Sizes	Function/Purpose
Chitosan	crustaceans and insects	76.2 nanometer	Antibacterial, DNA Nano vaccine against *Vibrio (Listonella) anguillarum* and as Nutraceutical in *O. niloticus* for survival and growth
AgNPs	*Cassia fistula* leaves.	24.94 nanometer	Antibacterial
Selenium	Bacteria and Fungi	30 nanometer	Feed supplement and antibacterial
Gold NPs	Plant source	25 nanometer	Gene delivery,Increased catalase activity in gill, lipid peroxidation (LPO) level in liver and lactate dehyrogenase (LDH) in tissues of *Oreochromis niloticus*
FeNPs	Ascorbic acid(from plant/fruit Juice)	50 nanometer	Feed supplement, Increased RBC count, Haemoglobin and iron content in muscle tissue of *Labeo rohita* Increased absorption and bioavailabity of iron
CeO_2NPs and ZnONPs	*Carica papaya* leaves	46.34 and 43.77 nanometer	Antibacterial

Source: [9] [24] [38]

Application in Aquatic pollution Prevention

Water is very essential in aquaculture. The success or failure of aquaculture practice largely depend on water quality. The most significant hazard to aquaculture globally have to do with water quality, and where there is high contamination of water whether due to chemical, microbial or otherwise, the fish and consumer's health are both at risk. Unfortunately, indiscriminate disposal of effluents from industries, hospital, agricultural farmlands and domestic sewage in addition to the faeces discharged by the fish into the aquatic environment continues to grow exponentially leading to heavy contamination of the water body and render fish in several rivers and streams unsuitable for human consumption [24]

Currently, NPs is gaining popularity due to their applications in removing aquatic pollutants (microbes, organics, inorganic chemicals, halogenated compounds like pesticides and heavy metals) from water bodies [39]. The major features of nanoparticles that make them very useful are sizes, high stability and ease of preparation. The most studied group of nanomaterials which have been used in aquaculture water quality management especially when synthesized using biological method includes: Zinc oxide (ZnO) NPs, Iron oxide (Fe_3O_4) NPs, Tin oxide (TiO_2) NPs, Silver (Ag) NPs, and carbon nanotubes (CNTs) [40].

Also, their performance has been reported to significantly improve water quality. In a situation when used along with biopolymer as composites such as algae, taking advantage of their inherent surface hydrology and photosynthetic potential, the water quality and availability has tremendously improved [41]. When several of these nanomaterials were synthesize biologically, they exhibit excellent performance with little or no toxicity compare to chemical and physical methods.

Iron oxide (Fe_3O_4) NPs have been used because of their extremely small sizes, high surface area to volume ratio, excellent magnetic properties and biocompatibility as reported by Hesni *et al.* [42] which has made it highly effective in removing heavy metal ions from aquatic water effluents. It was reported that the maximum absorption capacity for Pb ions by Fe_3O_4 NPs was 360 mg/g. which is higher than previously reported values for cheaper adsorbents [43]

According to Sathe, *et al.* [44], sea weeds was used to synthesized ZnONPs. He reported that biosynthesized ZnO nanocoated layer reduced the abundance of the microorganisms by three-fold compared to an uncoated layer (control) with a higher antifouling performance than the copper based coatings. Also, the *in-vitro* and *in-vivo* effect of copper-based nanoparticles (Cu NP-s) against *Vibrio alginolyticus, Vibrio parahaemolyticus* and *Aeromonas hydrophila* as reported by Chari *et al.* [45], showed that *Vibrio spp* and *Aeromonas spp* which has earlier caused high mortality in shrimp and prawn were effectively inhibited at a very little concentration (>90% inhibition) and a very significant reduction of the cell surface hydrophobicity and extracellular polysaccharide production, which are two major factors influencing biofilm formation by the aquatic pathogens [46]. The biosynthesized nanoparticles were also proven to be non-toxic through the in-vivo study where the mortality of *Artemia salina* was reduced significantly. It was also reported that a solution of AgNPs exhibited antibacterial activity to *Aeromonas hydrophyla* and *Aeromonas caviae* isolated from inland aquaculture and *Vibrio harveyi* and *Vibrio alginoliticus* from white shrimps' ponds [47]. A concentration of 25 ppm of the nanoparticle solution inhibited *A. carviae* and *A. hydrophila* at a peak time of 24 h after exposure to the bacteria while a concentration of 12.5 ppm inhibited *V. harveyi* and *V. alginoliticus* at a peak time of 48 h after the bacteria exposure

In another study which was aimed at investigating the efficiency of green synthesized iron oxide NPs to remove contaminants from fish farm effluents (in a laboratory system), it was reported that nitrate, nitrite, phosphate, ammonium, TDS, TSS and BOD levels were reduced apart from BOD where it increased to meet the required standard value [48]. Hydrogen ion concentration (pH) and Electrical Conductivity (EC) values were also improved upon to make it suitable for aquatic biota from 6.36 and 1362 µm ho cm^{-1} to 7.22 and 1466 µS cm^{-1} respectively after treatment in the reactor. It was concluded that iron oxide nanoparticles in a reactor system within the 6h and 18 h have great efficacy to reduce the discharge burden of the waste waters from inland aquacultures.

Application in Aquaculture nutrition (fish nutrition)

The purpose of fortification of fish feeds with nutrients or non-nutrient biologically active components is to improve the total nutrient profile balance of a diet and replace lost nutrients in the course of processing. This ensures enough nutrient intake by cultured fish [49]. It was observed that nanoparticles easily diffuse when compared with their bulky counterparts [50]. Nps also behave like gas molecules in the air, and like large molecules in solutions. Several authors have used green synthesized NPs of different formulations in fish feed with notable results. Dietary nanoparticles in fish provide increased availability of surface area for biological support and improve interactions especially when it is biosynthesized using plant materials (leaf, root, bark, flower etc.)

One of the most important micronutrients is iron (Fe) because of its effects in building immune activities against infectious diseases. Iron is obtained from water by fish through the gill membrane. Another source of iron to fish is through their diet and iron status parameter as a traditional indicator in fish is the serum iron due to its entering and leaving the bloodstream of fish [24]. Behara *et al.* [51] reported the increase in iron content in the muscle tissues and serum of experimental fish fed green synthesized nano-Fe-based diet compared to the fish control diet. It was further reported that there was an increase in the concentration of haemoglobin and red blood cells in experimental fish fed with green synthesized Fe-Nps-based diet. Moreover, fish-fed with green FeNPs-based diet also revealed an increase in serum bactericidal and respiratory activities. Therefore, the supplementation of green synthesized FeNPs in fish feed has improved the bio availability and absorption of iron in fish with little or no hazard or toxicity.

Dietary selenium is vital nutrients for metabolism and effective body functions. Selenium helps to catalyse activities of various enzymes that are involved in the immune system and hormonal secretion. In a feeding trial, juvenile of Tor putitora was fed green synthesized dietary SeNP (Selenium Nanoparticles), it showed a marked increase in red blood cell count, haematocrite percentage (Hct %), and Haemoglobin, while improved protein content and lysozyme activity were observed in the liver and muscle tissues. In addition, GSH-Px activity was improved, as well as an increase in serum growth hormone concentration.

According to El Basuini *et al.* [52], supplementation of green synthesized CuNP in the diet of red sea bream (Pagrus major) improved growth parameters, immune responses, and health quality of the experimental fish. Wang *et al.* [53] in a feeding trial of dietary CuNPs and CuSO4 on Russian sturgeon for 56 days, observed an increase in bioavailability of Cu in experimental fish fed dietary CuNP compared to those fed with $CuSO_4$ based diet.

The supplementation of green synthesized Nanoparticles such as FeNPs, SeNPs and CuNps in fish feed has improved the bioavailability, absorption, growth and entire well fare of fish with little or no hazard due to toxicity.

Application in fish diseases management

The applications of nanotechnology in aquaculture is a promising venture and have been found to be more effective than the use of chemicals treatments and drugs, in water quality improvement, aquatic animal nutrition, drug delivery, disease diagnosis and management. However, much are yet to be done because there are very few works on green chemistry approach in nanomaterials synthesis which is the most suitable and biocompatible method for application in aquaculture. Moreover, several reports are available on high potency of nanoparticles (such as silver nanoparticle-AgNPs) against fish pathogens, such as: *Bacillus subtilis*, *Vibrio cholerae* and *Escherichia coli, Aeromonas hydrophila, other Vibrio spp, Mycobactreria spp, Edwarsiella spp, Yesinia spp, Flavobacteria spp, Streptococcus spp, Aerococcus spp, etc.* It was reported that the large surface area to volume ratio of nanoparticles provides a better contact with microorganisms. For instance, biogenic synthesis of Ag-NP using tea leaf extract (*Camellia sinensis*) at higher dose showed bactericidal activity against *Vibrio harveyi* in juvenile *Feneropenaeus indicus* [54]. Likewise, when used leaves of *Mangifera indica* (mango), *Eucalytus terticonis*, *Carica Papaya* and *Musa paradisiacal* (banana) to synthesize silver nanoparticles, and tested against *Aeromonas hydrophila*. *Carica papaya* (papaya) was found to exhibit higher antimicrobial activity with 153.6 μg mL^{-1} concentration [55]. In 2015, research on biosynthesized CuO NPs shows enhanced antibacterial activity against some selected fish pathogens even at lower concentrations, (i.e. above 20 mu g/mL) which was tested against *Aeromonas hydrophila, Pseudomonas fluorescens* and *Flavobacterium branchiophilum* [56]. Also, Rather *et al.* [57] used *Azadirachta indica* to synthesize silver nanoparticle and was used to determine the immune modular effect in infected mirgal with *Aeromonas hydrophila,* the result revealed an excellent effect against *A. hydrophila*. Further works on antimicrobial activity of *Leucas aspera*-engineered silver nanoparticles against *A. hydrophila* infections were done in *Catla catla*. The result of the biochemical parameters and histological analysis after in-vivo studies provided evidence of antibacterial effect of silver nanoparticles in *Catla catla* [58]. Moreover, broth of *Aloe vera* leaf extract was used for green synthesis of Zinc Oxide Nanoparticles (ZnO-NPs), it showed higher bactericidal activity against *A. hydrophilla* [59]. Also, leaf bud extract from mangrove *Rhizophora mucronata* was used to synthesis Ag-NPs, the result shows an excellent antibacterial efficacy against *Pseudomonas fluorescens*, *Proteus* sp and *Flavobacterium* sp [60].

Engaging the green approach in the NPs synthesis to treat fish diseases and parasites can be a perfect approach in therapeutic applications in aquaculture industry if serious effort is taken to conduct more researches in his area.

Conclusion

In conclusion, green chemistry technology has become an enviable approach almost in all field of Science and Technology where chemical synthesis and applications are involved, owning to its eco-friendliness, sustainability and reliability. If employed the principles of green technology in aquaculture as discussed in this article, it is certain that there will be a tremendous improvement in aquaculture production, disease management, fish nutrition, water quality management and pollution control. Also, it should be noted that stakeholders must be current with the on-going development because technology kept on improving. Currently, green nanotechnology seems to be a leading technology in aquaculture development with so many outstanding results, coupled with its eco-friendliness, high biocompatibility, effectiveness and non-toxicity.

References

1. Anastas N (2012) Green Toxicology, in: Green Techniques for Organic Synthesis and Medicinal Chemistry, W. Zhang and B. Cue, eds., J Wiley.

2. Anastas ND, JC Warner (2005) Incorporating Hazard Reduction as a Design Criterion in Green Chemistry, Chem. Health. Safety, 3-15.

3. Igwegbe CA, Ighalo JO, Onukwuli OD, Obiora-Okafo IA, Anastopoulos I (2021) Coagulation-flocculation of aquaculture wastewater using green coagulant from garcinia kola seeds: Parametric studies, kinetic modelling and cost analysis. Sustainability. 13: 9177.

4. FAO (2018) The State of the world Fisheries and Aquaculture 2018 – Meeting the sustainable development goals. Rome, 227.

5. Ighalo JO, Sagboye PA, Umenweke G, Ajala OJ, Omoarukhe FO et al. (2021) CuO Nanoparticles (CuO NPs) for Water, Treatment: A Review of Recent Advances. Environ. Nanotechnol., Monit. Manage, 15: 100443.

6. Cann MC, Connelly ME (2000) Economy: A Measure of the Efficiency of a Reaction. Real-World Cases in Green Chemistry; ACS, Washington.

7. Hardy RW, Kaushik SJ (2021) Fish nutrition. Academic press, 883-905.

8. Anastas P, Eghbali N (2010) Green Chemistry: Principles and Practice, Chem. Soc. Rev, 39: 301-12.

9. Olugbojo JA, Akinyemi AA, Obasa SO, Dare EO (2024a) Comparative Studies on Antibacterial Potentials of Biosynthesized Cerium Oxide and Zinc Oxide Nanoparticles against Fish Pathogens. Egyptian Journal of Aquatic Biology & Fisheries, 28: 1733-54.

10. Olugbojo JA, Akinyemi AA, Obasa SO, Dare EO (2024b) Extraction and Utilization of Chitin and Chitosan from Waste Yields of Economically Important Crustaceans and Molluscs for Improved Fish Production. Asian Journal of Fisheries and Aquatic Research, 26: 95-114.

11. Reverter M, Tapissier-Bontemps N, Sasal P, Saulnier D (2017) Use of Medicinal Plants in Aquaculture: In Diagnosis and Control of Diseases of Fish and Shellfish, 223-61.

12. Punitha SMJ, Babu MM, Sivarar V, Shankar VS, Dhas SA et al. (2008) Immunostimulating influence of herbal biomedicines on non-specific immunity in Grouper Epinephelus lauvina juvenile against Vibrio harveyi infection. Aquaculture Int, 16: 511-23.

13. Talpur AD, Ikhwanuddin M (2013) Azadirachta indica (neem) leaf dietary effects on the immunity response and disease resistance of Asian seabass, Lates calcarifer challenged with Vibrio harveyi. Fish Shellfish Immunol, 34: 254-64.

14. Yousefi M, Farsani MN, Ghafarifarsani H, Hoseinifar SH, Doan HV (2021) The effects of dietary supplementation of mistletoe (Viscum album) extract on the growth performance, antioxidant, and innate, immune responses of rainbow trout (Oncorhynchus mykiss). Aquaculture, 536: 736385.

15. Harikrishnan R, Balasundaram C, Heo MS (2011) Impact of plant products on innate and adaptive immune system of cultured finfish and shellfish. Aquaculture, 317: 1–15.

16. Ji H, Zhang J, Huang J, Cheng X, Liu C (2013) Effect of replacement of dietary fish meal with silkworm pupae meal on growth performance, body composition, intestinal protease activity and health status in juvenile Jian carp (Cyprinus carpio var. Jian). Aquaculture research.

17. Roomiani L, Soltani M, Akhondzadeh Basti A, Mahmoodi A, Taheri Mirghaed A, Yadolahi F (2013) Evaluation of the chemical composition and in vitro antimicrobial activity of Rosmarinus officinalis, Zataria multiflora, Anethum graveolens and Eucalyptus globulus against Streptococcus iniae; the cause of zoonotic disease in farmed fish. Iranian Journal of Fish Science, 12: 702–16.

18. Sharma JG, Kumar N, Mittal P, Chakrabarti R (2022) Evaluation of UV-B protective properties of leaves and seeds of Achyranthes aspera in Asian catfish Clarias batrachus (Linn.). Photochemical & Photobiological Sciences, 21: 1341-56.

19. Balasubramanian G, Sarathi M, Venkatesan C,Thomas J, Sahul Hameed AS (2008a) Oral administration of antiviral plant extract of Cynodon dactylon on a large scale production against White spot syndrome virus (WSSV) in Penaeus monodon. Aquaculture, 279: 2-5.

20. Xu, P., Zeng, G.M., Huang, D.L., Feng, C.L., Hu, S., Zhao, M.H., Lai, C., Wei, Z., Huang, C., Xie, G.X., Liu, Z.F. (2012). Use of iron oxide nanomaterials in wastewater treatment: a review. Sci. Total Environ. 424, 1–10.

21. Fu Y, Zhang Q, Xu DH, Xia H, Cai X, Wang B, Liang J (2014) Parasiticidal effects of Morus alba root bark extracts against Ichthyophthirius multifiliis infecting grass carp. Dis Aquat Organ, 108: 129-36.

22. Ji J, Lu C, Kang Y, Wang GX, Chen P (2012) Screening of 42 medicinal plants for in vivo anthelmintic activity against Dactylogyrus intermedius (Monogenea) in goldfish (Carassius auratus). Parasitol Res, 111: 97-104.

23. Reverter M, Tapissier-Bontemps N, Sasal P, Saulnier D (2017) Use of Medicinal Plants in Aquaculture: In Diagnosis and Control of Diseases of Fish and Shellfish, 223-61.

24. Omosanya TA, Yekeen TA, Fawole OO, Azeez MA, Lateef A, Ajala OO (2021) Applications and Benefits of Dietary Nanoparticles in Aquaculture: A Review. Stnanomat Journal, 2: 13.

25. Lanje AS, Shama SJ, Pode RB, Ningthoujam RS (2010) Synthesis and optical characterization of copper oxide nanoparticles. Advance Applied Science Resources, 2: 36-40.

26. Rauwel P, Küünal S, Ferdov F, Rauwel E (2015) A Review on the green synthesis of silver nanoparticles and their morphologies studied via TEM. Advances in Materials Science and Engineering, 682749: 9.

27. Welz PJ, Khan N, Prins A (2018) The effect of biogenic and chemically manufactured silver nanoparticles on the benthic bacterial communities in river sediments Science of The Total Environment, 644: 1380-90.

28. Xu B, Jahic M, Blomsten G, Enfors SO (1999) Glucose overflow metabolism and mixed-acid fermentation in aerobic large-scale fed-batch processes with Escherichia coli. Applied Microbiology and Biotechnology, 51: 564-71.

29. Kitching M, Ramani M, Marsili E (2014) Fungal biosynthesis of gold nanoparticles: mechanism and scale up. Mini Review Microbial Biotechnology, 904-17.

30. Murali S, Absar A, Khan IM, Rajiv K (2003) Biosynthesis of metal nanoparticles using fungi and actinomycetes. Current Science, 85: 62-170.

31. Mandal D, Bolander ME, Mukhopadhyay D, Sarkar G, Mukherjee P (2006) The use of microorganisms for the formation of metal nanoparticles and their application. Applied Microbiology and Biotechnology, 69: 485-92.

32. Ahmad N, Sharma S, Singh VN, Shamsi SF, Fatma A (2011) Biosynthesis of silver nanoparticles from Desmodium triflorum: A novel approach towards weed utilization. Biotechnology Research International, 1: 1-8.

33. Mourato A, Gadanho M, Lino AR, Tenreiro R (2011) Biosynthesis of crystalline silver and gold nanoparticles by extremophilic yeasts. Bioinorganic Chemistry and Applications, 546074: 8.

34. Singaravelu G, Arockiamary JS, Kumar VG, Govindaraju K (2007) A novel extracellular synthesis of monodisperse gold nanoparticles using marine alga, Sargassum wightii Greville. Colloids and Surfaces B: Biointerfaces, 57: 97-101.

35. Olugbojo JA (2023) In-vitro utilization of nanoparticles as antibacterial agents against bacteria pathogens isolated from catfish Clarias gariepinus (Burchell, 1822). Ph.D Thesis.

36. Parashar UK, Srivastava SP (2009) Bioinspired synthesis of silver nanoparticles. Digest Journal of Nanomaterials and Biostructures, 4: 159-66.

37. Harekrishna B, Dipak KB, Gobinda PS, Priyanka S, Santanu P, Ajay M (2009) Green synthesis of silver nanoparticles using seed extract of Jatropha curcas. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 348: 212-6.

38. Olugbojo JA, Akinyemi AA, Obasa SO, Dare EO (2025) Comparative studies on antibacterial activities of Chitosan, Silver Nanoparticles and Maggot-based Chitosan silver nanocomposites against fish pathogens. Jordan Journal of Biological Sciences, 18: 19-31.

39. Iwuozor KO, Oyekunle IP, Oladunjoye IO, Ibitogbe EM, Olorunfemi TS (2021) A Review on the Mitigation of Heavy Metals from Aqueous Solution using Sugarcane Bagasse. Sugar Tech.

40. Ighalo JO, Adeniyi AG (2020) A comprehensive review of water quality monitoring and assessment in Nigeria. Chemosphere, 260: 127569.

41. Nasr-Eldahan S, Nabil-Adam A, Shreadah MA, Maher AM, El-Sayed Ali T (2021) A review article on nanotechnology in aquaculture sustainability as a novel tool in fish disease control. Aquacult. Int, 29: 1459-80.

42. Hesni MA, Hedayati A, Qadermarzi A, Pouladi M, Zangiabadi S, Naqshbandi N (2020) Using Chlorella vulgaris and iron oxide nanoparticles in a designed bioreactor for aquaculture effluents purification. Aquacult. Eng, 90: 102069.

43. Xu A, Shang-Guan J, Chen Q (2020) Effects of dietary Chinese herbal medicines mixture on feeding attraction activity, growth performance, nonspecific immunity and digestive enzyme activity of Japanese seabass (Lateolabrax japonicus). Aquaculture Reports, 17: 100304.

44. Sathe P, Laxman K, Myint MTZ, Dobretsov S, Richter J, Dutta J (2017) Bioinspired nanocoatings for biofouling prevention by photocatalytic redox reactions. Sci. Rep, 7: 1–12.

45. Chari N, Felix L, Davoodbasha M, Sulaiman Ali A, Nooruddin T (2017) In vitro and in vivo antibiofilm effect of copper nanoparticles against aquaculture pathogens. Biocataly. Agric. Biotechnol. 10: 336-41.

46. Ogunfowora L.A, Iwuozor K.O, Ighalo, J.O and Igwegbe, C.A (2021): Trends in the treatment of aquaculture effluents using nanotechnology. Cleaner Materials.

47. Van Khanh N, Van Cu P (2019) Antibacterial activity of silver nanoparticles against Aeromonas spp. and Vibrio spp. isolated from aquaculture water environment in Thua Thien Hue. Hue University J. Sci.: Agric. Rural Dev, 128: 51-65.

48. Askari-Hesni M, Hedayati S, Qadermarzi A, Pouladi M, Zangi Abadi Z et al. (2020) Application of iron oxide nanoparticles in the reactor for treatment of effluent from fish farms. Iranian J. Fisheries Sci, 19: 1319-28.

49. Dwyer JT, Wiemer KL, Dary O, Keen CL, King JC, Miller KB et al. (2015) Fortification and health: Challenges and opportunities. Advance Nutri-tion, 6: 124–131.

50. Singh PK (2016) Use of Nano Feed Additives in Livestock Feeding. International Journal of Livestock Research.

51. Behera T, Swain P, Rangacharulu PV, Saman-ta M (2013) Nano-Fe as feed additive improves the hematological and immunological parameters of fish, Labeo rohita H. Applied Nanosciences, 4: 687–94.

52. El Basuini MF, El-Hais AM, Dawood MAO, Abou-Zeid AES, EL-Damrawy SZ et al. (2017) Effects of dietary copper nanoparticles and vitamin C supplementations on growth performance, immune response and stress resistance of red sea bream, Pagrus major. Aquaculture Nutri-tion, 23: 29-1340.

53. Wang H, Zhu HY, Wang XD, Li EC, Du ZY, Qin JG et al. (2018) Comparison of copper bioavailability in copper-methionine, nano-copper oxide and copper sulfate additives in the diet of Russian sturgeon Acipenserguel denstaedtii. Aquaculture, 482: 146-54.

54. Vaseeharan B, Ramasamy P, Chen JC (2010) Antibacterial activity of silver nanoparticles (AgNPs) synthesized by tea leaf extracts against pathogenic Vibrio harveyi and its protective efficacy on juvenile Feneropenaeus indicus. Letters in Applied Microbiology, 50: 352-6.

55. Kurcheti PP, Dhayanath J, Mary AJ, Jeena, Hina Alim (2020) Biosynthesis of Nanoparticles - A New Horizon in Fish Biomedicine. HSOA Journal of Aquaculture & Fisheries, J Aquac Fisheries, 4: 035.

56. Kumar VK, Shameem U, Kollu P, Kalyani RL, Pammi SVN (2015) Biosynthesis of CUO Nps and their antibacterial activities against Aeromonas hydrophila, Pseudomonas fluorescens and Flavobacterium branchiophilum BioNanoScience.

57. Rather MA, Bhat IA, Sharma N, Gora A, Ganie PA, Sharma R (2016) Synthesis and characterization of Azadirachta indica constructed silver nanoparticles and their immunomodulatory activity in fish. Aquaculture Research, 1-13.

58. Antony JJ, Nivedheetha M, Siva D, Pradeepha G, Kokilavani P et al. (2014) Antimicrobial activity of Leucas aspera engineered silver nanoparticles against Aeromonas hydrophila in infected Catla catla. Colloids Surf B Biointerfaces, 118: 306.

59. Sangeetha G, Rajeshwari S, Venckatesh R (2011) Green synthesis of zinc oxide nanoparticles by aloe barbadensis miller leaf extract: Structure and optical properties. Materials Research Bulletin, 46: 2560-6.

60. Umashankari J, Inbakandan D, Thipramalai T, Ajithkumar T, Thangavel, Balasubramanian T (2012) Mangrove plant, Rhizophora mucronata (Lamk, 1804) mediated one pot green synthesis of silver nanoparticles and its antibacterial activity against aquatic pathogens. Aquatic Biosystem, 8: 11.