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Nanotechnology in Agriculture and Animal Husbandry

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Nanotechnology is basically the study and application of extremely small things (about 1 to 100 nanometres) which includes science, engineering, and technology at the nanoscale. Nanotechnology is the promising and emerging technology that has tremendous potential to revolutionize science fields, such as chemistry, biology, physics, materials science, and engineering including agriculture and livestock sectors. Nano is a Latin word meaning 'dwarf'. The concept nanotechnology was explained for the very first time in 1959 by renowned physicist Richard Feynman. However, the term was coined in 1974 by Norio Taniguchi of Tokyo Science University to describe semiconductor processes. Though nanotechnology is an emerging branch of science, it has been found to be naturally occurring as well as used by man since the early Roman Empire. Metal nanoparticles embedded in glass have been used to impart colour in the "stained glass" of medieval European cathedrals. Even in photography, the pixels of the images formed are silver nanoparticles generated by the photo-chemical decomposition of silver halides. The integration of nanotechnology into agriculture has given rise to a new era of innovation, enhancing various aspects of crop cultivation, pest management, soil health, and food production. Nanotechnology plays a crucial role in animal husbandry and livestock sector as it is used in nutrition, therapy, targeted drug delivery, preparations of vaccines, genetic manipulation, medical imaging and various purifications processes.

Why they are called as nanomaterials?

According to International System [IS] of Units, nano refers to the one-billionth or 10^{-9}. It is very difficult to imagine size of nanoparticles as they are much smaller than very tiny things like a strand of human DNA (2.5 nanometres in diameter), human hair (80000-100000 nanometres wide) and a sheet of newspaper (100000 nanometres thick).

Classification of nanomaterials

Nanomaterials are classified as Nanocages (10-150 nm), Nanocrystal (100 nm), Nanobelts (30-300 nm), Nanofiber (up to 1 um), Nanoparticles (1 nm), Nanotubes (0.4-40 nm), Nanowires (3-100 nm), Quantum Dots (QD) (10-50 atoms) and Nano-composites (up to 100 nm) based on shape/geometry.

On the basis of chemical nature, nanomaterials ae classified as Organic (Fullerene, Nanotubes, Nanofibers) and Inorganic (Metals, Metal oxides, Quantum Dots).

Synthesis of nanomaterials

Table 1. Various approaches for synthesis of nanomaterials

Physical approach	Chemical approach	Biological approach
•High energy ball milling • Inert gas condensation • Physical vapour deposition • Laser pyrolysis • Flame spray pyrolysis • Electrospraying • Melt mixing	• Sol-gel synthesis • Micro-emulsion synthesis • Hydrothermal synthesis • Polyol synthesis • Chemical vapour deposition • Plasma enhanced chemical vapour deposition	• Biogenic synthesis using microbes • Biomolecules as template to design nanomaterials • Plant extract for nanomaterial synthesis

There are two broad approaches for synthesis of nanomaterials - one being the top-down approach, in which a bulk material is manipulated to have one or more dimensions in the nonorange. Whereas, bottom-up approach focuses on self-assembly. Synthesis of nanomaterials using plant extracts such as sugars, polyphenols, terpenoids, proteins, etc. act as a reducing agent to maintain the minerals in reduced state. Also, their excretory products are highly biodegradable and hence no adverse effect to the environment.

Application of nanotechnology in agriculture

Nanomaterials can be used directly into the soil as fertilizers or can be given to roots or shoots to provide nutrients. They are used for Foliar Spray, Floral Spray, Pre seed treatment and post-harvest operations along with clean the water bodies (purification) which provide water for agriculture.

Also, they can be used as pesticides, insecticides, weedicides.

Nano Iron Pyrite (FeS_2) is one of the most studied and most useful nanomaterial which can be used for almost all types of crop plants. Stoichiometric defect in pyrite releases traces of hydrogen peroxide, iron ion, and sulphate ion. The hydrogen peroxide traces thus released helps in increasing the germination rate by mimicking amylase action and thus breaking the carbohydrates in seed faster. Using Iron pyrite for enhancing germination shows some long term effects in crops such as increase in biomass, increase in germination rate, increase in root length and shoot length, significantly bigger leaves, higher chlorophyll contents (which traps more sunlight) and increased contents of Mn, S, Ca and other nutrients.

❖ **Precision Farming**

In this type of farming, crop yield is maximized and the usage of pesticides, fertilizers and herbicides is minimized through efficient monitoring procedures. It utilizes remote sensing devices, computers, real-time data and global satellite positioning systems to analyze various environmental conditions in order to determine the plant development, soil conditions, nutrient levels, usage of water and chemicals, fertilizers and seeding and disease presence at nanoscale. For example, plant disease management is achieved with the help of nano silver or titanium oxide nanoparticles. Zinc spray is used to enhance the quality of agricultural products.

❖ **Efficient Nutrient Delivery**

Encapsulating active agricultural ingredients, such as fertilizers, pesticides, and herbicides, within nanoscale particles enhances the efficiency of delivery, ensuring controlled release, avoids degradation and targeted application of these substances. For example, slow release of agrochemicals like acetamiprid and hexaconazole minimize the potential risks associated with traditional chemical applications, making agriculture more sustainable.

❖ **Nano fertilizers**

These are the modified form of traditional fertilizers emerged as a promising solution to address the challenges of nutrient management in agriculture. They are extracted from different vegetative or reproductive parts of the plant by different chemical, physical, mechanical or biological methods with the help of nanotechnology to improve soil fertility, their efficient utilization by crops, minimizing wastage and nutrient runoff. Uptake and utilization are improved due to large surface area and small particle size of nano fertilizers.

For example, application of zinc and iron on the plant increase total carbohydrate, starch, chlorophyll and protein content in the grain. Nano-Fe2O3 increases photosynthesis and growth of the peanut plant.

❖ **Nanobiotechnology**

It offers immense potential for crop improvement through various techniques, including nano genomics and nano biomaterials. Nano genomics can develop genetically superior crops that are more resistant to pests, diseases, and environmental stressors. It can be used to deliver DNA and other desired chemicals into plant tissues for protection of host plants against insect pests. Nano biomaterials can stimulate plant growth, enhance photosynthesis, and improve overall crop productivity by manipulating nanoparticles and using plant tissue engineering and regeneration.

❖ **Nano-enabled food technology**

Nanotechnology has contributed significantly to improving food safety and quality, by reducing post-harvest losses and ensuring longer shelf life. Nano capsules delivery systems, nanodrops etc. play an important role in processing sector by encapsulating simple solutions, colloids, emulsions, biopolymers and others into foods. Nano sensors can detect contaminants and pathogens in food products. For example, nano sensors include gold nano particle incorporated enzymes are used for microbes' detection. Nanofibrils of perylene-based fluorophores indicates fish and meat spoilage by detecting gaseous amines. Whereas, zinc oxide and titanium oxide nanocomposites detect the volatile organic compounds. Nano barcodes are used for tagging and security.

Application of nanotechnology in animal husbandry and livestock

With regard to animal husbandry, major applications of nanotechnology are in administration of nutrients, supplements, probiotics and drugs, diagnosis and treatment of diseases, reproductive aid, biocides, nano vaccines, genetic manipulation and food safety. Different mechanisms of action of Nanoparticles may include, increasing the surface area for better interaction and distribution with biological support, prolonged retention time in gut, penetrate deep into tissues by fine capillaries thereby ensuring efficient uptake, cross epithelial lining fenestration, effective delivery of functional compounds to target sites and ultimately better bioavailability.

- **Livestock and Poultry Feeding**

The application of nanotechnology in animal feeding is mainly in the form of nano-minerals. Nanoparticles increase the absorption of trace minerals by reducing mineral-mineral/mineral-vitamin antagonism and thereby increase the bioavailability which is a main concern. Studies have suggested that feeding of nanoparticles improved the digestive efficiency, immunity and performance in livestock and poultry. Supplementation of nano-zinc in the basal diet of broilers showed improved immune status and bioavailability along with inhibition of mycotoxin fungi. Sheep supplemented with nano-selenium significantly reduced ruminal pH and ammonia concentration and increased total VFA (volatile fatty acids) concentration, immunity and final body weight. Feeding of silver nano particles in pig and poultry as an antibiotic growth promoter significantly reduced the microbiota of gut. Though studies are limited, this novel approach holds greater promises for sustainable livestock future by eliminating antibiotic residue and ensuring better utilization of feed.

- **Disease diagnosis and treatment**

Nanoparticles have developed new mechanisms for pharmaceutical uptake and release in nanomedicine, potentially serving as methods to reduce lag times between drug delivery and its effect. Being an emerging and efficient diagnostic tool, metallic and nanostructured particles can be used to visualize the status of a cell or drug distribution in the body. Molecular based lab-on-a-chip technologies are available for qualitative and quantitative biological analyses. Drug delivery can be monitored through fluorescent nano-carriers. For example, light activated, fluorescent nanostructured glucose and sucrose-derived nanoparticles can be used to monitor the localization of bound chemotherapies.

- **Nano vaccines**

Nano vaccines are based on the principle of self-assembling proteins, virus-like particles, liposomes, virosomes, and polymeric nanoparticles. They offer novel, safe, and high-potential approaches. Nano vaccines have encapsulation ability and serve as effective vehicles for antigen delivery and immunostimulatory agents due to their small size and large surface area. Research on nano vaccines for thileria, FMD (foot and mouth disease), New castle disease has been carried out.

- **Reproductive aid**

In order to optimize the efficiency of artificial insemination, Quantum dots can provide targeted or non-targeted imaging as a function of size, emitted wavelengths, and conjugation possibilities of sperm. Nano purification of semen can be used to separate damaged sperm from undamaged, healthy sperm. Addition of nano-protectant additives in extenders ensures Cryopreservation of sperm by providing sperm with nutrients required for prolonged storage. Further advancements in reproductive biotechnology may be possible with sperm-mediated gene transfer, where mesoporous silica nanoparticles can be loaded with nucleic acids and proteins which form strong associations with spermatozoa in vitro, and have no tiny effect on sperm function or quality. Transfections with polymeric nanoparticles have been reported to be advantageous.

- **Food safety**

Novel foodborne pathogen detection techniques such as nanocomposites containing anti-S. aureus antibodies, gold nanoparticles, and magnetic nanoparticles provide a calorimetric test for the presence of S. aureus in milk thereby ensuring the quality of milk for human consumption. Immunochromatographic strips containing polyclonal antibodies and gold nanoparticle can detect the toxins present in milk within 10 minutes. Inclusion of nanoparticles (e.g. Chromium) in feeding of pig and poultry enhances the meat and egg quality.

Table 2. Application of various nanomaterials in agriculture and animal husbandry

Sr. no.	Nano material	Application in Agriculture	Application in Animal Husbandry
1.	Silver	Increases germination rate	Antibiotic growth promoter and prevents wound infection
2.	Zinc	Increases stress tolerance	Feed additive in poultry
3.	Zinc oxide	Increase in root length, shoot length, biomass, root dry mass and fruit starch	Aid in reproduction, food safety
4.	Carbon nano tubes	Increases germination and overall growth	Monitoring drug delivery
5.	Iron	Increase in dry weight and chlorophyll content	Diagnosis in veterinary medicine
6.	Copper	Increases photosynthetic rate, plant biomass, root and shoot length	Nutrient delivery and Biocide
7.	Gold	Enhancing seed germination, plant growth and development	Biocide, nano vaccine and food safety
8.	Lipid nano particles	Plant growth promoter	Nutrient delivery
9.	Selenium	Control of pests and diseases	Increases immune status and overall performance of animals
10.	Calcium carbonate	Increase in seedling growth	Nutrient delivery and increases bioavailability

Conclusion

The integration of nanotechnology into agriculture and animal husbandry holds immense promise for transforming the future of food production. From precision farming to nanobiotechnology and from feed additives to nano vaccines, these advancements offer sustainable solutions to create a more efficient, sustainable, and resilient food system for a growing global population. Though the technology is attaining constant development with varied applications, further research and development are still needed to address concerns regarding the potential environmental and health impacts of nanomaterials. The production of nano particles by green synthesis could be exploited as a viable alternative to the chemical synthesis method thereby ensuring biosafety and one health of the planet.

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