



## Review Article

# Myconanotechnology in veterinary sector: Status quo and future perspectives

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## ABSTRACT

Nanotechnology is no longer a concept or a theory of the new world, it has turned into a new enabling technology over the years, with tremendous potential to revolutionize agriculture and livestock sector all over the globe. Moreover, nanotechnology provides new tools for molecular and cellular biology, biotechnology, veterinary physiology and reproduction, giving more promising solutions in both pathogen detection and therapy, engineering of agriculture, incredible results in animal and food systems and many more. Nanotechnology means manipulation, reduction and synthesis of materials at nano scale. Nanoparticles have distinct unique morphological characteristics which are quite different from their original bulk form. Recently, nanoparticles have been produced by industries for commercial applications having huge benefits. Since nanotechnology serves various fields of science and technology, the fabrication of nanoparticles using the biological route is becoming the need of the day. Biosynthesis of nanoparticles attracts the attentions of many researchers and industries to study microorganisms such as bacteria, fungi, algae and others as perfect biological factories for the fabrication of different nanoparticles. Among the different bionanofactories, the fungal system has emerged as an efficient most suitable system synthesizing metal nanoparticles by different mechanisms and for many reasons mentioned later. This review highlights the term “Myconanotechnology” in an attempt to direct more attention on fungi as a potential effective green approach in nanotechnology through conducting a SWOT analysis consisting of strengths, weaknesses, future opportunities of myconanosynthesis and probable constraints through eliciting questions for the possibility of using them in a large scale production.

## 1. Introduction

The world's nowadays challenges are demanding effective scientific contribution to solve major problems regarding national security like food safety, both early diagnosis and treatment of diseases and others using green approaches.

Nanotechnology is a multidisciplinary science involving diverse parts of research and innovation [1]. Nanoparticles are metal particles in the size scope of 1–100 nm [2]. Metal nanoparticles like gold, silver and platinum have won awesome consideration lately because of their crucial and mechanical intrigue. These nanoparticles have kind synergistic, electronic and optical properties particular from the first metallic particles [3].

Previously, physical, chemical and biological approaches have been designed to synthesize nanoparticles [3–5]. The physical and chemical methods use strong chemical reducing agents such as sodium borohydride, weak reducing agents like sodium citrate and alcohols, gamma rays, UV rays and others [6].

The biological methods have an inexpensive and eco-friendly route

for synthesis of nanoparticles. So far, synthesis of nanoparticles has been demonstrated by the use of biological agents like bacteria, fungi, yeast and plants [3]. A number of bacteria like *Bacillus subtilis* [7], *Pseudomonas stutzeri* [8], *Thermonospora* sp. [9], *Shewanella algae* [10], *Lactobacillus* strains [11] and others have been proven for the synthesis of metallic nanoparticles.

Yeasts have also been studied for the biosynthesis of nanoparticles including; *Candida glabrata* [12], *Schizosaccharomyces pombe* [13] and MKY3 [14].

While, a number of plants like *Medicago sativa* [15], *Pelargonium graveolans* [16], *Azadirachta indica* [17], *Triticum* [18], *Cinnamomum camphora* [19], *Capsicum annum* [20] have been used for the fabrication of metal nanoparticles.

Myconanotechnology means synthesis of nanoparticles by fungi, and their subsequent application, particularly in medicine. It is the interface between mycology and nanotechnology and has a considerable potential, partly due to the wide range and diversity of the fungi [21].

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## 2. Applications of nanotechnology in the veterinary sector

Nanotechnology has a great potential for solving many problems related to animal health, production, reproduction and effective hygienic practices related to livestock production [22]. On the other hand, more research is still necessary before nanotechnology could have common place in veterinary and animal sciences. This review highlights the most common and effective applications in the veterinary medicine.

### 2.1. Drug delivery systems

Drug delivery systems in animals in all probability contain little, fixed bundles of the medication to be conveyed. Drug delivery systems permit reasonable utilization of tiny amounts of anti-microbial than at any other time. A sub-atomic coded 'address mark' in the bundle could enable the bundle to be conveyed to the particular right site in the body [23].

Nano and microscale mechanical frameworks would fill in as the 'transporters' in such a framework. Drug delivery systems could likewise contain on-board synthetic location and basic leadership ability for self-directed medication conveyance or supplement medicines according to require. This will help domesticated animals proprietors to control the utilization of anti-microbial and to decrease the consumption taking drugs. Smart drug delivery systems can likewise have the capacity to screen the impacts of the conveyance of pharmaceuticals, nutraceuticals, supplements, sustenance supplements, bioactive mixes, probiotics, synthetic concoctions and antibodies [23].

### 2.2. Diagnosis and treatment of animal diseases

Biochips can be utilized for early diagnosis of diseases in animals. A Biochip (or microarray) is a gadget regularly made of hundreds or thousands of short strands of artificial DNA saved unequivocally on a silicon circuit. Biochips can also be used to trace the original source of food and feeds to detect the presence of animal products from different species as a mean to determine the source of pathogens such as avian flu and mad cow disease. Besides, there are different varieties recognizing minute amounts of proteins and synthetic substances in an example, making them compelling for identifying biowarfare specialists or malady. Utilizing biochips, natural examples, for example, blood, tissue and semen can be momentarily broke down and controlled. Bioanalytical nanosensors are gadgets or frameworks that measure or distinguish a substance with the utilization of an organic material or tissue which will empower us with recognition of moment measures of an either synthetic or natural contaminants as infection or microscopic organisms in farming and domesticated animals framework. Nanoshells are another sort of optically tunable nanoparticle made out of a dielectric (for instance, silica) center covered with an ultra-thin metallic (for instance, gold) layer. Nanoshells can be infused into the animal's circulation system with focused operators connected to the nanoshells to search out and append to the surface receptors of tumor cells. Brightening of the body with infrared light raises the cell temperature to around 55 °C, which 'consumes' and demolishes the tumor [24]. Others have been exploring different avenues regarding 'keen' super paramagnetic nanoparticles, which when infused in the circulation system target tumor receptor cells. These nanoparticles are produced using iron oxides that when subjected to an attractive field upgrades the capacity of the nanoparticles to find tumor cells. At the site of the tumor, the nanoparticles discharge the stacked medication to decimate the malignancy cells. Other type of nanomaterial is Quantum dots which are nanometre-scale gems that were initially produced for optoelectronic applications [25]. Quantum spots might be infused into the circulation system of animals and they may distinguish cells that are breaking down. As quantum dots react to light it might be conceivable to enlighten the body with light and animate the quantum dab to warm up adequate to execute the carcinogenic cell. Nucleic corrosive building

based tests and techniques offer great better approaches to convey helpful or protection treatment for specific ailments [25]. These different techniques for nanotechnology can be a fantastic remedial apparatus in beating the health problems of animals.

### 2.3. Food safety through identity preservation

Identity preservation (IP) framework is a framework that builds up an expanded incentive by furnishing customers with data about the practices and exercises used to deliver a horticultural item. Today, through IP it is conceivable to give partners and customers the access to data, records and provider conventions in regards to the homestead of starting point, natural practices utilized as a part of creation, nourishment wellbeing and security, and data with respect to creature welfare issues. Quality confirmation of the wellbeing and security of farming and creature items could be essentially enhanced through IP at the nanoscale. The eventual fate of the meat business may well rely upon a capacity to track all phases in the life of the item, including the introduction of the animal, its medicinal history, and its developments between ranches, the slaughterhouse and the meatpacking plant, directly to the consumer's table.

### 2.4. Breeding and reproduction

Administration of rearing is a costly, difficult and tedious issue for dairy and swine ranchers. Among arrangements, a nanotube embedded under the skin to give constant estimation of changes in the level of estradiol in the blood. The nanotube [26] is utilized as an apparatus for following oestrus in animals on the grounds due to its ability to tie and distinguish the estradiol counter acting agent at the season of oestrus by close infrared fluorescence. The flag from this sensor will be joined as a piece of a focal checking and control framework to incite reproducing. Microfluidics is utilized today in animal science to essentially streamline customary *in vitro* treatment techniques utilized as a part of animal reproduction. It is being utilized as a part of domesticated animals reproducing to physically sort sperm and eggs. Microfluidic and nanofluidic are the frameworks which examine by controlling the stream of fluids or gases through a progression of little channels and valves, in this way arranging them, much as a PC circuit sorts information through wires and rationale doors. With the mapping of the human genome behind them, geneticists are currently quickly sequencing the genomes of steers, sheep, poultry, pig and other animals wanting to recognize quality successions that identify with financially profitable characteristics, for example, ailment obstruction and leanness of meat. By including tests for these attributes on biochips, raisers will have the capacity to in a split second distinguish champion reproducers and screen out hereditary diseases.

## 3. Microorganisms as bionanofactories

Lately nanoparticles have been created by enterprises for commercial application with numerous advantages. Green synthesis of nanoparticles pulls in numerous scientists and enterprises to investigate and demonstrate microorganisms could be the ideal organic framework for the generation of various nanoparticles [27]. The metabolic action of these microorganisms empowers the additional cell or intracellular amalgamation of nanoparticles using diverse method of blend [28–30]. Bacteria, viruses, actinomycetes, plants, fungi and parasites are altogether demonstrated for their capacity of metal particles reduction.

## 4. Advantages of biologically synthesized nanomaterials

Microorganisms exhibit the capability to reduce the toxicity of metal ions through bioreduction or by the aggregation of non-soluble complexes with metal ions to produce colloidal particles. Nanomaterials are more definite in size than the chemically synthesized

ones. In addition nanobiosynthesis is of course a less expensive and an eco-friendly method.

## 5. Mycofabrication

When fungi are involved in the synthesis of nanoparticles, the process is called mycofabrication. Recently, the fungal system has been proved as “Bionanofactories” synthesizing nanoparticles of many metals as silver, gold, platinum and CdS. Actually fungi are blessed; being a source of a lot of reducing enzymes makes it able to play a pivotal role in nanoparticle synthesis.

## 6. Fungi in nanoparticle synthesis

From a total of 1.5–5.1 million species of fungi found on earth about seventy thousands species have been documented [27,31]. Choosing fungi for mycofabrication techniques is the best choice because of its high metal ion tolerance and bioaccumulation capacities [32] beside many other advantages that will be mentioned later in details.

Trials on mycosynthesis started at the beginning of this millennium [33] demonstrated the intracellular synthesis of gold nanoparticles by the fungus *Verticillium* sp. by growing the fungus in a liquid medium and then transfer it to an aqueous solution of auric chloride. Then the fungal cells changed to vivid purple within 24 h, the synthesis of gold nanoparticles was proven by UV visible spectra of the fungal cells at 540 nm absorption peak which is characteristic for gold nanoparticles. With Transmission Electron Microscope (TEM), the presence of nanoparticles was demonstrated with an average size of 20–28 nm on both cell wall and in the cytoplasm, the synthesized nanoparticles were mostly spherical and some were triangular and hexagonal. After that, intracellular or extracellular mycosynthesis of a number of different metallic nanoparticles have been reported including cadmium [34], zirconia [35], magnetite [36] and platinum [37]. However, silver nanoparticles had the lion’s share in researchers’ work with a diverse fungal species which are capable to synthesize it either intracellular as *A. flavus* [38] or extracellular as *Phoma* sp., *A. fumigatus*, *A. niger*, *Penicillium* sp., *F. oxysporum*, *F. solani*, and *Cladosporium* sp. [39–45].

Nowadays, working on biosynthesized silver nanoparticles is still having a great share. The extracellular biosynthesis of silver NPs was studied using the algicolous endophytic fungus *Penicillium polonicum* which was isolated from marine algae and proved to have efficient antibacterial properties against biofilm forming, and multidrug resistant *Acinetobacter baumannii* [46]. In addition, a study was conducted in 2018 representing the 1st report on the potential of biosynthesized silver NPs from coprophilous fungi, to be used in wound dressings and as a potent antibacterial alone and in combination [47]. Another study took place recently displaying the capability of silver Nps biosynthesis by the fungus *Trichoderma harzianum* as a safe fungus for human and animals [48]. Furthermore, the extracellular production of silver NPs was also proved using *Trichoderma longibrachiatum*, the same study evaluated the resulting nanoparticles for having a considerable antifungal activity against many plant pathogenic fungi as *Fusarium verticillioides* and *Fusarium moniliforme* [49].

Recently, a study was conducted comparing 3 different approaches for synthesis of gold nanoparticles using either intracellular fraction or extracellular one of 29 thermophilic fungi, the study brought gold nanoparticles back into the playground of biosynthesized nanoparticles [50].

Yeasts have also been studied for the biosynthesis of nanoparticles including *Candida glabrata* [12], *Schizosaccharomyces pombe* [13], MKY3 [14] etc. Research continued on myconanosynthesis by *Aspergillus* sp. [51–55], as well as dermatophytes as *M. canis*, *T. rufum* and *T. mentagrophytes* [54].

## 7. Mechanisms of mycosynthesis

Both intracellular and extracellular syntheses were reported as above mentioned and the definitive mechanisms of both were studied. The cell wall plays a primary role in the absorption of heavy metals in the intracellular synthesis allowing trapping of metal ions which are reduced by enzymes within the cell wall and the cytoplasm and leads to the aggregation metal ions and formation of nanoparticles. On the other hand, researches proved that *reductase* enzyme is responsible for reduction of metal ions and subsequent synthesis of nanoparticles in the extracellular myconanosynthesis [1].

## 8. Why fungi being the most appropriate bionanofactories?

Using fungal biomass or biomass extracts for the production of nanoparticles is more advantageous compared to other biological methods for many reasons because fungi, being abundant in nature can be easily isolated by plating, serial dilutions and hyphal extraction. Culturing/subculturing of fungi requires simple media. As fungi are found to secrete high amount of protein they may result in the profound mass productivity of nanoparticles. In addition, the fungal proteins are capable of hydrolyzing metal ions. But the main advantage of the biological method is its ability to manipulate nanoparticle properties by gaining control over the size and shape of nanoparticles [37,55]. Also fungi have the potential to be scaled up for large-scale synthesis by producing huge amounts of extracellular enzymes which catalysis the heavy metal ions to produce the respective metallic nanoparticle of definite size and shape. Lastly, myco-nano synthesis offers simple downstream processing for product recovery with convenient biomass handling and the whole process is eco-friendly and cost effective.

## 9. Future insights

Nanotechnology is one of the most significant areas of research and its impact is obvious in our present day life. With the advancement of the technology, nanoparticles are expected to solve large scale puzzles using nanoscale solutions.

The biosynthetic route for the synthesis of metal nanoparticles using fungi is a simple process involving the reaction of fungal culture with aqueous solutions of metal ions. However, there are a number of questions, which need to be addressed here. The synthesis process points out that there are a number of reducing agents involved in the reduction of metal ions and corresponding formation of nanoparticles. These reducing agents also affect the size and shape of nanoparticles hence, there is a great need to study the exact mechanism involved in the biosynthesis of nanoparticles. Studies on the synthesis of nanoparticles of specific size and shape rely on different factors like temperature and light intensity. Biosynthetic approach for nanoparticle synthesis also needs to highlight the shape selectivity and size mono-dispersity of nanoparticles. Studying the novel shape and size dependent physical and chemical properties of nanoparticles and their subsequent interaction could help in creation of new generations of photonic and electronic devices that can control and manipulate light at nanoscale.

Investigation of low-cost recovery methods to make the synthesis process commercially feasible also needs to be undertaken. In addition, since silver and gold have the lion’s share in research, more studies are needed regarding mycosynthesis using less commonly used metals like copper and magnetite both *in vitro* and *in vivo* to evaluate their potentials

## 10. Conclusions

The fungi are now known to be an efficient incredible tool for green synthesis of nanoparticles by both intra- and extracellular methods. The fungal system has been studied for its compatibility over other

microorganisms as the handling of fungal biomass and its downstream processing is much simpler. A number of metallic nanoparticles including silver, gold, titanium, silica, zirconium and platinum have been successfully synthesized using the fungal species. The fungal-synthesized nanoparticles have been used successfully in a wide range of applications in different fields of science including medicines, pharmaceutical industry, agriculture and electronics. But there are certain areas which needed to be more explored before revealing the complete potential. The definitive mechanism of synthesis of nanoparticles is yet to be discovered. Understanding the exact mechanism involved in the synthesis of nanoparticles and the effect of different factors on the reduction of metal ions will help in developing low-cost techniques for the synthesis and recovery of nanoparticles. Thus, studying different practicalities and reducing agents involved in the synthesis of nanoparticles, would help in understanding the fungal system as one of the most efficient spectacular biosystems for synthesis of nanoparticles.

### Competing interests

The author declares no competing interests.

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