

Nanotechnology: A Novel Tool for Aquaculture and Fisheries Development. A Prospective Mini-Review

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Abstract

Nanotechnology has a tremendous potential to revolutionize agriculture and allied fields including aquaculture and fisheries. It can provide new tools for aquaculture, fish biotechnology, fish genetics, fish reproduction and aquatic health etc. Nanotechnology tools like nanomaterials, nanosensors, DNA nanovaccines, Gene delivery and smart drug delivery etc. have the potential to solve many puzzles related to animal health, production, reproduction, prevention and treatment of diseases. It is sensible to presume that in the upcoming years, nanotechnology research will reform the science and technology and will help boost livestock production. Nanotechnology applications in the fish processing industry can be utilized to detect bacteria in packaging, produce stronger flavors, colour quality, and safety by increasing the barrier properties. This paper presents the review of nanotechnology and its applications in aquaculture and fisheries.

Keywords: Nanotechnology; Nanomaterial; Nanosensors; DNA nanovaccine; Aquaculture.

1. Introduction

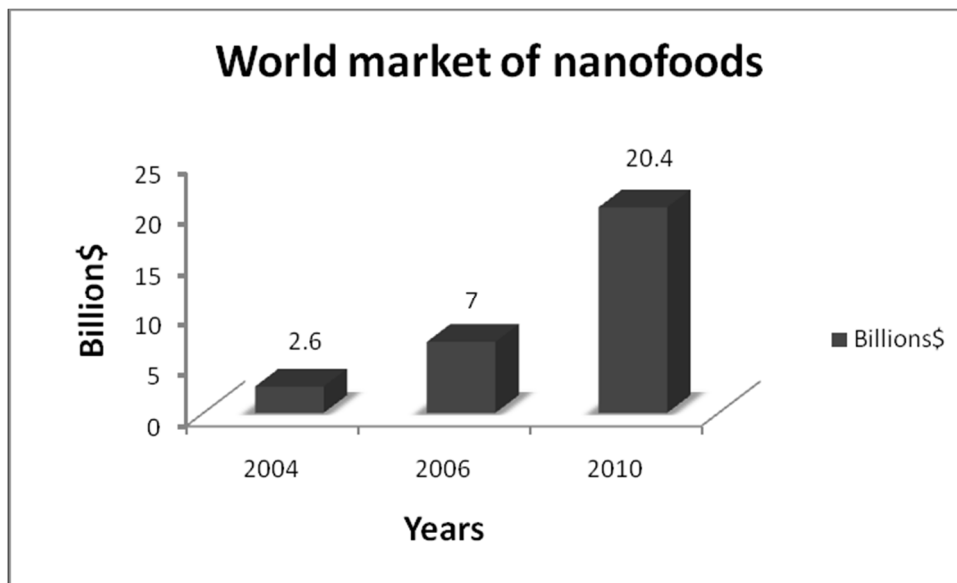
Nanotechnology is a highly promising technology that spans many areas of science and technological applications. Rapid advancements in nanosciences and nanotechnologies in recent years have opened up new horizons for many industrial and consumer sectors that have been regarded as the hotbed of a new industrial revolution including agriculture and allied sectors. Among the recent advancements in science, nanotechnology is fast emerging as the new science and technology platform for the next generation of development and transformation of agri-food systems [1] as well as for improving the conditions of the poor people.

2. Definition

Nanotechnology has been defined by the U. S. National Nanotechnology Initiative (NNI) as “understanding and control of matter at dimensions of roughly 1 to 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 nanometers, one nanometer 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 commercialise nanotech products.

3. Nanotechnology in Agrifood Sector

Globally, the potential of nanotechnology in the agrifood sector has been identified and been attracting significant investment. Currently, over 300 nanofood products are available in the international markets. According to a recent study by Helmuth Kaiser Consultancy (Germany), the nanofood market is expected to surge from USD 2.6 billion in 2004 to USD 20 billion by 2010. The report suggests that with more than 50% of the world population, the largest market for nanofood in 2010 will be Asia, led by China.



Source: Helmuth Kaiser Consultancy, 2004

4. Nanotechnology in Aquaculture and Fisheries

The fisheries and aquaculture industry can be revolutionized by using nanotechnology with new tools like rapid disease detection, enhancing the ability of fish to absorb drugs like hormones, vaccines and nutrients etc. rapidly. As per National Science Foundation (USA), current prediction estimates the emergence of value of the global nanotechnology industry at USD one trillion by 2015. This could be possible due to vast potential of nanotechnology not only in electronic and materials science but also in humans, animal food and agriculture sectors involving aquaculture and its application in biomedical and biological sciences for analysis of biomolecules, cancer therapy, development of non-viral vectors for gene therapy, as transport vehicle for DNA, protein or cells; targeting drug delivery, clinical diagnosis and therapeutics etc. Although much of development research is needed to enhance the potential use of nanotechnology in aquaculture, at present, there are numerous glimpses of the future application of this technology in fish health management, water treatment in aquaculture, animal breeding, harvest and post-harvest technology.

The areas related to aquaculture and fisheries where nanotechnology can be applied are:

4.1 DNA nano-vaccines

Outbreak of disease is one of the major stumbling blocks in the development and sustainability of aquaculture. A number of approaches have been made in attempts to solve disease problem in aquaculture, one among these is vaccination. The use of oil emulsion as adjuvant in this effort may cause major drawbacks as some fishes and shellfishes show unacceptable levels of side effects. In this context, use of nanoparticle carriers like chitosan and poly-lactide-co-glycolide acid (PLGA) [2] of vaccine antigens together with mild inflammatory inducers may give a high level of protection to fishes and shellfishes not only against bacterial diseases, but also from certain viral diseases with vaccine-induced side effect. Further, the mass vaccination of fish can be done using nanocapsules containing nano-particles. These will be resistant to digestion and degradation. These nanocapsules contain short strand DNA which when applied to water containing fishes are absorbed into fish cells. The ultrasound mechanism is used to break the capsules which in turn release the DNA thus eliciting an immune response to fish due to the vaccination. Similarly, oral administration of these vaccines and site-specific release of the active agent for vaccination will reduce the cost and effort of disease management, application of drug and vaccine delivery etc., at the same cost of feeding leading to sustainable aquaculture.

Briefly stated, nanoparticles are used as oral drug carriers for several reasons:

- 1) Improvement of the bioavailability of drugs with poor absorption characteristics [3]
- 2) Prolongation of the residence time and digestive stabilisation of drugs in the intestine.
- 3) High dispersion at the molecular level and consequently efficient absorption.
- 4) Delivery of vaccine antigens to gut-associated lymphoid tissue [4] and
- 5) Control of the release of the drugs [5]

4.2 Gene delivery

The development of new carrier systems for gene delivery represents an enabling technology for treating many genetic disorders. However, a critical barrier to successful gene therapy remains the formulation of an efficient and safe delivery vehicle. Non-viral delivery systems have been increasingly proposed as alternatives to viral vectors owing to their safety, stability and ability to be produced in large quantities [6]. Some approaches employ DNA complexes containing lipid, protein, peptide or polymeric carriers, as well as ligands capable of targeting DNA complexes to cell-surface receptors on the target cells and ligands for directing the intracellular traffic of DNA to the nucleus. Promising results were reported in the formation of complexes between chitosan and DNA [7]. 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 [8]. 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*.

4.3 Smart Drug Delivery

Today, application of antibiotics, probiotics and pharmaceuticals / nutraceuticals is delivered through feed or injection system either as preventive treatment or when symptoms are evident. Nanoscale devices may have the capability to detect and treat infection and health problems. With the help of smart delivery system that poses multifunctional characteristics such as pre-programmed, time controlled, monitoring the effect of the delivery of probiotics, hormones, chemicals and vaccines is possible [9].

4.4 Nanoparticles for Enhancement of Fish Growth

Scientists from the Russian Academy of Sciences have reported that young carp and sturgeon exhibited a faster rate of growth (30% and 24% respectively) when they were fed nanoparticles of iron [10]. Research had demonstrated that different Selenium sources (nano-Se and selenomethionine) supplemented in basal diet could improve the final weight, relative gain rate, antioxidant status as well as Glutathione Peroxidase (GSH-Px) activities and muscle Se concentration of crucian carp (*Carassius auratus gibelio*). Moreover, nano-Se appeared to be more effective than organic selenomethionine in increasing muscle selenium content [11]. Similarly, the growth and performance of the experimented fishes have been assessed higher at nano-level delivery of these nutraceuticals.

4.5 Nanodelivery of Nutraceuticals

Use of nutraceuticals for health management, value addition and stress mitigation in fish and shellfish is an emerging area of aquaculture research. In spite of their low requirement, incorporation of nutraceuticals involves higher cost. Thus, it needs to be used in such a way that wastage will be minimised for efficient utilisation and to make the final product economically viable. Development of nanodelivery system for these kinds of molecules may address the problems of their application in aquaculture practices at commercial level. There is an immense opportunity to use the nanoparticles to deliver nutraceuticals in fish feed and neurogenomics studies. Moreover, various nanoformulations of feed help to maintain better consistency and taste of feed [12].

4.6 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 a device to monitor the metabolism, swimming pattern and feeding behaviour of fish. A nano-barcode is a monitoring device consisting of metallic stripes containing nanoparticles 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 aquaprodukt until it reaches the market. Further, coupled with nanosensors and synthetic DNA tagged with colour coded probes, nano-barcode device could detect pathogens and monitor temperature change, leakage etc., thus improving the product quality.

4.7 Water filtration and Remediation

Nano-enabled technologies are available today for the removal of contaminants from water. Nano-materials in the form of activated materials like carbon or alumina, with additives like zeolite and iron containing compounds, can be used in aquaculture applications for holding aerobic and anaerobic biofilm for the removal of ammonia, nitrites and nitrate contaminants. Likewise,

ultrafine nanoscale powder made from iron can be used as an effective tool for cleaning up contaminants such as trichloroethane, carbon tetrachloride, dioxins and polychlorinated biphenyls to simpler carbon compounds which are less toxic, thus paving the way for nano-aquaculture.

4.8 Nanotechnology devices for Aquatic Environment Management

Nevada-based Altair Nanotechnologies makes a water-cleaning product for swimming pools and fishponds called NanoCheck. It uses 40 nm particles of a lanthanum-based compound which absorbs phosphates from the water and prevents growth of algae. NanoCheck is currently undergoing large-scale testing in swimming pools and Altair had launched a swimming pool cleaner in early 2005. Altair is hoping for use of NanoCheck in thousands of commercial fish farms worldwide, where algae and heavy metal removal and prevention are costly at present. According to Altair, the company plans to expand its tests to confirm its effect on fish, and impacts of nanoparticles-laden run-off on human health or on the environment. Besides, nanoscale delivery of weedicides and soil-wetting agents may be very useful for aquatic weed control in large water bodies, and mitigation of stress due to climate change and aquatic pollution.

4.9 Harvest and Post-Harvest Technology

To catch fish, fishing lures are painted to reflect light to attract the attention of fish. However, these conventional lures reflect light only in one direction. To overcome this problem, the surface of the lure is colored and then nano-coated with a polyimide film which enhances the chance of catching fish 2 to 3 times compared to the case where a lure without a polyimide coating is used.

5. Conclusion

Nanotechnology undoubtedly presents a major opportunity for the economy and sustainable development of aquatic resources in many countries. Although the application of nanotechnology is still at a very early stage in aquaculture, it may have the potential to solve most of the problems in aquaculture and fisheries with better technical innovation at different levels. At present, Central Institute of Fisheries Education (India) has initiated research on the application of nanotechnology in aquaculture and fisheries.

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