Use of Nano Feed Additives in Livestock Feeding

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Abstract

The word nano is derived from the Latin nanus, meaning dwarf. Nanotechnology is the study of phenomena and the manipulation of materials at the nano scales, where the properties differ from those at a larger scale. Manipulation of matter at the nanolevel opens up possibilities for improving the functionality of feed molecules to the benefit of productivity of livestock. Nanotechnologies have the potential to improve nutritional assessment, to acts as novel vehicles for nutrient delivery, as well as serving as a tool to enable further elucidation of nutrient metabolism and physiology. The particle size of minerals as feed additives in nanoparticle form can pass through the intestinal wall and into body cells more quickly than ordinary minerals with larger particle size and thus improves bioavailability. There are challenges with the emergence of nanonutrients that include alter metabolism, toxicity and the environmental impact of nanoscale materials compared with microscale materials, therefore, economical, social, ethical and legal implications of nanotechnology must also be considered. Thus, nanotechnology can be used in animal feeding to improve bioavailability of nutrients, production performance and immune status in livestock.

Key words: Nanotechnology, Feed additive, Nutrient bioavailability, Production performance, Immunity

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Introduction

The word nano technology is derived from the Latin *nanus*, meaning *dwarf*). Nanoparticles are of different types based on their ability to carry different ingredients and react to different environmental conditions. Nanotechnology is defined as the understanding and control of matter at the nanoscale, at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications" according to National Nanotechnology Initiative (2013), USA. A nanometer is one billionth of a meter. The typical nanotechnology utilizes structures under 100 nanometer in size, more than 1000 times narrower than the diameter of a human hair.

History of Nanotechnology

The concepts that seeded nanotechnology were first discussed in 1959 by renowned physicist Richard Feynman in his talk *There's Plenty of Room at the Bottom*, in which he described the possibility of synthesis via direct manipulation of atoms (Feynman, 1959). The term "nano-technology" was first used

by Norio Taniguchi in 1974, though it was not widely known. Inspired by Feynman's concepts, K. Eric Drexler independently used the term "nanotechnology" in his book *Engines of Creation: The Coming Era of Nanotechnology*, which proposed the idea of a nanoscale "assembler" which would be able to build a copy of itself and of other items of arbitrary complexity with atomic control. Also in 1986, Drexler co-founded The Foresight Institute to help increase public awareness and understanding of nanotechnology concepts and implications. Thus, emergence of nanotechnology as a field in the 1980s occurred through convergence of Drexler's theoretical and public work, which developed and popularized a conceptual framework for nanotechnology, and high-visibility experimental advances that drew additional wide-scale attention to the prospects of atomic control of matter.

Differences between nanomaterials and larger materials

The physical, chemical, electrical, optical, mechanical, and magnetic properties at an atomic scale are quite different from those present at a larger scale, even when compared with those present at a scale of microns (10^{-6}) (Buzea *et al*., 2007). Nanomaterials are different from larger ones because of two effects:

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 657°C, which is much lower than 1,063°C, the normal fusion point of this metal at greater volumes. Cao (2004) mentioned that this phenomenon is characteristic in metals, inert gases, semiconductors and molecular crystals when the size of the particle is less than 100 nm.

2. **Quantum effects**

Quantum points are a type of nanostructures, just a few nanometers in size that show a behaviour 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.

Classification of Nanoparticles

Nanoparticles can be broadly divided into inorganic, organic, emulsions, dispersions and nano clays based on the chemical characteristics of the nanoparticles (Table 1).

Inorganic nanoparticles are inorganic ingredients manufactured at the nanoscale and various feed additives are already approved for use in feed, e.g. titanium dioxide, a feed colorant, can be used as a UV

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protection barrier in feed packaging when used as a nanoparticle. The most common application is the use of nanoparticles of silver as an antimicrobial. Applications for nanosilver include use 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, killing bacteria from any feed that was previously stored in the bins and minimising health risks. Inorganic nanomaterials for applications in feed, feed additives, food packaging or storage 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.

Organic nanoparticles are likely to be used to enhance the nutrient value of feed systems through improvement or alteration of feed functionality. Organic nanoparticles also referred to as nanocapsules have been designed to deliver vitamins or other nutrients in feed without affecting the taste or appearance. These nanoparticles encapsulate the nutrients and carry them via the gastrointestinal tract (GIT) into the bloodstream, increasing their bioavailability. Also, several types of nanomaterials are considered relevant for applications in feed. Organic nano-materials include proteins, fat and sugar molecules. Nutraceuticals consisting of feed additives derived from plants are also organic nanomaterials used in feed. Nanoparticles already reported to be incorporated into foods/feeds include those engineered to provide encapsulation systems, e.g. micelles, liposomes, for delivery of food/feed ingredients, and those tailored for use in food/feed packaging such as biosensors, identification markers, shelf-life extenders and antimicrobials (FSAI, 2008).

Table 1: Types of nano materials used in animal nutrition research (FSAI, 2008)

SN	***Category***	***Example***	***Application***
1	**Nano Particles**		
	Inorganic	Iron	Food/Feed supplement
		Silver	Food/Feed supplement antimicrobial agent used in feed/food
		Zinc	Food/Feed supplement, colourant
		Platinum	Food/Feed supplement
		Iridium	Food/Feed supplement
	Organic	Liposomes	Encapsulation and targeted delivery of feed/food components
		Protein	Re-micelled calcium caseinate from dairy protein. Increased functionality (gelatation, heat stability and other properties)
		Polymeric	Non-degradable: Polysterene Bio-degradable: Gelatin, Collagen
2. Nanoemulsions/dispersion			
	Emulsions	Oil in water	Stabilisation of biologically active ingredients for delivery of active compounds: extended shelf-life; flavour release; low fat products
	Dispersions	Calcium Carbonate	Increased solubility of calcium carbonate can be used at higher additional levels.
3.	**Nanoclays**	Clay composites	Used in packaging materials to extend shelf-life durability, and thermal properties.

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Preparation of Nano Particles

There are different methods for the preparation of nanoparticles. The selection of any of these methods depends on the particular objectives and conditions for where and how they obtained particles are meant to be used. Thus, it is necessary to consider the physical and chemical stability of the active agent, as well as its toxicity, its liberation profile, among many other considerations. Agnihotri *et al*. (2004) specifies some common methods for the preparation of nanoparticles, such as:

1. **Cross-linking emulsion**

In this method, a water-oil (w/o) emulsion is prepared through emulsification of a watery solution in an oily phase, which when shaken vigorously separates and hardens the particles. It requires the use of agents that facilitate the union of the involved agents.

2. **Precipitation/ coacervation**

In this case, the particles are produced by "blowing" the interest agent in an alkaline solution. The separation and purification of the particles is done through filtration and centrifugation, followed by rinsing with hot and cold water.

3. **Spray-drying**

This is one of the best-known techniques used to produce dusts, granules, or agglomerates, besides being an easy and quick way to do it. It is based on the drying of droplets sprayed into compressed hot air. It requires the use of a solvent (for example, a solution of acetic acid), which is instantly evaporated, allowing the formation of particles.

The shape of the nanoparticles strongly influences its biological behaviuor. These are spherical, rectangular discs, cones, canes, worms, elliptical or circular discs, rolls, among many others. All these can come up in the 1st, 2nd or 3rd dimension, depending on the preparation method and the materials used. The viscosity and thickness of the material used determines whether the particle will show sharp or flattened endings. It is even possible that the nano particles will show regions with different curvature, texture, concavity, and other characteristics (Champion *et al*., 2007).

Besides capsules, other nano structured materials can be used, which have the potential of changing the structures of other particles. Some specific examples of these are fullerenes (structures made up of 60-80 carbon atoms arranged in spherical shapes, used for the controlled liberation of medication), dendrimers (branched structures which, due to their structure, can serve as vehicles for medication, liberating it in a

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specific location), and quantum dots (nanometric crystals designed for optical and electronic applications. When a quantum dot is stimulated, it emits a fluorescence of varying intensity) (Scott, 2005).

Mechanism of Action of Nanoparticles

The mechanisms of action of the nanoparticles are as follows (Chen *et al.,* 2006) below:

- 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

Application of Nanotechnology in Animal Feeding

There are mainly four possible applications of nanotechnology in animals -

- Administration of medication, nutrients, probiotics, supplements and other substances,
- Diagnosis and treatment of diseases with nanoparticles that allow the detection and elimination of the cause of the disease without the need for surgery,
- Identity registry that allows a follow up on the history of an animal and its products (meat, milk, eggs, mainly) and
- Management of reproduction with hormonal immunosensors.

Nanoparticles can enter the gastrointestinal tract (GIT) in many ways such as ingestion directly from food, water, administration of therapeutic nano-drugs (*Ingestion or swallow pathway*) and the respiratory tract (*Inhalation pathway*) (Hoet *et al.,* 2004). Nanoparticles diffuse more easily than solid particles and behave more like gas molecules in the air and like large molecules in solutions, being less subject to sedimentation than bigger particles. This may have implications also for the movement of nanoparticles in tissue. The smaller the particle diameter the faster is the diffusion through GIT mucus to reach the cells of the intestinal lining, followed by uptake through the GIT barrier to reach the blood. In a particle translocation experiment (Jani *et al.,* 1990), polystyrene spheres (50 nm-3 μm) were fed by gavage to female rats for 10 days, and the results demonstrated that about 34 and 26% of nanoparticles (50 and 100 nm, respectively) were absorbed while particles larger than 300 nm were absent from blood, heart or lung tissue. Depending on size, nanoparticles either pass through the GIT without uptake into the body and are eliminated rapidly (Oberdorster *et al.,* 2005), or they cross the lining of the GIT and enter the blood stream, from whence they relocate to other organs. Following uptake by the GIT, gold nanoparticles of less than 50nm translocated to the blood stream and distributed all over the body. As with absorption, the

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distribution, breakdown and excretion of nanoparticles in the body will be dependent on physico-chemical characteristics such as solubility, charge and size.

An additional aspect of the adsorption of biomolecules to the surface of nanoparticles is the effect on the conformation of proteins such as enzymes, and also on their function, stability, activity and aggregation state, among other properties. There are a number of examples of enhanced enzyme stability and function following adsorption to nanoparticles, e.g. the lifetime of the enzymes trypsin and peroxidase was shown to increase dramatically, from a few hours to weeks, by attaching them to magnetic iron nanoparticles (Sharma *et al.,* 2007). This ability to enhance protein stability by interfacing them with nanomaterials may impact numerous biological processes such as digestion, metabolism and nutrient uptake. Uptake of nanoparticle usually occurs through the intestinal tract by passive diffusion across the mucosal cells, via active transport mechanisms and intercellularly (O' Hagan, 1996), nanoparticles that are swallowed will sooner or later end up in the intestinal tract. The particles of under some 300 nm reach the bloodstream, while particles that are smaller than 100 nm are also absorbed in various tissues and organs (Hett, 2004). As a general rule, the smaller the particles are, the more of them are absorbed and the deeper into the body they can go. Following uptake from the GIT, nanoparticles can translocate *via* the lymph system to the liver and spleen, as demonstrated for polystyrene nano particles of 100 nm or less (Jani *et al.,* 1990). Smaller particles that are capable of being taken up by the villus epithelium (Hillery *et al.,* 1994) may directly enter the bloodstream, and are then predominantly scavenged by the liver and the spleen. 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. Insulin encapsulated in vitamin B_{12}-dextran nanoparticles has been shown to be taken up from the GIT without degradation (Florence and Hussain, 2001). Latour and co-workers at Clemson University have recently developed biofunctionalized nanoparticles (BN) (Taylor *et al.,* 2004). BN have attracted interest as a treatment for enteric infection, serving as pathogen purging agents prior to transporting and processing. Adherence to intestinal wall epithelial tissues is facilitated by adhesins, or surface molecules, on a bacterial cell which recognize the receptor sites on the epithelium. In addition, reports have shown that the presence of D-mannose inhibits the adherence of bacteria to both animal and human intestinal cells (Stanley and Dorris, 2000). The attachment of *Campylobacter jejuni* to epithelial cells is also mediated by mannose-specific, lectin-like adhesins present on the bacterial surface which bind to mannose receptor sites. Thus, the BN are hypothesized to be adhesion-specific to the enteropathogen *C. jejuni* (Cinco *et al.,* 1984). It has shown that the BN have an affinity for the mannose receptor sites on the *Campylobacter* cell surface and that cell aggregation or attachment between the bacteria and BN may occur. The ability of these BN to adhere to *Campylobacter* cell surfaces will enable BN to compete with host cell receptors to reduce or eliminate the

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extent of bacterial colonization on the poultry intestinal wall. BN synthesis is based on the self-assembly of organic polymers structured with intra-polymer binary pseudo-phase separation characteristics (McSweegan and Walker, 1986).

Nanoparticles are also used for oral delivery of peptides and proteins. 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. 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 (Lee and Yamamoto, 1990). 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. Polymeric nanoparticles allow encapsulation of bioactive molecules and protect them against enzymatic and hydrolytic degradation. For instance, it has been found that insulin-loaded nanoparticles have preserved insulin activity and produced blood glucose reduction in diabetic rats for up to 14 days following the oral administration (Damge *et al.*, 1990).

Use of Nanoparticles as Feed Additives

Nanoparticles can be used as feed additive to improve livestock production. Minute micelles (nanocapsules) are used as carriers for essential oils, flavor, antioxidant, coenzyme Q_{10} and vitamins, minerals and phytochemicals to improve their bioavailability (ElAmin, 2006). Encapsulating the nanoparticles of active ingredients (e.g. polyphenols, 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 (Heller, 2006). 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 (Wen *et al.*, 2006).

Nano-additives can also be incorporated in micelles or capsules of protein or another natural food/feed ingredient. Micelles are tiny spheres of oil or fat coated with a thin layer of bipolar molecules of which one end is soluble in fat and the other in water. The micelles are suspended in water, or conversely, water is encapsulated in micelles and suspended in oil. Such nanocapsules can contain healthy omega 3 fish oil (ώ3 fatty acids) which has a strong and unpleasant taste and only release it in the stomach. The wet milling of inexpensive feedstock and silicon nanoparticle consolidation as food additive releases

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orthosilicic acid in the gut, the bioavailable form of silicon for which proposed beneficial roles are under increasing scrutiny for the prevention of osteoporosis (Canham, 2007).

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. Rajendran *et al.*, (2013) conducted an experiment to improve the milk production and immunity by supplementing nano zinc oxide for a period of 75 days in lactating crossbred Holstein Friesian cow affected with subclinical mastitis. As a result, they observed an increase in milk production, immunity and suppression of subclinical mastitis (reduction in somatic cell counts values) by nano zinc oxide supplementation to dairy animals.

Dietary supplementation of nanoselenium in male goats at the rate of 0.3ppm showed that the final body weight was increased in bucks supplemented with Se compared to the controls, and average daily gain in nanoselenium (NS) and seleno-yeast (SY) supplemented groups were greater than sodium selenite (SS) or control bucks (Shi *et al.*, 2011b). Whole blood, serum and tissue Se concentration, serum antioxidant enzymes activity were also affected by dietary Se supplementation. Serum GSH-Px, SOD and CAT in nano-selenium supplemented group were higher than those in sodium selenite and selenoyeast supplementation groups and Se retention of whole blood, serum and some organs in nanoselenium were also higher than sodium selenite and selenoyeast supplementation groups (Shi *et al.*, 2011b).

Upon Nano-Se supplementation in sheep at rate of 3ppm in basal diet ruminal pH and ammonia N concentration was decreased, and total VFA concentration was increased linearly and quadratically with increasing nano-Se supplementation. The ratio of acetate to propionate was linearly and quadratically decreased due to the increasing of propionate concentration. *In situ* ruminal neutral detergent fiber degradation of crude protein (CP) of soybean meal was linearly and quadratically improved by feeding nano-Se. Similarly, nutrients digestibility in the total tract and urinary excretion of purine derivatives were also quadratically (p<0.01) changed by increasing nano-Se supplementation (Shi *et al.*, 2011a).

Dietary supplementation of chromium (Cr) as chromium nanocomposite (CrNano) at the rate of 200µg in finishing pigs significantly reduced serum levels of glucose, urea nitrogen, triglyceride, cholesterol and non-esterified fatty acid. In contrast, serum levels of total protein, high density lipoprotein and lipase activity were significantly increased in pigs offered the diets supplemented with CrNano. Supplementation of the diet with CrNano also increased serum insulin-like growth factor I and reduced serum insulin and cortisol levels significantly. In addition, supplemental CrNano resulted in significant increments of immunoglobulin M, immunoglobulin G contents in plasma (Wang *et al.*, 2007). Also,

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dietary supplementation of chromium (Cr) as chromium nanocomposite (CrNano) at the rate of 200 µg in finishing pigs resulted in higher carcass lean percentage, 19.96% larger *Longissimus* muscle area and 25.53% lower carcass fat percentage, 18.22% lower back fat thickness. Drip loss in chops from pigs fed CrNano was decreased by 21.48% and weights of *Longissimus* muscle and *Semimembranosus* were increased by 16.33% and 14.87%, respectively (Wang and Xu, 2004). In addition, supplemental CrNano resulted in 184.11, 144.99, 88.13 and 52.60% increment of Cr concentration in *Longissimus* muscle, liver, kidney and heart, respectively. These results suggest that supplemental CrNano has beneficial effects on carcass characteristics, pork quality and individual skeletal muscle weight, increase tissue chromium concentration in selected muscle and organs (Wang and Xu, 2004).

The supplementation of nano copper (nanoCu) in piglets at the rate of 50ppm produced statistically significant improvements in growth performance of the piglets when copper was supplemented at nanosize. Copper availability was significantly improved and fecal copper level was reduced in the nanoCu supplemented group, as compared to the copper sulphate ($CuSO_4$) group. Significant differences were observed in the improvement of the digestibility of crude fat and energy in pigs fed nanoCu diet. The serum copper level and serum cholesterol concentrations, as well as hematology traits were not affected by nanoCu supplementation. Statistically significant improvements were observed in the IgG, γ-globulin and total globulin protein levels, and in the SOD activity of the nanoCu group (Eguia *et al.*, 2009). Coliform reduction in ileal contents was observed *in vivo* by Fondevila *et al.* (2009) when 20 and 40 ppm of metallic silver nanoparticles were given to weaned piglets as metallic silver adsorbed in a sepiolite matrix as antimicrobial and growth promoter for weaned pigs during their transition phase (from 5 to 20 kg weight). Besides, concentration of major bacterial groups in the ileum of pigs were not markedly affected, the concentration of the pathogen *Clostridium perfringens/ Cl. histolyticum* group was reduced with 20 ppm silver.

An experiment was performed to explore the selenium retention of Nano elemental selenium (Nano-Se) in Arbor Acre male broiler chickens as compared with sodium selenite. A factorial arrangement with 0.15, 0.30 and 1.20 mg/kg dietary Se from Nano-Se or sodium selenite added to a maize–soybean meal diet was conducted to study the effects of Se source and level on growth performance, serum glutathione peroxidase (GSHPx) activity, Se concentration in serum and tissue. The results showed that the range between optimal and toxic dietary levels of Nano-Se was wider than that of sodium selenite, and Nano-Se was more efficiently retained in the body than sodium selenite (Hu *et al*., 2012).

Effect on Feed Quality and Nutritional Values

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Nanoparticles can also be used to improve feed quality. Manipulation of matter at the nano level also opens up possibilities for improving the functionality of food/feed molecules, to the benefit of product quality. Liquid droplet technology named 'Nano-sized Self-assembled Liquid Structures (NSLS) involves encapsulation and release particles in cells. The micellar particles are used to encapsulate nutraceuticals (beta-carotene, CoQ10, docosahexaenoic acid/eicosapentaenoic acid (DHA/EPA) and other compounds) into 30 nm diameter self-assembled spheres. Micelles are organic nanoparticulates that can be assembled by the thermodynamically driven process known as self-assembly. Micelles made in this way have the ability to encapsulate non-polar molecules such as lipids, flavours, antimicrobials, antioxidants and vitamins (Chen *et al.*, 2006). Compounds that are normally insoluble or only sparingly soluble in water can be made water soluble, extending their use in foods/feeds and potentially changing their bioavailability once ingested. The micelles are essentially made from lipid molecules and have a unique hydrophobic interior. The NSLS particles are reported to act as vehicles for compounds to be absorbed into the bloodstream from the gut more readily, increasing their bioavailability. Liposomes are another example of micelles and can be used to encapsulate both water and lipid soluble compounds (Taylor *et al.*, 2005). The dissolution of fat soluble nutrients in water-based drinks is one of the key applications of liposomes. Liposomes can be produced to differing sizes (10-500nm) and engineered to have different stability and/or surface charge under different environmental conditions. Liposome technology can be used potentially to target specific sites within a food/feed product for enzymatic degradation.

Nanoemulsions are emulsions which are thermodynamically stable compared to conventional emulsions under a range of different conditions. This is due to their small size (typically 50 to 500nm compared to 1200nm) and monodispersivity. They can be diluted with water without changing the droplet size distribution. The type of surfactant used to formulate a nanoemulsion is critical to the stability of the final emulsion. Preparations of nanoemulsions can be used to encapsulate functional food/feed components at oil/water interfaces, or throughout the continuous phase of the system (Weiss *et al.,* 2006). The applications of nanoemulsions include: delivery of active compounds in the body, stabilization of biologically active ingredients, extended shelf-life due to increased stability and increased viscosity at lower concentrations of oil phase. Research has shown that stabilized monodispersed oil-in-water (O/W) or water-in-oil (W/O) nanoemulsion systems can be used for controlled release of nutraceutical and other bioactive components in food/feed (Weiss *et al.,* 2006). The technology has been combined with advanced processing technologies to develop novel microencapsulated products that allow controlled release of food/feed bioactives in the gastrointestinal tract. These products may be either ready-to-drink or powdered formulations fortified with functional ingredients from a wide range of sources. Dziechciarek *et al.* (1998) have developed starch-based nanoparticles that behave like colloids in aqueous solution, and

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can be used in food/feed applications such as mixing, emulsification and imparting specific rheology to foods/feeds.

Effect on Feed Processing

The ultrafine dimensions of nanoparticles, and consequently their very large surface area, enable them to function more effectively than conventional macroscale structures. New types of membranes including micro and nano-sieves can be applied in food/feed processing. The pores of the sieves are in the micrometer and nanometer range. They can also be used for encapsulating valuable food/feed ingredients such as minerals in a coating of another ingredient to boost take up by the body or to avoid these ingredients being lost during processing. Nanotechnology is already making an impact on the development of functional or interactive foods/feeds, which respond to the body's requirements and can deliver nutrients more efficiently. Various research groups are also working to develop new "on demand" foods/feeds, which will remain dormant in the body and deliver nutrients to cells when needed. A key element in this sector is the development of nanocapsules that can be incorporated into food/feed to deliver nutrients. Other developments in food/feed processing include the addition of nanoparticles to existing foods to enable increased absorption of nutrients.

Risks and Hazards Related to Nanoparticles

Toxicity is the most important issue that must be addressed before the commercial exploitation of nano particles (Radha et al., 2014). The nano toxicity can be assessed by several criteria like toxicology of nano particles, exposure assessments, environmental and biological fate, recyclability and overall sustainability of nano materials. Growing scientific evidence indicates that insoluble nanoparticles may cross cellular barriers, and reach new targets in the body. Also exposure to insoluble/ biopersistent nanoparticles via food may lead to certain adverse health effects. Risk assessment consists of four components: hazard identification, hazard characterization, exposure assessment, and risk characterization. All four of these stages are essential to the process of risk assessment. A substance may be extremely hazardous, but have a small exposure potential, and the risk may be small, whereas something that is of limited hazard but to which exposure is high and/or over long periods may present a much greater risk. It is essential to characterize both the nature of the hazard and the exposure (FSAI, 2008).

The specific hazard issues relating to feeding of nanoparticles include -

- the increased bioavailability of nanoparticles compared with the macro-forms of the same material,
- the potential role of nanoparticles induced ROS in inflammatory digestive diseases

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- the potential effects of nanoparticles on protein and enzyme stability and functionality whereby the metabolic processes may be disrupted, or nutrient bioavailability may be altered,
- the potential effects of storage, heating/and ageing on nanoparticles biomolecule complexes in feed (FSAI, 2008).

Regulations of Nano Technology

The European Union regulations for food and food packaging have recommended that for the introduction of new nanotechnology, specific safety standards and testing procedures are required (Halliday, 2007). In the United States, nanofoods and most of the food packaging are regulated by the USFDA (Badgley *et al*., 2007), while in Australia, nanofood additives and ingredients are regulated by Food Standards Australia and New Zealand (FSANZ), under the Food Standards Code (Bowman and Hodge, 2006). In India food safety regulations are introduced but not adequate for the monitoring safety of nanoparticles. Existing laws are inadequate to assess risks posed by nano based foods and packaging because -

- Toxicity risks remain very poorly understood (because of their unique properties);
- Nano particles are not assessed as new chemicals according to many regulations
- Current exposure and safety methods are not suitable for nanomaterials and
- Many safety assessments use confidential industry studies (Chaudhry *et al*., 2008).

Up to now, there is no international regulation of nanotechnology or nanoproducts.

Conclusion

Nanotechnology can be used in animal feeding to improve bioavailability of nutrients, production performance and immune status in livestock. However, a great amount of research is still required to support the effectiveness, and mainly the safety of nanotechnology, avoiding any harm to the livestock, environment and to human beings.

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