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Role of Nanotechnology in Poultry Nutrition

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ABSTRACT

Nanotechnology is a promising and emerging technology that has tremendous potential to revolutionize poultry sector in India as well as all over the globally. The word nano technology is derived from the Latin word "nanus" meaning dwarf. Nanoparticles are generally having the dimensions between approximately 1 and 100 nanometers. So these nanoparticles can bypass the physiological ways of nutrient distribution and transport across tissue and cell membranes, and have more bioavailability to the target sites. Nanotechnology is an innovative technology which finally create materials and change structure, enhanced quality and texture of foodstuffs at the molecular level. This technology has a major impact on production, processing, transportation, storage, safety and security of food for both human and animal purpose.

Key words: *Nanoparticles, poultry, properties and preparation.*

INTRODUCTION

Indian poultry sector has been growing at around 8-10% annually over the last decade with broiler meat volumes growing at more than 10%, and table egg growing at 5-6% [11]. Microminerals participate in several biochemical processes and are parts of many enzymes which are necessary for normal biochemical reactions. Recently trace minerals in the form of nanoparticles are effectively used to fulfill the requirement of minerals in the poultry diets. Due to their extreme small size and unique physical properties, the nanoparticles are likely to be different when compared to their conventional forms. As a feed additive, these are expected to have the advantage of better bioavailability, small dose rate and stable interaction with other components. Although potential of nanotechnology in broiler production cannot be fully appreciated yet because of insufficient knowledge. From another point of view, feeding certain antibiotics at low levels in poultry for an extended period of time is a common practice in the poultry industry to improve bird's feed efficiency[26]. But recently, in-feed antibiotics has been banned due to the potential development of antibiotics-resistant bacteria and their residues in poultry production[2, 17, 27].

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Nano form of supplementation increases the surface area which possibly could increase absorption and thereby utilization of minerals leading to reduction in the quantity of supplements and ultimately reduction in feed cost. The growing concerns with regard to the potential contribution of phosphorus in poultry excreta on eutrophication of surface waters has led to increasing pressure to limit the amount of excess phosphorus in poultry ration and thus reduce faecal output of phosphorus. Mineral nanoparticles will be helpful in reducing the excretion of unutilized minerals minimizing the environmental pollution especially in large scale poultry farming.

In the field of veterinary medicine and poultry production there is a growing interest in the application of nanotechnology and various compounds are used as a supplemental source of trace minerals (Na_2O, MgO, Al_2O_3, SiO_2, K_2O, CaO, TiO_2 and Fe_2O_3) in diets. Nanotechnology can also reduce the time of production of meat and eggs. The potential of nanotechnology in broiler production cannot be fully appreciated yet because of insufficient knowledge. Feeding certain antibiotics at low levels for an extended period of time is a common practice in the poultry industry and provides economic benefits by increasing weight gain and improved feed efficiency[26]. With this background, they can replace antibiotics as growth promoters, eliminate the residue of the antibiotics in the animal products, reduce the environmental contamination[9, 22.]

Among these minerals one important mineral is “zinc”. Zinc participates as a cofactor or component of more than 240 enzymes and important for protein, carbohydrate metabolism, growth and reproduction.The most common forms of zinc used in feeding of poultry are zinc sulphates, zinc carbonates, zinc methionine, zinc proteinate etc. Iron is also essential for poultry and supplemented in their diets. Iron is an integral part of many proteins and enzymes that maintain good health and helps in oxygen transport. Another is selenium which is a part of oxidative enzymes of over 30 separate selenoproteins, especially oxidative enzymes such as glutathione peroxidase (GSH-Px) which contains this micro element in its active place [23].The activity of glutathione peroxidase depend on present adequate Se in diet and defend the body cells from damages induced by different factors (thermal stress, disease, toxin and so on) that stimulate oxidative stress condition and produced free oxygen and radical[1].

Properties of nanoparticles:

1. Surface effects: The atoms of nanomaterials are less stable than those of larger structures since the energy required to join adjacent atoms is less. As a consequence of this, the fusion point of a given element changes. For example, the fusion point of a gold particle measuring 2.5 nm is about 930K (≈ 657°C), which is much lower than 1336K (≈ 1,063°C), the normal fusion point of this metal at greater volumes. Nanoparticles diffuse more easily than solid particles and behave more like gas molecules in the air and being less subject to sedimentation than bigger particles. This may have implications also for the faster movement of nanoparticles in tissue.

2. Quantum effects: Quantum points are a type of nanostructures, just a few nanometers in size that show a behavior similar to a single atom. Their spatial arrangement allows them to have properties not proper to the element, such as magnetism in metals like gold or platinum when they are in the form of nanoparticles.

Table 1: Types of Nano materials used in Animal Nutrition Research[5]

Category	Materials	Application
Nanoparticles	**Iron**	Food/Feed supplement
Inorganic	**Silver**	Food/Feed supplement, antimicrobial agent
	Iridium	Food/Feed supplement
	Platinium	Food/Feed supplement
		Food/Feed supplement/colourant
	Zinc	Encapsulation and targeted delivery of food/feed component
Organic	**Liposomes**	
	Protein	Re-micellised calcium caseinate from dairy protein, increased functionality(gelatin, heat stability and other properties)
Nanoclays	**Clay composites**	Used in packaging materials to extend the shelf-life, durability and thermal properties.
Nanoemulsions/dispersions		
Emulsions	**Oil in water**	Stabilization of biologically active ingredients; delivery of active compounds.
Dispersions	**Calcium carbonate**	Increased solubility of calcium carbonate
Nutriceuticals	**Metal**	feed supplements at the nanoscale
	Natural	nanoparticle additives to food/feed products

Inorganic nanomaterials

Inorganic nanomaterials for applications in feed and feed additives include nano clay platelets for feed packaging; minerals such as silicon dioxide, calcium and magnesium; and silver nanoparticles for water purification or antimicrobial packaging or feed storage, zinc as a feed colourant. Titanium dioxide, a feed colorant used as a UV protection barrier in feed packaging industry is an approved inorganic nanoparticles because it becomes transparent and also loses its ability to act as a feed colorant in its nano form The nanoparticles of silver are used as an antimicrobial agent. Nano silver is used in fridge panels, storage boxes, packaging lines and other surfaces which come into contact with feed during manufacture. Feed storage bins are being produced with silver nanoparticles embedded in the plastic which kills bacteria from any feed that are stored in the bins and minimize the health risks.

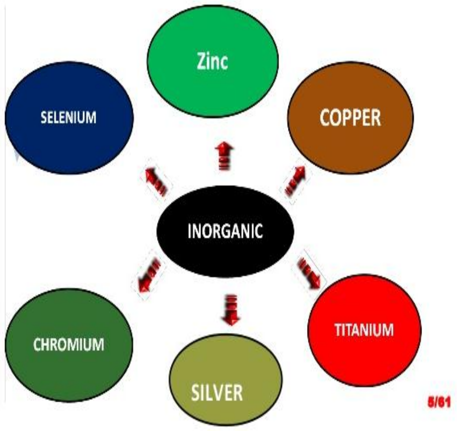

Fig. 1: Inorganic nanomaterials

Organic nanomaterials

Organic nanomaterials include proteins, fat and sugar molecules. Nutraceuticals consisting of feed additives derived from plants are also organic nanomaterials used in feed. The nanoparticles incorporated into feeds include those engineered to provide encapsulation systems e.g., micelles, liposomes, for delivery of feed ingredients and those tailored for use in feed packaging such as biosensors, identification markers, shelf-life extenders and antimicrobials. Organic nanoparticles are sometimes referred to as nanocapsules (when used as vehicles for delivery of essential nutrients or pharmaceuticals), are likely to be used to enhance the nutrient value of feed through improvement or alteration of feed functionality. These nanoparticles have been designed to deliver vitamins or other nutrients in feed without affecting the taste or appearance. Such nanoparticles encapsulate the nutrients and carry them via the gastrointestinal tract (GIT) into the bloodstream to increase their bioavailability.

Digestion and absorption of nano particles

Nanoparticles show several novel characteristics of transport and uptake and exhibit higher absorption efficiencies[7, 31, 15]. Nanoparticles can rout to the gastrointestinal tract (GIT) in many ways such as ingestion directly from food and water and from administration of therapeutic nano-drugs (ingestion or swallow pathway). Inhaled nanoparticles can also be swallowed and enter the GIT following clearance from the respiratory tract (inhalation pathway[10]). Finally, oral or smart delivery into GIT (oral pathway); particle uptake in the GIT depends on diffusion and accessibility through mucus and contact with the cells of the GIT. Smaller the particle diameter faster is the diffusion through GIT mucus to reach the cells of intestinal lining, followed by uptake through GIT barrier to reach the blood[10]. Uptake of nanoparticles from the intestinal tract occurs variously by passive diffusion across the mucosal cells, via active transport mechanisms[18]. Nanoparticles that are swallowed will sooner or later end up in the intestinal tract. It is not known clearly whether nano particle remain in the intestinal tract unabsorbed and excreted through feces as ‘unwanted substance’ or move into the body system readily. Existing evidences indicate that the particles smaller than 100 nm are absorbed in various tissues and organs. As a general rule, smaller the particles are, the more they are absorbed and deeper they can go into the body system. Insoluble nanoparticles (primarily inorganic, including man-made polymeric materials e.g., polystyrene and carbon-based nanoparticles e.g., fullerenes) might have a more restricted distribution. Following uptake from the GIT, nanoparticles can translocate via the lymph system to the liver and spleen, as demonstrated for polystyrene nanoparticles of 100nm or less[12]. Smaller particles that are capable of being taken up by the villus epithelium may directly enter the bloodstream, and are then predominantly scavenged by the liver and the spleen. The intestinal uptake of inorganic, insoluble nanoparticles such as titanium dioxide and gold particles will be readily taken up across the intestinal barrier and hence are bioavailable than their micro or macro equivalents. Uptake is largely determined by particle solubility, charge and size.

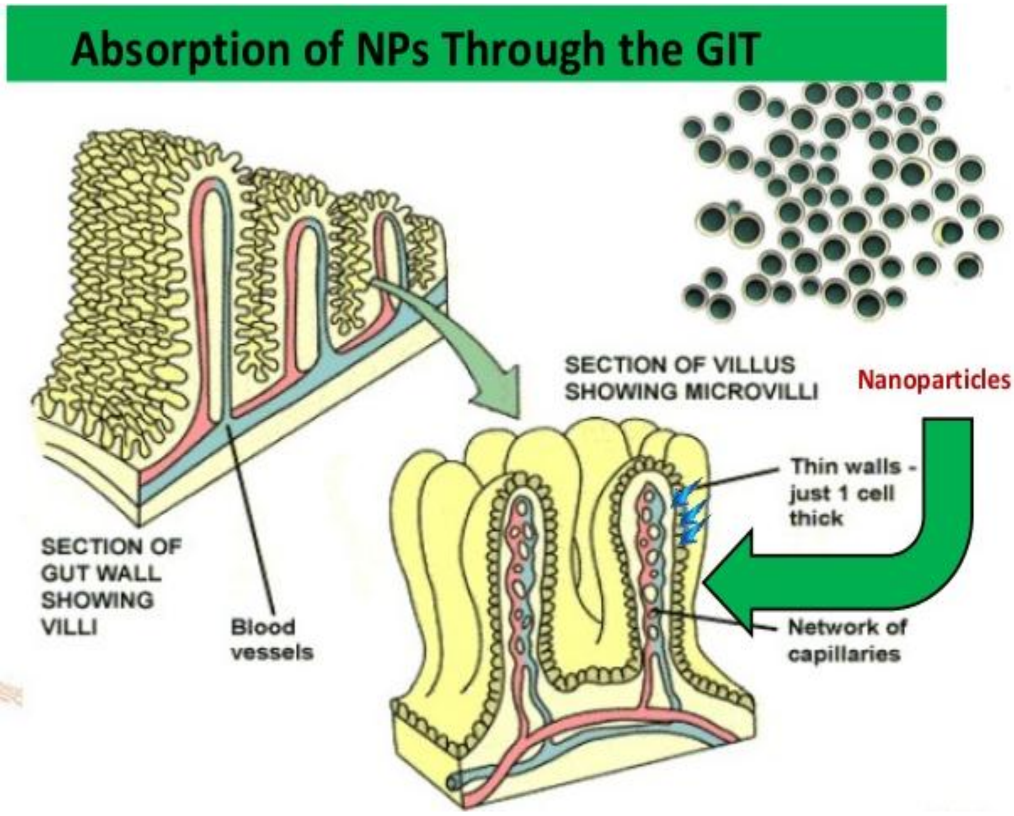

Fig. 2:

A number of experimental studies have demonstrated uptake of nanoparticles across the GIT following oral administration. Uptake of inert particles has been shown to occur trans-cellularly through the intestinal lining and to a lesser extent between epithelial cells[12]. Organic nanoparticles such as casein micelles are likely to behave similarly to their micro or macro equivalents and can be predicted to be readily absorbed and highly bio-available. It is not understood whether higher molecular weight organic nanoparticles such as proteins, fats or carbohydrates are broken down to lower molecular weight entities in the GIT in the same way as the native molecules are, or taken up intact. However recent evidence showed that insulin encapsulated in vitamin B12-dextran nanoparticles are taken up from the GIT without degradation[6].

Mechanism of action of nanoparticles:

- Action of the nanoparticles is described below[3]:
- Increase the surface area available to interact with biological support
- Prolong compound residence time in GIT
- Decrease influence of intestinal clearance mechanisms
- Penetrate deeply into tissues through fine capillaries
- Cross epithelial lining fenestration (e.g. liver)
- Enable efficient uptake by cells
- Efficient delivery of active compounds to target sites in the body.

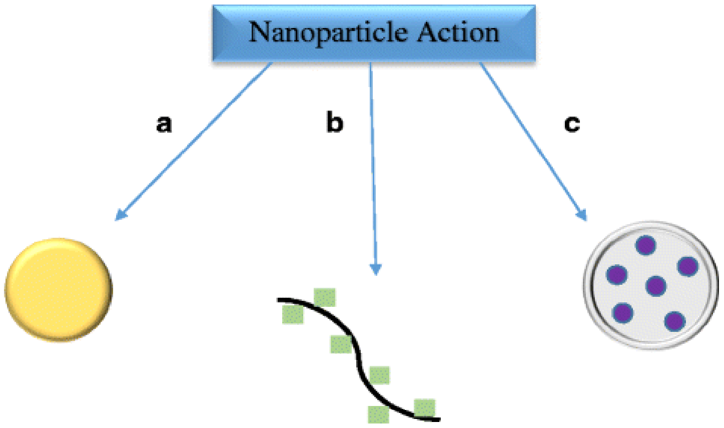

Fig 3: Nanoparticles can serve as the functional unit (a) but can also act as a delivery vehicle for materials conjugated to their surface (b) or encapsulated within (c)

Preparation of nanoparticles of different trace minerals

The preparation of nanoparticles varies and depends on the type of material and purpose for which they are intended to be. Nano form of copper can be produced by electrochemical method. A feed grade copper sulfate solution was subjected to electrolysis using copper rods as anode and cathode. The flow of a steady current into the electrolytic cell caused the ionization and disassociation of copper sulfate solution which removed the copper from the anode and deposited it in the cathode. Such deposited copper, was collected dried, yield determined, and characterized[25].

Preparation of nano selenium particles by water solution phase method from industrial dust[20]. Selenium powder 0.1 g was mixed with 2.4 g sodium hydroxide in 40 ml of distilled water. The contents were maintained at a temperature of 140°C for 1 h. The contents were then cooled to room temperature, filtered and washed using water and ethanol. The residue was dried yield determined and characterized.

Nano form of zinc can be produced by a chemical method using starch as a stabilizing agent. Starch solution (0.5%) was prepared and 20-50 ml of 0.2 M zinc acetate dihydrate was added with few drops of 0.2 M of sodium hydroxide. The pH was adjusted to 8.5 using 0.2 M NaOH. The contents were stirred continuously at 100°C. A milky white colloid was obtained; the colloid was stirred for 2 h and centrifuged at 9000 rpm for 15 min. The sediment was filtered and washed using initially acetone, followed by ethanol and water. After which the sediment was dried in hot air oven at 80°C for 3 h. Thus, produced nano form of zinc's yield was determined and characterized[29].

Iron nanoparticles were produced by co-precipitation from an aqueous Fe3+/Fe2+ solution (ratio 3:2) using concentrated ammonium hydroxide in excess. 14.6 g of $FeCl_3$ and 12.0 g of $FeCl_2 .4H_2O$ were dissolved in 50 ml distilled water, 40 ml of ammonium hydroxide were added rapidly. The mixture was centrifuged and precipitate was removed. The precipitate was washed for three times with highly purified water to remove the unreacted chemicals, then the product was dried in the vacuum. The brown mixture was then aged at 110°C for 6h to evaporate water and excess of ammonium. The black lump like residuum was cooled to room temperature and washed several times with distilled water. After drying, a powder was obtained. Iron oxide nanoparticles were identified by different analytical methods[21].

Green synthesis: The term green synthesis indicates that the preparation of a nano-material by exploiting the nanotechnology and plant biotechnology together. The plant extracts plays an important role in reduction of particle size in metal ions. The extracts containing various compounds are such as sugar, alkaloids, polyphenols, proteins, etc. These compounds in addition give stability to the metal ions (Fig. 1). The nano particles synthesized by this method will be of different colors like gold, gray and yellow based on the source of plant material used.

Development of suitable carriers remains a challenge due to the fact that bioavailability of these molecules is limited by the epithelial barriers of the gastrointestinal tract and their susceptibility to gastrointestinal degradation by digestive enzymes. Polymeric nanoparticles allow encapsulation of bioactive molecules and protect them against enzymatic and hydrolytic degradation. The gastrointestinal tract provides a variety of physiological and morphological barriers against protein or peptide delivery, e.g. (a) proteolytic enzymes in the gut lumen like pepsin, trypsin and chymotrypsin, (b) proteolytic enzymes at the brush border membrane (endopeptidases), (c) bacterial gut flora and (d) mucus layer and epithelial cell lining itself[13]. One important strategy to overcome the gastrointestinal barrier is to deliver the drug in a colloidal carrier system, such as nanoparticles, which is capable of enhancing the interaction mechanisms of the drug delivery system and the epithelia cells in the GIT. Targeting of nanoparticles to epithelial cells in the GI tract using ligands, targeting strategies to improve the interaction of nanoparticles with adsorptive enterocytes and mononuclear cell (M-cells) of Peyer's patches in the GI tract can be classified into those utilizing specific binding to ligands or receptors and those based on nonspecific adsorptive mechanism. The surface of enterocytes and M cells display cell-specific carbohydrates, which may serve as binding sites to colloidal drug carriers containing appropriate ligands. Certain glycoproteins and lectins bind selectively to this type of surface structure by specific receptor mediated mechanism.

Minute micelles (nanocapsules) are used as carriers for essential oils, flavor, antioxidant, coenzyme Q10 and vitamins, minerals and phytochemicals to improve their bioavailability[4]. Encapsulating the nanoparticles of active ingredients (e.g. minerals and micronutrients) to protect them from oxidation and getting to the taste receptor site, thus to reduce their undesirable off-tastes in the finished application[8]. In food industry application of liposomal nanovesicles for the encapsulation and delivery of nutrients and functional ingredients such as proteins, enzymes, flavors and antimicrobial compounds were conducted[28]. The particle size of minerals as feed additives in nanoparticle form is claimed to be smaller than 100 nanometre so, they can pass through the stomach wall and into body cells more quickly than ordinary minerals with larger particle size and effectively used to ful fill the requirement of minerals in the poultry feed.

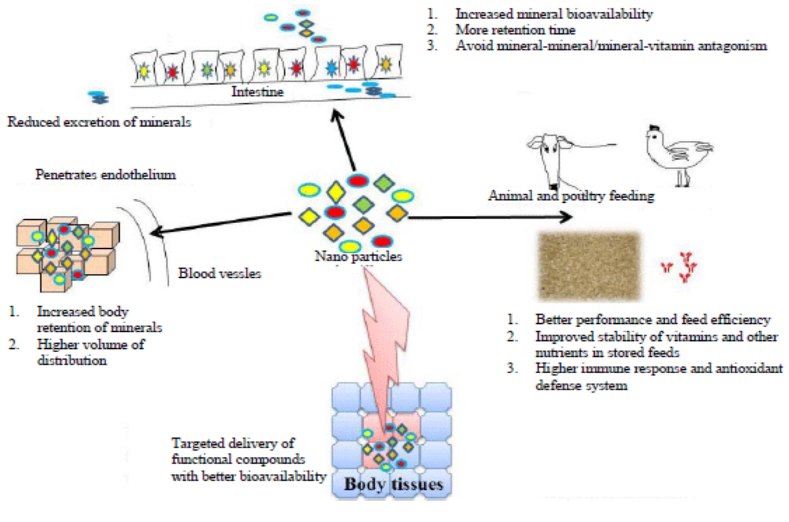

Fig 4: Applications of nano-particles in poultry nutrition

Remove enteric pathogen in poultry

Nanoparticles in poultry had given to remove the *Campylobacter*[13] (harmful for human consumption not for birds). When the nanoparticles added feed is ingested by the birds these nanoparticles attach to *Campylobacter*, ensures its excretion. Nanoparticles would be specifically designed to attach on to molecules that exist on the surface of *Campylobacter* and removed from chicken before they reach humans. Such nanoparticles are called as biofunctionalized nanoparticles (BN) which have been developed as an alternative to mannose through which *Campylobacter jejuni* attaches to the epithelial cells[24, 16, 19].

Thus nanotechnology can be applied in the production of nanoparticles which can be used in improving the digestion and absorption as novel food additives. Applications of nanotechnology are ever more varied and specific, with a high potential for improving poultry production. Thus nanoparticle incorporation in animal nutrition studies greatly enhance the efficiency of growth and production of poultry. However, a great amount of research is still required to support the effectiveness, and mainly the safety of nanotechnology, avoiding any harm to the birds.

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