

Nanotechnology in Animal Nutrition: Improving Digestion and Nutrient Absorption

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The livestock sector is continuously looking for innovative feed additives that can improve nutrient utilization, animal performance and feed efficiency. Although conventional feed ingredients supply essential nutrients, their effectiveness may sometimes be limited by poor solubility, instability, degradation during digestion and inefficient absorption. Nanotechnology has emerged as a promising approach for overcoming some of these limitations by manipulating materials at the nanoscale, generally between 1 and 100 nm (Buzea et al., 2007). At the nanoscale, materials can exhibit properties that differ considerably from their conventional forms. The reduction in particle size increases the surface-area-to-volume ratio and may alter surface reactivity, physicochemical behaviour and biological interactions (Cao, 2004; Buzea et al., 2007). These characteristics have generated interest in the use of nanoparticles as carriers and delivery systems for nutrients, minerals, antioxidants, vitamins, phytochemicals and other biologically active compounds in animal nutrition.

Why particle size matters

One of the most important characteristics of nanoparticles is their large surface area relative to their volume. Smaller particles provide more surface sites for interaction with digestive enzymes, feed components and tissues of the gastrointestinal tract. Consequently, reducing particle size may improve the interaction between a nutrient and its surrounding biological environment (Arbos et al., 2002). Nanoparticles may also provide prolonged interaction with the gastrointestinal tract and facilitate the delivery of active compounds to specific sites. Their small dimensions can allow them to interact closely with biological membranes and, depending on their physicochemical characteristics, improve cellular uptake (Chen et al., 2006; Medina et al., 2007). The increased surface area and altered properties of nanoparticles therefore form the basic scientific rationale for their application in animal feeding.

Nanoparticles and gastrointestinal absorption

After ingestion, feed additives must pass through the gastrointestinal tract before their nutrients or active components can be absorbed. The mucus layer lining the gastrointestinal tract represents an important barrier to particle transport. Particle size, surface characteristics and interactions with mucus can influence how efficiently particles move through this barrier (Crater and Carrier, 2010). Research on mucus-penetrating nanoparticles has demonstrated that appropriately designed nanoparticles can move through mucus more effectively than conventional particles because they can be engineered to minimize adhesive interactions with mucin fibres (Lai et al., 2009). The PPT also describes the possibility of nanoparticle uptake through passive diffusion or active transport mechanisms. Following uptake by intestinal epithelial cells, some nanoparticles may enter the circulation and subsequently be distributed

to tissues (Hillery et al., 1994). This property makes nanoparticles attractive as delivery systems for compounds whose absorption is otherwise limited. However, absorption depends strongly on particle composition, size, surface charge, coating and biological conditions, so increased absorption should not be assumed for every nanoparticle formulation.

Nanoparticles as carriers of feed additives

Nanoparticles can function as carriers for several classes of feed additives. Essential oils, antioxidants, vitamins, minerals, phytochemicals and fatty acids can potentially be incorporated into nano-sized delivery systems. Encapsulation can protect sensitive compounds against environmental degradation and may improve their dispersibility and bioavailability (Fletcher, 2006). The use of nanocapsules has also been proposed for the delivery of omega-3, omega-6 and omega-9 fatty acids and for carrying vitamin E. Such approaches may be particularly useful for compounds that are poorly soluble or susceptible to oxidation (Canham, 2007). An important advantage of encapsulation is that the active compound does not necessarily have to be released immediately. Instead, the carrier can be designed to protect the compound and facilitate its release under appropriate gastrointestinal conditions. Thus, nanotechnology provides opportunities not only for improving nutrient absorption but also for controlling when and where an active compound becomes available.

Nano-selenium and rumen fermentation

Trace minerals are among the most extensively investigated applications of nanotechnology in animal nutrition. Selenium is an essential trace element involved in antioxidant defence and several biological functions. However, the efficiency of selenium supplementation depends on its chemical form, dose and bioavailability. Shi et al. (2011) investigated elemental nano-selenium in sheep and evaluated its effects on feed digestibility, rumen fermentation and urinary purine derivatives. Eight ruminally cannulated sheep were used in a replicated 4×4 Latin-square experiment, with nano-selenium supplied at different levels. The study found that nano-selenium supplementation influenced ruminal pH, ammonia-N concentration, total volatile fatty acids and the acetate-to-propionate ratio. It also affected nutrient digestibility and urinary purine derivatives. The findings suggested that nano-selenium could influence rumen fermentation and feed utilization, although the response depended on supplementation level (Shi et al., 2011). The study therefore provides an important example of how changing the physical form of a trace mineral can influence its interaction with the rumen environment.

Nano-selenium and antioxidant status

The use of nano-selenium has also been examined in growing goats in comparison with conventional selenium sources such as sodium selenite and selenium yeast. The PPT describes evaluation of growth performance, selenium concentration and antioxidant-related parameters following supplementation with different selenium sources (Shi et al., 2011). Because selenium is closely associated with antioxidant enzymes, nano-selenium may have potential applications where improved selenium availability and antioxidant protection are desired. Nevertheless, selenium has a relatively narrow margin between nutritional requirement and toxicity, making appropriate dosage particularly important.

Nano-copper in pig nutrition

Copper is another mineral that has received attention in nanoparticle research. Gonzales-Eguia et al. (2009) investigated nano-copper supplementation in piglets and evaluated copper availability, nutrient digestibility, growth performance and serum characteristics. The study reported that nano-copper affected copper availability and nutrient digestibility and reduced copper excretion compared with conventional copper supplementation under the experimental conditions. The study also examined growth performance and serum traits, including immune- and antioxidant-related parameters (Gonzales-Eguia et al., 2009). These findings indicate that nano-copper may have potential as an alternative form of copper supplementation. However, the biological response to nano-minerals depends on dose, particle characteristics, dietary

composition and animal species, and therefore results should not automatically be generalized to all livestock.

Nano-chromium in finishing pigs

Chromium nanoparticles have also been investigated in finishing pigs. Wang and Xu (2004) studied the effects of chromium nanoparticles on growth performance, carcass characteristics, pork quality and tissue chromium concentration. Their experiment involved finishing pigs receiving a diet supplemented with chromium nanoparticles. The researchers reported effects on feed-to-gain ratio, carcass characteristics, pork quality and tissue chromium concentration (Wang and Xu, 2004). The study illustrates another potential application of nanotechnology: improving the biological utilization of minerals while potentially influencing production-related traits. However, such results should be interpreted in the context of the particular animal population, supplementation level and experimental conditions.

Nanoemulsions for improved nutrient delivery

Nanoemulsions are another important nanotechnology-based delivery system. They consist of very small droplets and can be used to encapsulate or disperse compounds that have limited solubility. Weiss et al. (2006) described nanoemulsions and other nanostructured systems as potential tools for protecting functional food components and controlling their release. Nanoemulsions can incorporate bioactive compounds into droplets or at interfaces, potentially reducing chemical degradation and improving the stability of sensitive ingredients (Weiss et al., 2006). In animal feed applications, such systems could potentially be used to improve the delivery of essential oils, antioxidants, carotenoids, fatty acids and other bioactive compounds. The PPT specifically highlights controlled release and enhanced bioavailability as important potential benefits of nanoemulsion-based feed systems.

Liposomes and nanocapsules

Liposomes are spherical structures capable of carrying both water-soluble and lipid-soluble compounds. They have attracted interest in food and agricultural applications because they can encapsulate sensitive compounds and modify their stability and release characteristics. Taylor et al. (2005) reviewed the application of liposomal nanocapsules in food science and agriculture, including their potential for encapsulating bioactive compounds and improving delivery. In animal nutrition, liposomal systems may have potential for delivering enzymes, antimicrobial compounds, vitamins, minerals and extracts of beneficial microorganisms. The PPT specifically describes their possible use for encapsulating enzymes, lactic acid bacterial extracts and antimicrobial compounds (Taylor et al., 2005).

Nanotechnology for targeted delivery

Another interesting application is the development of nanoparticles that can interact with specific biological targets. The PPT describes bifunctionalized nanoparticles containing functional groups such as D-mannose that may interact with bacterial adhesions. Mannose-mediated interactions have been investigated because certain pathogenic bacteria use carbohydrate-binding mechanisms to attach to host cells. Functionalized nanoparticles may therefore provide a means of interfering with bacterial attachment and potentially reducing colonization (Stanley et al., 2000; Taylor et al., 2004). This concept expands the role of nanotechnology beyond nutrient delivery. In the future, specifically designed nanoparticles could potentially be used as targeted carriers for compounds intended to act at particular locations within the gastrointestinal tract.

Nanoparticles and feed processing

Nanotechnology may also contribute to feed processing. Nano-sieves, encapsulation systems and nanostructured ingredients may help reduce nutrient losses during processing and facilitate controlled nutrient delivery. The PPT describes potential applications including starch-based nanoparticles, membrane nanosieves, colloids, emulsification and the development of functional feed products. Nanotechnology may also influence the physical characteristics and

rheological properties of feed materials (Dziechciarek et al., 1998). Another potential application is improving enzyme stability. The presentation cites the use of magnetic iron nanoparticles to increase the functional lifespan of enzymes such as trypsin and peroxidase (Sharma et al., 2007). Such applications could become increasingly relevant as livestock diets incorporate more sensitive bioactive ingredients and functional additives.

Potential benefits in livestock production

The potential applications of nanotechnology in animal nutrition are broad. They include the delivery of minerals, vitamins, antioxidants, probiotics and other feed additives; improvement of nutrient bioavailability; controlled release of bioactive compounds; targeted gastrointestinal delivery; and potentially improved feed stability. The PPT identifies applications ranging from medication and nutrient delivery to probiotics, supplements, diagnosis, treatment and meat-quality improvement. However, the actual benefits depend on the characteristics of the nanoparticle and the biological system in which it is used. A nanoparticle that performs effectively as a carrier for one nutrient may not produce the same response with another compound.

Safety: the major consideration

Despite its potential, nanotechnology should be approached carefully in animal nutrition. The same properties that make nanoparticles biologically active—small size, high surface area and altered surface characteristics—can also change their interactions with cells and tissues. Potential concerns include changes in physicochemical properties, altered physiological processes, effects on cellular biochemistry and homeostasis, changes in protein interactions and possible gastrointestinal toxicity. The PPT therefore emphasizes that further research is needed to establish both the effectiveness and safety of nanoparticles before their widespread use in livestock feeding. Safety assessment should consider not only the animal receiving the feed but also tissue accumulation, residues in animal products, environmental release and possible exposure of humans. Long-term feeding studies are particularly important because short-term improvements in nutrient utilization do not necessarily establish the safety of a nanoparticle for continuous use.

Future prospects

Nanotechnology has introduced a new dimension to animal nutrition by allowing nutrients and bioactive compounds to be designed for improved delivery. Nano-minerals such as selenium, copper and chromium have already been investigated in livestock, while nanoemulsions, liposomes and nanocapsules provide additional approaches for protecting and delivering sensitive compounds (Shi et al., 2011; Gonzales-Eguia et al., 2009; Wang and Xu, 2004; Weiss et al., 2006). Future research should focus on identifying appropriate particle size, dose, surface characteristics and delivery systems for individual nutrients. Equally important will be investigations into long-term animal health, tissue deposition, product safety and environmental effects. Thus, nanotechnology has considerable potential to improve digestion, nutrient absorption and bioavailability in livestock, but its successful application will depend on scientifically demonstrated efficacy together with rigorous safety evaluation.

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