Applications of Nanotechnology in Animal Husbandry

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ABSTRACT

Nanotechnology is the promising and emerging technology that has tremendous potential to revolutionize agriculture and livestock sectors globally. It is an innovative technology which finally creates materials and change structure, enhanced quality and texture of foodstuffs at the molecular level. A disruptive technology, with a potential to change the world as we know it today. Study of controlling and manipulating matter on an atomic, molecular, and/or supramolecular. It deals with structures the size of 100 nanometres or smaller in at least one dimension. The use of nanotechnology in animal production is still in its infancy but encouraging results from nutrition, biocidal, remedial, and reproductive studies are driving further investigation.

INTRODUCTION

The term 'nano' is a Greek word, means dwarf and signifying 1 billionth of a meter (1 nm = 10-9m). In the recent years the application of nanotechnology in human and veterinary medicine has shown a great progress. Scientists foresee that this progress in the field of nanotechnology could represent a major breakthrough in addressing some of the technical challenges faced by human and veterinary profession. While the great hopes of nanomedicine are disease detection and new pharmaceuticals for humans, veterinary applications of nanotechnology may become the proving ground for untried and more controversial techniques from nano capsule vaccines to sex selection in breeding. Nanotechnology has the potential to impact not only the way we live, but also the way we practice veterinary medicine. Examples of potential applications in animal agriculture and veterinary medicine include disease diagnosis and treatment delivery systems, new tools for molecular and cellular breeding, the security of animal food products, modification of animal waste, pathogen detection, and many more. Existing research has demonstrated the feasibility of introducing nano shells and nanotubes into animals to seek and destroy targeted cells. These building blocks of nanotechnology are expected to be integrated into systems over the next couple of decades on a commercial basis. This article describes some of the principal areas of nanotechnology currently being undertaken in the world of medicine. The main purposes of this article are to trigger the interest of discoveries of veterinary profession in the field of nanotechnology and to provide a glimpse at potential important targets for nanotechnology in the field of veterinary medicine. Also, it is important to mention that because nanotechnology is at a very early stage of development, it may take several years to perform the necessary research and conduct clinical trials for obtaining meaningful results. This tool as it develops over the next several decades will have major implications in veterinary and animal science.

Nanoparticles have been used as diagnostic and therapeutic agents in the human medical field for quite some time, though their application in veterinary medicine and animal production is still relatively new. Recently, production demands on the livestock industry have been centered around the use of antibiotics as growth promoters due to growing concern over microbial antibiotic resistance. With many countries reporting increased incidences of antibiotic-resistant bacteria, laws and regulations are being updated to end in-feed antibiotic use in the animal production industry. This sets the need for suitable alternatives to be established for inclusion in feed. Many reports have shown evidence that nanoparticles may be good candidates for animal growth promotion and antimicrobials. The current status and advancements of nanotechnological applications in animal production will be the focus of this post and the emerging roles of nanoparticles for nutrient delivery, biocidal agents, and tools in veterinary medicine and reproduction will be discussed. Additionally, influences on meat, egg, and milk quality will be illustrated.

Nanotechnology is the study of materials at the nanoscale. With at least one dimension generally ranging between 1 and 100 nm (10^{-9} – 10^{-7}m), nanomaterials are best referred to as particles. These nanoparticles are particularly appealing as they take up very little space yet have relatively large surface areas, and therefore an increased ratio between surface atoms and interior atoms. As a result, when bulky materials are scaled down to nano sizes, their surface chemistries become more influential and alter the physical properties of the material. For example, copper is known for its malleability, a useful feature for wiring and piping. However, when copper is scaled down into a nanoform, it loses its malleability as its surface atoms resist bending. The interior copper atoms in a bulkier form facilitate bending but are out-numbered by surface atoms in the nanoform. Enlarging the ratio of surface area to volume allows for nanoparticles to be more versatile, whether as a single functional unit, or as a carrier for functional units which can be adhered to their surfaces or encapsulated within. Nanoparticles are becoming more attractive as novel uses, from medical diagnostics to gene therapy vehicles, are discovered.

TYPES OF NANOPARTICLES:

Nanoparticles, currently available or under development, can be categorized into four groups: metals, polymers, natural compounds, and nanostructured materials. Although different engineering techniques are required depending on the group, nanoparticles can facilitate an array of biotechnical functions through different mechanisms of action. Metal nanoparticles are the powdery version of solid metal, after large pieces have been ground down to nano sizes, effectively changing its associated physical properties. These particles have drawn the attention of the medical field for their use in imaging and as antimicrobial therapies that lyse Gram positive and Gram-negative bacterial cell walls. External or topical applications may be more suitable for some metal nanoparticles to avoid accumulation in the body, as certain species can elicit harmful dosage-toxicity responses, although this is not always the case. The non-biodegradable nature of metal is a major drawback for these particles. Polymeric nanoparticles, or nano-polymers, are polymers that have been synthesized or fragmented into pieces that are nanometers long. Nano-polymers have the ability to be grafted onto other materials, potentially improving their biocompatibility and degradation while expanding their utility. Biocompatibility is highly advantageous for the medical and food industries as working concentrations of biocompatible nanoparticles will have few to no negative side effects on patients or consumers. Similar to the metal varieties, polymeric nanoparticles with a fluorescent or radiolabeled component may be used for medical imaging, although dosage toxicity would still have to be considered.

Nanoparticles made of natural compounds are materials that come from nature with limited manipulation, such as natural polymers or proteins. With few alterations, natural compounds are more likely to be biocompatible, distributable in the body, and biodegradable. Nanostructured materials are synthesized nanoparticles that originate from many sources, including natural compounds such as lipid- and protein-based nanoparticles. Natural and nanostructured nanoparticles share many advantages and can serve as the sole functioning unit or carriers for functional groups, such as drugs and nutrients, via encapsulation or superficial adhesion. While nature-derived nanomaterials may seem a safer choice, these particles could elicit toxic or immunogenic responses if not carefully engineered or appropriately distributed in a biological system. Despite these potential limitations, the advantages of employing nanotechnology are far greater.

APPLICATIONS OF NANOTECHNOLOGY:

Nanotechnology has the potential to solve many more puzzles related to animal health, production, reproduction, good hygienic practices during rearing and maintaining of food animals, the possible applications of the technology is almost incredible in relation to livestock. Although much research and major company developments are necessary before nanotechnology is common place in veterinary and animal sciences, there are numerous glimpses of applications as discussed below.

1. Diagnosis and treatment of disease:

Biochips can be used for early disease detection in animals. A Biochip (or microarray) is a device typically made of hundreds or thousands of short strands of artificial DNA deposited precisely on a silicon circuit. Biochips can also be used to trace the source of food and feeds to detect the presence of animal products from different species as a means to locate the source of pathogens a response to public health threats such as avian flu and mad cow disease. In addition to DNA biochips, there are other variations that detect minute quantities of proteins and chemicals in a sample, making them useful for detecting biowarfare agents or disease. Using biochips, biological samples such as blood, tissue and semen can be instantaneously analyzed and manipulated. Bioanalytical nano sensors are devices or systems that measure or detect a chemical with the use of a biological material or tissue. These will enable us with detection of very small amounts of a chemical contaminant, virus or bacteria in agriculture and livestock system. Nano shells are a new type of optically tunable nanoparticle composed of a dielectric (for example, silica) core coated with an ultra-thin metallic (for example, gold) layer. Nano shells can be injected into the animal’s bloodstream with targeted agents applied to the nano shells to seek out and attach to the surface receptors of cancer cells. Illumination of the body with infrared light raises the cell temperature to about 55°C, which ‘burns’ and kills the tumour (Hirsch et al., 2003). Others have been experimenting with ‘smart’ super paramagnetic nanoparticles, which when injected in the bloodstream target tumour receptor cells. These nanoparticles are made from iron oxides that when subjected to a magnetic field enhances the ability of the nanoparticles to locate tumour cells. At the site of the tumour the nanoparticles emit an attached drug to kill the cancer cells. Other form of nanomaterial is Quantum dots which are nanometre-scale crystals that were originally developed for optoelectronic applications (Scott and Chen, 2002). Quantum dots may be injected into the bloodstream of animals and they may detect cells that are malfunctioning. Because quantum dots respond to light it may be possible to illuminate the body with light and stimulate the quantum dot to heat up sufficient to kill the cancerous cell. Nucleic acid engineering-based probes and methods offer powerful new ways to deliver therapeutic or preventative treatment for particular diseases (Luo, 2003). These various methods of nanotechnology can be a potential therapeutic aid in extenuating the health problems of the animals.

2. Drug delivery system:

Smart drug delivery systems in animals would most likely contain small, sealed packages of the drug to be delivered. Smart drug deliveries allow judicious use of smaller quantities of antibiotics than would otherwise be possible. A molecular coded 'address label' in the package could allow the package to be delivered to the correct site in the body. Nano and microscale mechanical systems would serve as the 'carriers' in such a system. Smart delivery systems could also contain on-board chemical detection and decision-making capability for self regulated drug delivery or nutrient treatments as per need. This will aid livestock owners to minimize use of antibiotic and to reduce the expenditure on medication. Smart delivery systems can also have the capacity to monitor the effects of the delivery of pharmaceuticals, nutraceuticals, nutrients, food supplements, bioactive compounds, probiotics, chemicals and vaccines. Thus, in the future, further technological advances will make it possible to develop delivery systems more precisely with use of nanomaterials (are materials that provide the potential to manipulate structures or other particles at the nanoscale and to control and catalyze chemical reactions, e.g. buckeyballs, nanotubes, quantum dots and dendrimers etc.) for biological and bioactive organisms for targeted site, develop integrated sensing, monitoring and controlling capabilities, including the ability of self-regulation, develop large as well as small animal health monitoring and therapeutic intervention

3. Food safety through identity preservation:

Identity preservation (IP) system is a system that creates increased value by providing consumers with information about the practices and activities used to produce an agricultural product. Today, through IP it is possible to provide stakeholders and consumers with access to information, records and supplier protocols regarding the farm of origin, environmental practices used in production, food safety and security, and information regarding animal welfare issues. Quality assurance of the safety and security of agricultural and animal products could be significantly improved through IP at the nanoscale. The future of the meat industry may well depend on an ability to track all stages in the life of the product, including the birth of the animal, its medical history, and its movements between the ranch, the slaughterhouse and the meatpacking plant, right through to the consumer's table.

4. Breeding and Reproduction:

Management of breeding is an expensive and time-consuming problem for dairy and swine farmers. One solution that is currently being studied is a nanotube implanted under the skin to provide real time measurement of changes in the level of estradiol in the blood. The nanotubes (O'Connell et al., 2002) are used as a means of tracking oestrus in animals because these tubes have the capacity to bind and detect the estradiol antibody at the time of oestrus by near infrared fluorescence. The signal from this sensor will be incorporated as a part of a central monitoring and control system to actuate breeding. Microfluidics is used today in animal science to significantly simplify traditional in vitro fertilization procedures used in animal breeding. It is being used in livestock breeding to physically sort sperm and eggs. Microfluidic and nanofluidic are the systems which analyze by controlling the flow of liquids or gases through a series of tiny channels and valves, thereby sorting them, much as a computer circuit sorts data through wires and logic gates. With the mapping of the human genome behind them, geneticists are now rapidly sequencing the genomes of cattle, sheep, poultry, pig and other livestock hoping to identify gene sequences that relate to commercially valuable traits such as disease resistance and leanness of meat. By including probes for these traits on biochips, breeders will be able to speedily identify champion breeders and screen out genetic diseases.

5. BIOCIDES:

Nanoparticles may present a feasible alternative to antibiotics and may help bar pathogens from entering animal production sites. The unregulated use of antibiotics, a common practice in many countries, provides the impetus for bacteria to become drug-resistant. New legislation for the restriction of prophylactic antibiotic use in agriculture is gaining ground as a method to combat this growing problem. Limiting antibiotic use necessitates the development of alternatives due to the high-density nature of modern animal production facilities which invites and expedites disease transmission.

6. MEAT AND EGG QUALITY:

The possibility of using nanoparticles to enhance meat and egg quality has also been investigated. For example, Wang and Xu demonstrated that when finishing pigs destined for market were given chromium nanoparticles (200 μg/kg) in feed, they were 14.06% leaner at slaughter than control pigs fed a basic diet of corn-soybean meal. An increase in skeletal muscle mass and improved pork quality were achieved, with similar effects found when finishing pigs were fed chitosan nanoparticle supplements loaded with chromium. These chromium-loaded chitosan nanoparticles elevated the activity of hormone-sensitive lipase in adipose tissue while decreasing fatty acid synthase activity and boosting blood serum immune components. These data provide a compelling insight into the mechanism of action these nanoparticles have in pigs, and how they affect meat quality. Of further interest is the heightened chromium content in selected tissues, such as 184.11% in the longissimus muscle compared to the control, as some nanoparticles, i.e., Ag^+ and Cu^{2+}, have been found to cross the blood–brain barrier.

The inclusion of nanomaterials in livestock feed or water can benefit the quality of product obtained, as well as the production cycle. Chromium nanoparticles added to poultry feed not only positively affected breast and thigh muscle protein content while simultaneously lowering cholesterol, but raised the average daily gain and feed efficiency of the broilers in the experimental group fed 500 μg/kg Cr^{3+}. The implications of these results are shorter production cycles for better quality meat with less feed required to have broilers reach market weight. Conversely, when chromium nanoparticles were supplied to layers, there was no significant effect on body weight or egg production. However, Sirirat et al. did find that egg quality improved from higher chromium and calcium levels in the yolks and shell, respectively. Bioaccumulation of nanoparticles in the liver was noted for the experimental group, an observation shared with Chauke and Siebrits in a study that replaced an antibiotic against coccidiosis with silver nanoparticles in water (0.083 mg/kg of silver compared to 0.001 mg/kg in the control). More information on the interplay between nanoparticle concentration and meat quality would be useful to ensure that quality is not sacrificed after long-term exposure. The inclusion of nutrient supplements in livestock feed, regardless of particle size, will benefit the producer if there is still consumer demand for the final product. If meat and eggs obtained from an animal fed nanoparticle supplements are enhanced, or indiscernible from the original product, they are then likely to still be favourable to consumers. However, it is important to understand the role of the nanoparticle additive in a given biological system and by-products from that system to ensure it is safe for consumption before its application in animal production.

7. MILK:

Mastitis is an example of a common ailment among dairy cows with a variety of inciting factors, often bacterial, that can require the use of antibiotics to clear. Tilmicosin is an example of a drug used in mastitis cases that has negative side-effects if given at too high a concentration. In consideration of this, Han et al. sought to control the release of tilmicosin by using hydrogenated castor oil-solid lipid nanoparticle carriers. Of concern was what the extended half-life of the therapeutic would mean for milk discard times, as tilmicosin was present in mouse blood serum for 5 h without nanocarrier delivery, and 8 d with nanocarrier delivery. However, a lower dosage was required for resolution in a S. aureus-induced murine mastitis model (10 mg/kg versus 20 mg/kg) . Careful manipulation of therapeutic nanocarriers to find a balance between dosage and half-life could serve to benefit producers by minimizing milk discard times and the amount of milk wasted.

Nanotechnology can also help to ensure that the quality of milk is safe for human consumption through novel foodborne pathogen detection techniques. Sung et al. developed nanocomposites containing anti-S. aureus antibodies, gold nanoparticles, and magnetic nanoparticles to provide a 40 min colorimetric test for the presence of S. aureus in milk. An interesting feature of these nanocomposites is the antibody, whose specificity and selectivity could be modified to capture a variety of pathogens. Wang et al. demonstrated a similar technique, employing polyclonal antibodies and gold nanoparticle immunochromatographic strips to detect toxins present in milk within 10 min, using the carcinogenic aflatoxin M1 as an example. While a large focus has been to remove potentially harmful contaminants from milk, there has also been some interest in mixing nanoparticle supplements directly into cow's milk for human consumption. Lee et al. combined nano powdered oyster shell into milk with the intention of increasing the calcium content from 100 to 120 mg/mL to a level more suitable for growing children and post-menopausal women. Supplementing milk with calcium from nano powdered oyster shell did not negatively alter its sensory or physicochemical qualities after 16 d of storage at 4 °C.

8. VETERINARY MEDICINE:

Nanomedicine is an intriguing discipline in nanotechnology that is showing progress in both diagnostics and therapeutics. Metallic and nanostructured particles are useful diagnostic tools in biomedical research that can be used to visualize the status of a cell or drug distribution in the body. Magnetic nanoform metals, i.e. iron oxide, can be taken up by cells and imaged in vivo at high concentrations using magnetic resonance imaging (MRI) . Nanostructured particles can be made to fluoresce through light activation or two-photon excitation. Further to these diagnostic nanoparticles, exciting developments have been made in molecular-based lab-on-a-chip technologies for qualitative and quantitative biological analyses. Requiring small volumes of analyte and reagents, producing little waste, and shortening wait times make these lab-on-a-chip technologies an attractive option. There are currently a number of products functioning at the microscale available on the market with nanoscale products just emerging; see Tian et al. for more information.

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. The biocompatibility of carbohydrate-derived nanoparticles has been demonstrated in a human lung carcinoma cell line by Ajmal *et al*. Their findings showed that upon binding methotrexate, a chemotherapeutic drug, the conjugate nanoparticles were reported to have a cytotoxicity close to that of cells treated only with methotrexate. However, the advantage of delivering this drug with a nanoparticle that fluoresces after light activation is the ability to trace the drug. For even better tracking, using a carrier nanoparticle capable of being activated via two-photon excitation can provide a 3D spatial image over a greater tissue depth than a particle activated with visible UV light. As chemotherapies are typically delivered in a high dose regimen, the ability to observe their distribution in the body through fluorescence could help to reduce off-target side effects by better targeting them to desired areas.

Fluorescence is not a shared trait among all nanoparticle drug carriers, and their mechanisms of drug binding and release can be quite varied, especially amongst nanostructured particles. Cylindrical nanotubes can trap pharmaceutical agents within an internal matrix surrounded by an outer layer of poly (L-lactide) or poly (D-lactide). When these enantiomers come together in solution, they interact with each other to reconfigure their structures from cylinders to spheres, releasing trapped materials in the process. There is no requirement for external stimuli for drug release as there is in some light activated nanoparticles, only that the two nanotubes interact. Other nanostructured particles can be self-loading like albumin-dextran nanoparticles with hydrophobic drugs. Albumin from bovine serum can be stabilized with dextran in aqueous solutions and can bind medicine through hydrophobic and electrostatic interactions. When tested with ibuprofen, albumin-dextran nanoparticles could take up 0.7-unit weight of ibuprofen per 1-unit weight of the conjugated particle. These nanostructured materials present new mechanisms for pharmaceutical uptake and release in nanomedicine, potentially serving as methods to increase release specificity and reduce lag times between drug delivery and effect in the future.

9. REPRODUCTION:

Animal production revolves around animals meant for slaughter. Finishing livestock are the offspring of individuals intended for breeding who have highly ranked genotypes and phenotypes. The traits and reproductive abilities of breeders gives them high value. Some nanoparticles have been demonstrated to enhance fertility and protect spermatozoa through the functional groups they carry. Artificial insemination is widely preferred in animal production as an alternative to live cover strategies due to the lower risk for animals and producers. Commonly done to diversify genetic backgrounds and boost selection of livestock traits, artificial insemination has the potential to be enhanced through the integration of nano-techniques such as the non-invasive bioimaging of gametes, nanopurification, and protectants in cryopreservation.

In order to optimize the efficiency of artificial insemination, livestock gamete biology and reproductive obstacles to fertilization must first be elucidated. Recently, quantum dots have been explored as a research method to improve understanding of mammalian spermatozoon and oocyte movement and their interactions in a physiological setting. These self-illuminating, inorganic nanoparticles are of interest to the field of theriogenology as they are biocompatible, photo-stable, and have a greater signal intensity than organic fluorescent molecules previously used to image gametes and other cell types in vivo. Feugang et al. have demonstrated the real-time tracking ability of bioluminescent resonance energy transfer-conjugated quantum dot (BRET-QD) nanoparticles in vitro, in situ, and ex vivo using pig male gametes (*Sus scrofa domesticus*). Quantum dots can provide targeted or non-targeted imaging as a function of their size, emitted wavelengths, and conjugation possibilities. This engineered nano particle provides a new mean to visualize the molecular and cellular events during fertilization, in a similar way to fluorescent proteins, but at greater tissue depths. Signal strength of quantum dots are dose-dependent and a higher concentration may be required for in vivo imaging on larger animals. Thus, the composition of quantum dots should be further optimized for biocompatibility as many of the current ones include heavy metals, such as cadmium and lead, which may be cytotoxic at high levels. However, if quantum dot concentrations and surface chemistries are carefully selected, cytotoxicity may be decreased or eliminated.

Nanopurification of semen can be used to separate damaged sperm from undamaged, healthy sperm. One method is to coat magnetic nanoparticles with antibodies against ubiquitin, a surface marker of defective sperm, for a protein-based removal strategy. A lectin-based strategy features magnetic nanoparticles coated with lectins that bind glycan exposed at the surface of the sperm through acrosomal damage. Nanopurified bull spermatozoa (Bos taurus) achieved conception rates equal to those of unpurified semen at half the concentration with no negative impacts reported for inseminated cows or calves. Thus, more females can be inseminated from one sample of nanopurified, diluted ejaculate. Further identification of spermatozoa biomarkers will allow for increased selection ability and fertility improvement, as targeted through the antibody or lectin strategies.

Cryopreservation of sperm can be enhanced by turning to nano-protectant additives in extenders. Used to dilute sperm, extenders are buffering agents and provide sperm with nutrients required for prolonged storage. They serve to protect and contain antibiotics, to prevent bacterial growth from affecting sperm quality and infecting inseminated females. Antimicrobial nanoparticles may serve to replace extender antibiotics in the future as some antibiotics have been shown to inhibit sperm motility and viability in a dose-dependent manner. Nanoparticles may also facilitate the addition of natural products in extenders to increase sperm motility. Research groups have reported that the addition of honey, sugarcane juice, tomato juice, and pineapple juice can increase the survivability of sperm stored at room temperature. While nanoparticles were not involved in those studies, it would be interesting to know how sperm quality would be affected if the functional groups of each product were to be delivered via nanoparticle. As sperm can be shipped internationally over multiple days, extenders with a higher capacity for preserving samples undergoing freeze-thaw cycles would be beneficial.

Further advancements in reproductive biotechnology may be possible with the greater inclusion of nanoparticles in molecular biology techniques. Sperm-mediated gene transfer is one such approach where mesoporous silica nanoparticles can be loaded with nucleic acids and proteins. These nanoparticles can form strong associations with spermatozoa in vitro, and do not have any diminutive effects on sperm function or quality. Transfections with polymeric nanoparticles, such as PDMAEMA, chitosan, and polyethylenimine, have been reported to be advantageous over traditional viral approaches provided low concentrations of polymers are used. The molecular weight of the nanopolymer has great influence over transfection efficacy and toxicity, i.e., the optimal molecular weight for transfection with PDMAEMA has been determined to be 60 kDa. With continued exploration and refinement, nanoparticles could play a significant role in animal reproduction. However, it should be noted that some nanoparticles are spermatotoxic which may have serious consequences if breeder reproduction is affected. Zinc oxide and titanium oxide nanoparticles are two examples that reduce in vitro sperm viability in a dose- and time-dependent manner by membrane weakening and DNA fragmentation. Barkhordari et al. incubated human sperm with zinc oxide nanoparticles and found that a concentration of 500 µg/mL would significantly increase cell death after 45 min, while a concentration of 100 µg/mL would significantly increase cell death after 180 min. Pawar and Kaul found that buffalo sperm (Bubalus bubalis) incubated with 100 µg/mL of titanium oxide nanoparticles would have reduced viability. At 10 µg/mL titanium oxide was found to prematurely increase sperm capacitation, which is the final required step in sperm maturation for oocyte penetration and fertilization. While nanoparticles may be points of advancement for the animal production industry, precautions should also be taken when considering the employment of nanoparticles for assisting reproduction.

FUTURE PROSPECTS:

As nanotechnology continues to develop and garner more attention, its applications in the animal production industry will become more expansive. The regular inclusion of nano-supplements to fortify livestock feed is likely possible in the near future; however, it will take longer for nanoparticles to fully replace antibiotics in feed as many biocidal candidates must still be tested in vivo before undergoing clinical trials and food safety tests in accordance with government regulations. External uses for nanoparticles have already been integrated into some aspects of animal production, i.e., antiseptic wound dressings, and more are to follow. For studies interested in nanoparticles with anti-cancer properties, it is important to investigate nanoparticle cytotoxicity in both cancer cell lines and normal, healthy cell lines. Only using cancer cells and claiming the nanoparticle under investigation has anti-cancer properties may be misleading, as the nanoparticle may be cytotoxic to all cell types. In vivo studies are needed for verification of nanoparticle functions seen in in vitro research.

CONCLUSION:

There are many applications for nanoparticles in animal production and this review serves to highlight these uses and to identify potential opportunities for future applications. Nanoparticles are already available on the market and, with continued development; their properties will be more finely optimized for a wider selection of applications. The use of nanotechnology in animal production is still in its infancy but encouraging results from nutrition, biocidal, remedial, and reproductive studies are driving further investigation.

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