14 Nanobiotechnology: Prospects and Applications in Aquaculture

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Abstract

Application of nanotechnology in biological fields is known as Nanobiotechnology**.** Nanotechnology is fast emerging and most promising technology applied in all areas of science including aquaculture. Nanoparticles are those particles which have the dimension or size in the range of 1–100 nm. Different types of organic and inorganic nanoparticles have been developed for different purposes in fisheries and aquaculture research. Several methods have been used for the synthesis of nanoparticles, but the green synthesis of nanoparticles has emerged as an alternative to overcome the toxic effect of chemically synthesized nanoparticles. Nanoparticles have been used in many applications in the field of aquaculture medicine, including drug and gene delivery vaccination and diagnostics. Polymeric nanoparticles like chitosan, poly lactic-*co*-glycolic acid (PLGA) have been used for drug delivery because of their several key characteristics, like biocompatibility biodegradability, a stability of the drug, specificity of delivery etc. Use of nano-vaccines against many bacterial and viral pathogens has gained much interest in the last few years

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in aquaculture. Recently nanoparticles have been used specific and sensitive tool for diagnosis of various bacterial, fungal and viral diseases in aquaculture.

Keywords

Nanobiotechnology · Nanoparticles · Nanodelivery · Aquaculture

14.1 Introduction

Among all food producing sectors, aquaculture comes to be the fastest growing food production sector with a rate of 8.8% annually (FAO 2012). But the single unsolved question mark for aquaculture and its sustainability is—"*disease prevalence and the poor health of system.*" In spite of the several strategies adopted on the national and international level, as improved laboratory facilities, diagnostic expertise and control and therapeutic strategies in order to handle disease outbreaks more effectively. The aquaculture industry is under uncertainty and the progress has not matched that of the rapidly developing aquaculture sector. The sector demand more technical innovation for the drug use, disease treatment, water quality management, production of tailored fish for suiting better health, productivity drive by epigenetic and nutrigenomic interaction, better breeding success by efficient delivery of maturation and spawning inducing agent, nutraceutical delivery for rapid growth promotion and culture time reduction, successful use of auto-transgenic and effective vaccines. For these multiple purposes the effort and importance of the nanotechnology and nanodelivery of drugs, vaccines, nutraceuticals, inducing hormones and growth-promoting anabolic bears the promise (Rather et al. 2011).

Nanotechnology has been defined by the US National Nanotechnology Initiative (NNI) as "understanding and control of matter at dimensions of roughly 1–100 nm where unique phenomena enable novel applications." More elaborately, it may be defined as "the study, design, creation, synthesis, manipulation and application of functional materials, devices, and systems through control of matter at the nanometer scale (1–100 nm, 1 nm being equal to 1×10^{-9} of a meter), that is at the atomic and molecular levels, and the exploitation of novel phenomena and properties of matter at that scale." Several applications of nanotechnology for aquaculture production are being developed. With a strong history of adopting new technologies, the highly integrated fish farming industry may be among the best to incorporate and commercialize nanotech products.

14.2 Types of Nanomaterials

As nanomaterials are small, they have a much greater surface area to volume ratio than the conventional forms. They can be produced in one dimension (surface film), two dimension (strand or fibers), or three dimension (particles) and in different irregular and regular shape such as sphere, rod tubes wires, etc. Because of their

Table 14.1 Classification of nanomaterials

Nature of material	Examples	Applications
Organic materials	Chitosan, alginates, gelatin	Drug and gene delivery
	Starch, liposomes, dextran	
Inorganic or metal based	Quantum dots, nanogold, nanosilver, metal oxides, etc.	Imaging, diagnostic
Carbon based	Fullerenes, dendrimers, nanotube	Drug and gene delivery
Polymeric carrier	Poly lactic-*co*-glycolic acid (PLGA), poly-alkylcyanoacrylates, polyethyleneamine	Drug, vaccine and gene delivery

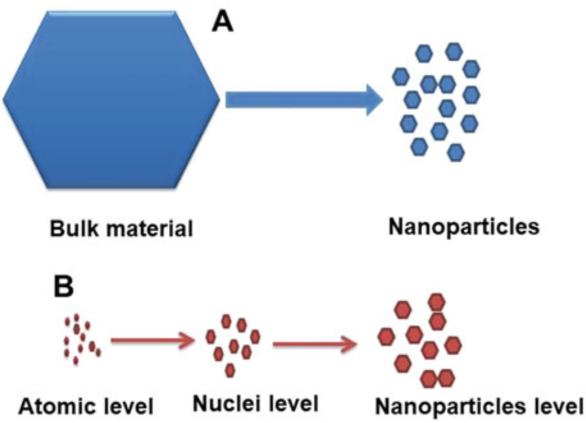

Fig. 14.1 (**a**) Top-down method. (**b**) Bottom-down method

unique electrical, catalytic, magnetic and thermal features, these materials have received much attention among researcher in many fields of biological science including fisheries and aquaculture. Nanomaterials can be broadly classified based on nature or material used for their manufacture as given below Table 14.1.

14.3 Synthesis of Nanoparticles

Generally, there are two main methods for nanoparticle synthesis top-down and bottom-up. The top-down method involves mechanical breakdown, lithography techniques or grinding process of bulk metal to transform it from macroscale to nanoscale, which is followed by addition of stabilizing agents to confirm that the nanoparticles do not oxidize or congregate back to the microscale (Gaffet et al. 1996) (Fig. 14.1). On the other hand, bottom-up approaches include assembly of nanoparticles by various physical and chemical methods, including electrochemical reduction of metals, chemical vapor method or solution evaporation method or atoms self-assemble to new nuclei which grow into a particle of nanoscale (Fig. 14.2).

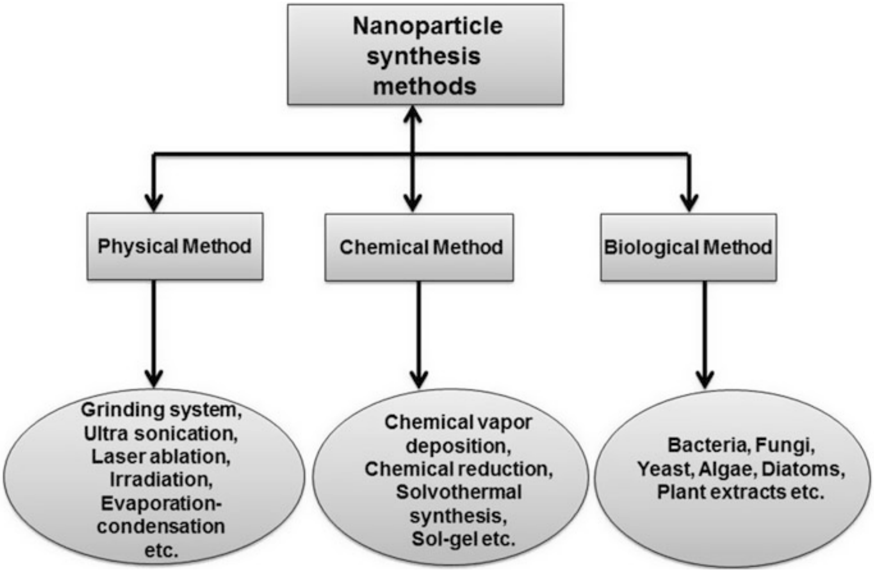

Fig. 14.2 Different methods for synthesis of nanoparticles

14.4 Biological or Green Synthesis of Nanoparticles

Biological synthesis of nanoparticles by using different biological agents has appeared as an alternative to overcome the toxic effect of chemically synthesized nanoparticles. In recent years, green synthesis and biological methods of metal nanoparticle formation has become a major area of interest for research across the globe. Biological synthesis of nanoparticles is a bottom-up approach that mostly involves reduction or oxidation reactions. Biologically synthesized nanoparticles are deduced from three main groups of organisms by:

1. Use of microorganisms like bacteria, algae (*Chlorophyceae, Phaeophyceae, Cyanophyceae, Rhodophyceae*), fungi, actinomycetes (prokaryotes), yeast, etc.
2. Use of plant extracts or microbial enzymes.
3. Use of templates like DNA, membranes, viruses, and diatoms.

The use of biological agents such as leaf extracts, bacteria, fungi and yeast for the synthesis of metallic nanoparticles is safe for biological applications with zero chemical toxicity (Antony et al. 2013; Mathur et al. 2014). The three main elements of a biosynthetic nanoparticle system are a solvent medium for synthesis, a reducing agent, and a nontoxic stabilizing agent. A flow diagram or procedure of synthesis of silver nanoparticles from neem plant is given in Fig. 14.3.

The leaf extracts acts both as reducing agent as well as a capping agent. Silver nitrate ions in aqueous form were reduced by neem leaf extract. The change in color

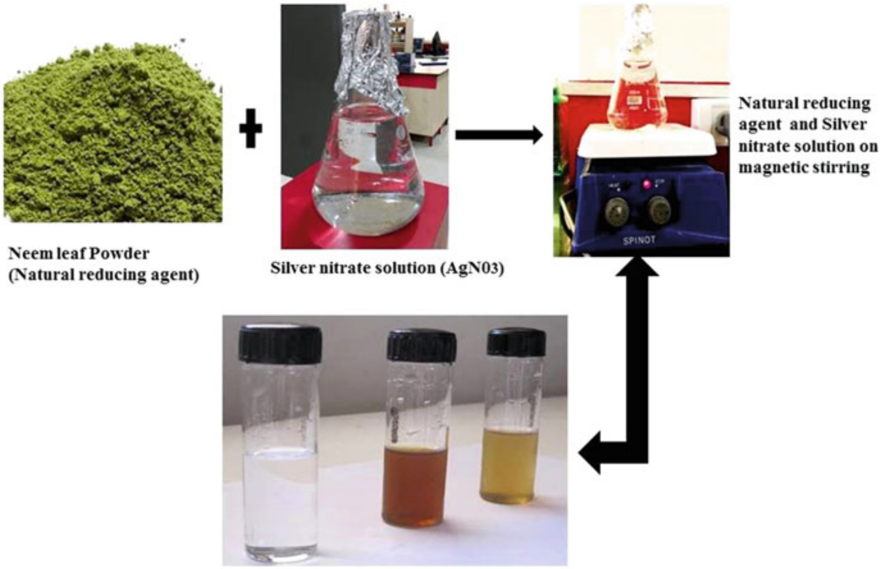

Fig. 14.3 Green syntheses of silver nanoparticles at different time interval

of the reaction mixture from reddish yellow to brown indicated the formation of silver nanoparticles. Biosynthesis of metal nanoparticles is a kind of bottom-up approach for nanoparticle formation, where the central reactions like reduction/ oxidation take place. Generally, two possible ways of the conversion of silver nitrate to silver nanoparticles by biological methods are found. The first reason may be the secondary metabolites (phenolic acid, terpenoids) existing in neem extract is believed to help in conversion of silver nitrate to the silver nanoparticles. The energy released during glycolysis process might be the second reason (Vignesh et al. 2013). Synthesis of metallic nanoparticles like silver, gold etc., using various plants and their extracts can be advantageous over other biological synthesis processes which involve the very complex events of maintaining microbial cultures.

Various algae such as *Spirulina platensis, Lyngbya majuscula,* and *Chlorella vulgaris* were used for the synthesis of metallic nanoparticles like silver, gold nanoparticles (Chakraborty et al. 2009; Niu and Volesky 2000). Among the biological resources, algae are called as bionano factories because both the live and dead dried biomasses were applied for the synthesis of metallic nanoparticles (Davis et al. 1998). Using *Ulva fasciata* extract as a reducing agent, synthesis of silver nanoparticles inhibited the growth of *Xanthomonas campestris pv. malvacearum* (Rajesh et al. 2012). Diatoms like *Navicula atomus* and *Diadesmis gallica* have been used to synthesize gold nanoparticles, and silica–gold bionanocomposites (Schröfel et al. 2011). Comparing with other biological material such as bacteria, fungi, and yeast, algae is correspondingly an essential organism in the synthesis of different nanoparticles. Hence, the studies of algae-mediated biosynthesis of nanometals have come under new branch of nanotechnology and it has been termed as phyconanotechnology (Sharma et al. 2016).

Nanobiotechnology is the unique combination of biotechnology and nanotechnology by which classical micro-technology can be merged to a molecular biological approach in real. Nanobiotechnology is the combination of small engineering and molecular biology that is leading to a new class of multifunctional devices and systems for biological and chemical analysis with better sensitivity, specificity and a higher rate of recognition. Nanobiotechnology is relatively new and although the full scope of contributions to these technological advances in the field of aquaculture remains unexplored, recent advances suggest that nanobiotechnology will have a profound impact on disease prevention, diagnosis, drug delivery, gene delivery, vaccine formation and delivery and so on. Some of the applications of nanobiotechnology in aquaculture are given in detail.

14.5 Nanodelivery of Drugs in Aquaculture

Aquaculture drugs are mostly administered through major three delivery routes as bath or immersion, second through in-feed or oral, and the third by injection. While the first mode of immersion or bath is more applicable, but it requires the drug in more amounts and the handling to fish cause unavoidable stress. So the most ease method come to be through in-feed formulation where the drugs are applied with normal feeding without stress and extra cost. And lastly, the injection seems to be impractical for fishes. The oral administration of drugs essentially needs the study of toxic kinetics, pharmacokinetics and pharmacodynamics of drugs in species and stage-specific manner before in-feed administration. In the in-feed delivery of drugs especially for the peptides, vaccine, and the DNA or RNA components the major problem is the gastric digestion or denaturation before reaching to the intestine for absorption (Florence et al. 1995). So the in-feed formulation and delivery of drugs through feed needs an immediate intervention of an innovative step. Here the nano-encapsulated or nano-coated drug delivery give a solution where the drugs, vaccines, adjuvant, enzymes, etc. as protected and passed to the intestine and made to stay for longer time in the intestine for better absorption and assimilation. One of the most promising and productive areas of nanotechnology application to animal research is the nano-pharmaceuticals (Tomlinson and Rolland 1996). One of the major classes of drug delivery systems is materials that encapsulate drugs to protect them during transit through the body. When encapsulation materials are produced from nanoparticles in the 1 to 100-nm size range instead of bigger micro particles, they have a larger surface area for the same volume, smaller pore size, improved solubility and different structural properties. This can improve both the diffusion and degradation characteristics of the encapsulation material. Another class of drug delivery system is nanomaterials that can carry drugs to their destination sites and also have functional properties. Certain nanostructures can be controlled to link with a drug, a molecule or an imaging agent, then attract specific cells and release their payload when required. The antibacterial properties of nanotubes are being studied.

Self-assembled stacking of cyclic peptides having an even number of alternating and L-amino acids forms the nanotubes. The nanotubes insert themselves readily into bacterial cell membranes and act as potent and selective antibacterial agents; both nanomaterials bucky balls and nanotube will undoubtedly become an important part of the total pharmaceutical tool kit over the next few years (Kannaki and Verma 2006). Targeting Ligands and receptor or ligand specific delivery of the drug is one key for targeted drug or gene or DNA delivery, which needs various ligands as small molecules galactose, glucose, and mannose, protein like transferins, antibodies, and low-density lipids (LDLS). Drug delivery is an area where nanotechnology has already had a significant impact (LaVan and McGuire 2003) and surely for this aquaculture drugs has the major share, because the drugs and nutraceuticals in aquaculture and their delivery methods need several concern as:

1. Cost of the drugs and nutraceutical used in culture.
2. Same time we need to target less waste as feed cost is the major cost and aquaculture is the margin sifting industry.
3. Efficacy and cost analysis of such drugs being used in aquaculture.
4. Environmental impact of these additives and drugs used.
5. Monitoring the residues level and its impact on food value.
6. Uncertain fate of the administered feeds in the water.
7. Feed palatability and acceptance by fish after use of drugs and nutraceuticals.
8. Toxicity of drugs to fishes at higher dose.

The factors mentioned above strongly suggest the need of the effective delivery of the drugs where the efficacy can be achieved at low dose in a sustained manner, without any toxicity to fish and residue of drug in the flesh. Nanodeliveries—has satisfaction for several of these issues in aquaculture drugs like drug safety, residue level in flesh and sustain release to reduce the frequency of dosing and overall cost of drug or treatment. There are several natural polymeric and other nano carriers which can easily be applied for aquaculture drug without adding much cost. Goal of more sophisticated drug delivery techniques like nanodelivery is to

1. Deploy to a target site to limit side effects.
2. Shepard drugs through specific areas of the body without degradation.
3. Maintain a therapeutic drug level for prolonged periods of time.
4. Predictable controllable release rates.
5. Reduce dosing frequent and increase fish compliance without frequent handling and stress.

Therefore, the delivery of drugs and nutraceuticals in aquaculture will have to find the way through nano-delivery (Rather et al. 2011). Nanomedicine is a rapidly growing aspect of nanotechnology and there is an opportunity to use these technological advances to monitor and improve fish health. The poor stability of pharmaceuticals in natural water has inevitably led to many fish medicines being delivered via the food or accepting that much of any aqueous treatment may be simply washed away. Nano carriers have been exploited to make new drug delivery systems for humans, and these may also be used for veterinary medicines including those for fishes. The approaches include solid core drug delivery systems (SCDDS), which involve coating a solid NP with a fatty acid shell to contain the drug of interest. This methodology works at relatively low temperature and pressure, making it especially useful for heat sensitive or labile pharmaceuticals. Porous NMs can also be used as a drug delivery matrix. For example, mesoporous silica particles can be used for the controlled release of substances. Oral delivery is the easiest and practical through in-feed formulations and only option for the nutraceuticals delivery. The various in-feed formulation forms like pelleted form, micro encapsulated, microparticulate form and nano particulate or encapsulated forms are the means of delivery. As the immersion pose handling stress and more amounts of drugs required which raise the treatment cost, impact on the environment and may cause possible threat on other organism and resistance building. While the Injection method becomes unrealistic for field application, the oral/ in-feed delivery with add of nano carriers becomes excellent mean of delivery for drugs and nutraceuticals (Rather et al. 2011).

14.6 Gene or DNA Delivery

There is a relation between nanoparticles and gene or DNA delivery, Polynucleotide vaccines work by delivering genes encoding relevant antigens to host cells where they are expressed, producing the antigenic protein within the vicinity of professional antigen-presenting cells to initiate immune response. Such vaccines produce both humoral and cell-mediated immunity because intracellular production of protein, as opposed to extracellular deposition, stimulates both arms of the immune system (Gurunathan and Freidag 2000). The key ingredient of polynucleotide vaccines, DNA, can be produced cheaply and has much better storage and handling properties than the ingredients of the majority of protein-based vaccines. Hence, polynucleotide vaccines are set to supersede many conventional vaccines, particularly for viral diseases. However, there are several issues related to the delivery of polynucleotide which limits their application. These issues include efficient delivery of the polynucleotide to the target cell population and its localization to the nucleus of these cells, and ensuring that the integrity of the polynucleotide is maintained during delivery to the target site (Mohanraj and Chen 2006). Nanoparticles loaded with plasmid DNA could also serve as an efficient sustained release gene delivery system due to their rapid escape from the degradative endolysosomal compartment to the cytoplasmic compartment (Panyam et al. 2002). Hedley et al. (1998) reported that following their intracellular uptake and endolysosomal escape, nanoparticles could release DNA at a sustained rate resulting in sustained gene expression. This gene delivery strategy could be applied to facilitate the transgenic production, for modulating the expression of a gene, say GH gene in fishes to boost growth, produce the tailored fish product or health food. The DNA vaccines administered as liposomal complexes also improve the antibody response over that seen with free

DNA (Gregoriadis et al. 1997). These include a reduction in the rapid clearance of cationic liposomes and the production of efficiently targeted liposomes. At the cellular level, the problems may be overcome by improving receptor-mediated uptake using appropriate ligands, the endowment of liposomes with endosomal escape mechanisms, and a more efficient translocation of DNA to the nucleus and the efficient dissociation of the liposome complex just before the entry of free DNA into the nucleus. If it is delivered though in-feed formulations, then the protection of the chitosan or alginate nano-capsulation in a single layer or a layer over another carrier will ensure the gastric protection. Promising results were reported in the formation of complexes between chitosan and DNA. Although chitosan increases transformation efficiency, the addition of appropriate ligands to the DNA–chitosan complex seems to achieve a more efficient gene delivery via receptor-mediated endocytosis (Eldridge et al. 1990). These results suggest that chitosan has comparable efficacy without the associated toxicity of other synthetic vectors and therefore, can be an effective gene delivery vehicle in vivo (Murata et al. 1998).

In aquaculture, several gene expression studies have been done through nanoparticle administration in different fish species. The first report on use of chitosan-conjugated nanodelivery of gonadotropic hormone in fish was done in *Cyprinus carpio* trough administration of chitosan-gold nanoconjugates LHRH to investigate the surge of gonadotropins and reproductive output in female fish (Rather et al. 2013). Later, Rather et al. (2016), analyzed the expression of kisspeptin gene through nano-delivery of chitosan encapsulated nanoparticle of kisspeptin-10 in *Catla catla*. In fishes, several genes have been reported which affect the gonadal development and maturity. One of the gene sox9 plays a crucial role in determining the fate of several cell types and is a primary factor in regulation of gonadal development. In *Clarias batrachus*, the expression of sox9 was analyzed through the nanodelivery of Chitosan-conjugated LHRH (Rather et al. 2016). Expression vector have also been used in the nanodelivery of specific gene constructs. A chitosan nanoparticle conjugated StAR gene construct was prepared in a eukaryotic expression vector and administered in the *Clarias batrachus* through intramuscular injection. The StAR gene was detected in several tissues to get the regulating rate and timing of steroidogenesis (Rather et al. 2017). Identification of key genes responsible for any physiology in fishes is a crucial step which can be done through transcriptomics analysis. RNA sequencing of the cell or tissue before or after some stimulation leads to the identification of several differential expressed genes (Agarwal et al. 2020). These genes can be conjugated with nanoparticles and administered in the fish to analyze the phonotypical changes, though the use of different nanoparticles might affect the physiology of the animal through accumulation in the body.

14.7 Vaccine-Adjuvant

Vaccination is one of the important methods of prevention of disease in advance by developing antibody agents the particular pathogen. Most of the vaccines are applied as a fluid form and generally injected into blood stream. These vaccines require the cool temperature to be stored and they also have limited life span within which they are to be utilized. These two limitations have prevented the utility of vaccines, particularly in the fishes and shrimp. Therefore, more robust and durable vaccines are the only solution for the successful eradication of the particular disease.

Many organisms, particularly microorganisms, have novel and interesting structures that could be exploited, for example, the lattice-type crystalline arrays of bacterial S-layers and bacterial spore coats both of which have protective prosperities. In principle, the spore coat could be used not only as a delivery vehicle for a variety of different molecules but also as a source of new and novel self-assembling proteins. Spore coats are comprised of protein, have ordered arrays of photometric subunits, exhibit self-assembly and have protective prosperities. A spore-based display system provides several advantages with respect to systems based on the use of conventional vaccines; these include the robustness of the bacterial spore allowing storage in the desiccated form, ease of production and safety. And it can be suitably used for aquaculture bacterial vaccines. Similarly, in the liposomes as vaccine adjuvants, liposomes have been firmly established as immune-adjuvants (enhancers of the immunological response), potentiating both cell-mediated and humoral immunity (Gregoriadis et al. 1996). Liposomal vaccines can be made by associating microbes, soluble antigens, cytokines (Gregoriadis et al. 1996) or deoxyribonucleic acid (DNA) (Gregoriadis et al. 1997) with liposomes, the latter stimulating an immune response on the expression of the antigenic protein (Gregoriadis 1997). Liposomes encapsulating antigens which are subsequently encapsulated within alginate lysine microcapsules (Cohen et al. 1991) or to chitin or chitosan or other polymeric microcapsules to protect the gastric digestion and to control antigen release for improving the antibody response. Liposomal vaccines may also be stored dried at refrigeration temperatures for up to 12 months and still retain their adjuvanticity (Kim and Jeong 1995). In DNA nano-vaccines using nanocapsules and ultrasound methods, the United States Department of Agriculture (USDA) is completing trials on a system for mass vaccination of fish in fishponds using ultrasound. Nanocapsules containing short strands of DNA are added to a fishpond where they are absorbed into the cells of the fish. Ultrasound is then used to rupture the capsules, releasing the DNA and eliciting an immune response from the fish. This technology has so far been tested on rainbow trout by Clear Springs Foods (Idaho, US) a major aquaculture company that produces about one-third of all U.S. farmed trout (Mongillo 2007; ETC 2003).

Advances in nanotechnology have also proved to be beneficial in therapeutic fields such as drug discovery, drug delivery, and gene/protein delivery. Now a day synthetic siRNA is considered as a highly promising therapeutic agent for a viral disease like WSSV. However, clinical use of siRNA has been hampered by instability in the body and inability to deliver sufficient RNA interference compounds to the tissues or cells. To address this challenge, we present here a single siRNA nanocapsule delivery technology, which is achieved by encapsulating a single siRNA molecule within a degradable polymer nanocapsule with a diameter around 20 nm and positive surface charge. Several works provide a potential novel platform for siRNA delivery that can be developed for therapeutic purposes.

14.8 Management of Animal Breeding

Aquaculture today is growing vertically and horizontally, growing rate of mariculture indicates the kind of horizontal expansion in the sea where the immediate need felt is for potentiating the maturation of the fishes for early and effective breeding same time easy artificial spawning to ensure uninterrupted supply of quality seed which is the backbone for aquaculture growth. The nano-delivery of the hormones, anabolic agents, hormone analogue and the spawning inducing agent is very important for it where the effective delivery without much wastage can be targeted through in-feed formulation in marine cages. Same time the oral delivery of the nano carrier-based or nano-encapsulated hormones will have an option of mass breeding of the fishes in confined water in natural or artificial habitat (Rather et al. 2011).

14.9 Nano Smart Delivery System in Cell vs. Transgenic

Today the worldwide discussion is about the uses and abuse of transgenics. Human need and greed over the luring enhanced production and desirable trait attainment for diseases resistance and environmental tolerance seems necessary but same time the impact on biodiversity and food safety bring a big question mark even on survival and sustainability. Here the big dilemma can be solved by the nano-delivery by using smart nano cell delivery, which will ensure only the cell specific or tissue specific modification of expression leading production of particular hormone say growth hormone in a specific tissue. The delivery will be on the basis of cell surface-based receptor interaction and multiple nanocoating materials, this will be able to release the gene or DNA construct in the nucleus of decided cell. It will also be used for triggering the protein- protein interaction channel to trigger the various synthetic cascade of the cell leading to expression of the particular gene by various factors or cofactors activation and triggering binding to genes response element. This particular mean will be effective as it will lead to temporary and even long lasting change in the somatic cell only. The epigenetic or protein-protein based triggering will have a definite life of triggering, while the genetic integration or transgenics will be a lifelong modification of expression in that animal. Besides that, it will have the chance of genetic contamination and environmental impact. As the somatic cell, alteration will not be carried to the germplasm. Oral delivery if achieved it becomes super simple, overall it will be the least tedious than transgenic gene transfer to embryo where the success rate is less and it requires the sophisticated techniques or equipment.

14.10 Disease Diagnosis

Unlike higher animals, this application of nanobiotechnology seems to be meaningless in aquaculture. To prevent the mass mortality of commercially important fish and shellfish due to diseases at an early stage needs an important attention. The technologies that are used in higher animals can be mimicked and applied in aquaculture for example in animals the tumor detection is possible now at an early stage by RNA nanoparticles (Guo et al. 2012). Similarly, there are some other techniques that can be applied in aquaculture like nanobodies, a new generation of antibody-based therapeutics for disease diagnosis (Jain 2005).

14.11 Nano-biosensors

Nanotechnology based biosensors can be used in the aquaculture industry for microbe control. Researchers at NASA, USA have developed a sensitized carbon nanotubes based biosensor that is capable of detecting minute amount of microbes including bacteria, virus, parasite, and heavy metals from water and foods sources. Nano colloidal sliver is one the most beneficial product of nanotechnology and act as a catalyst and work on a wide spectrum of bacteria, fungi, parasites and virus by rendering an enzyme inoperative, which is used for their metabolism. Unlike antibiotic resistant strains of bacteria, no such strain is known to develop by using colloidal sliver. Even these sliver nanoparticles are able to kill methicillin-resistant *S. aureus*. Tracking nano-sensors are being developed. "Smart fish" may be fitted with sensors and locators that relay data about their health and geographical location to a central computer. Such technology may be used to control cognitive cage systems or individual fish (ETC Group Report 2003).

14.12 Tagging and Nano-barcoding

Radio frequency ID (Rfid) is a chip with a radio circuit incorporating nanoscale component with an identification code embedded in it. These tags can hold more information, scanned from a distance and embedded in the product to identify any object anywhere automatically. These tags may be used as a tracking device as well as device to monitor the metabolism, swimming pattern and feeding behavior of fish. A nano-barcode is a monitoring device consisting of metallic stripes containing nanoparticle where variations in the striping provide the method of encoding information. By incorporating the nano-barcoding, processing industry and exporters can monitor the source or track the delivery status of their aqua product till it reaches the market. Further, coupled with nanosensors and synthetic DNA tagged with color-coded probes, nanobarcode device could detect pathogen and monitor for temperature change, leakage etc.

14.13 Conclusion and Future Direction

Nanotechnology is a global business enterprise impacting industries, universities, industry regulation agents Worldwide. Nanobiotechnology in all sectors including aquaculture is still in its early stages of expansion; however, the development is multidirectional and fast-paced. Although there are many exhilarating potential biological applications of nanomaterials, one needs to distinguish definite scientific promises from the hype and to constantly improve the understanding of their interactions with intracellular structures, the process, and the environment.

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