Chapter 48

Role of Nanoparticles in Livestock Management

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ABSTRACT

This paper explores the potential of nanoparticles in transforming livestock management practices. At nano scale, Nano particles have shown number of characteristics which prove to be the solution of number of problems in livestock industry related to nutrition animal health and production. Nano particles have shown promising effects on semen quality enhancement, improving fertility and reproductive efficiency, environmental implications and sustainability, production efficiency, growth promotion, vaccination, bacterial infections, viral infections, parasitic infections, antimicrobial properties of nanoparticles, disease prevention and control, and feed supplementation. To ensure the ethical and sustainable use of nanoparticle in livestock management, it is important to address the ethical concerns and establishing a strong regulatory framework. Continued research and innovation in nanoparticle technology are needed to take its advantage and improve the sustainability and resilience of livestock industry.

KEYWORDS
Nano particles, Livestock management, Sustainability, Disease prevention, Nutrition, Fertility

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INTRODUCTION

Livestock management is a challenging essential to the health, production, and sustainability of animal agriculture. The expanding global population contributes to up demand for products derived from animals, including meat, milk, and eggs. So that in order meet needs that developing by avoiding dangerous impacts and maintaining animal welfare, it is very necessary to meet developing needs. To improve the efficiency and sustainability, modern technology has been used in agricultural sector these days. One of these modern technologies is use of nanoparticles in livestock management. Due to their unique characteristics at Nano scale, Nanoparticles give the solution to different problems including boosting animal nutrition and health faced by livestock producers. This chapter explores the potential of nanoparticles in transforming livestock management practices (Sargison, 2020).

Definition and Characteristics of Nanoparticles

Nanoparticles are defined as particles having a size between one and one hundred nanometers. At this level, materials demonstrate unique characteristics that differentiate them from bulk materials. These characteristics, which include increased solubility, enhanced reactivity, and larger surface area, make nanoparticles extremely versatile for a variety of uses (Mody et al., 2010). Nanoparticles provide enormous potential for enhancing animal welfare, food intake, and general efficiency in livestock management. These tiny structures have altered electromagnetic characteristics and an increased surface area to volume ratio, in addition to size-dependent qualities that make them desirable for a range of applications (Talapin andShevchenko, 2016). Materials that can be employed to create nanoparticles with distinctive characteristics and features include metals, metal oxides, polymers, and ceramics (Astruc, 2020). In addition to their tiny size, which allows for efficient transport and individual action inside biological systems, they are also good candidates for application in illness prevention, growth promotion, animal feed vitamin supplementation, and reproductive control (Mohanraj and Chen, 2006).

Livestock Management

Livestock management contains number of different techniques which maintain the production and health of livestock in agriculture system. These techniques include reproducing and breeding, giving housing and shelter, treating and

preventing diseases, controlling nutrition, and basics husbandry procedures. Livestock manager take decisions on a variety of factors including resource availability, market demand, animal genetics, and environmental considerations to ensure the best productivity for their animals.

Different sustainable techniques emphasize a balance between the objectives of environmental protection and needs of livestock for managing grassland and cattle (Nienaber et al., 2007). Putting grazing management plans into actions is essential to preserve the health of grassland and prevent overgrazing, to support the sustainable livestock managing system (Teague et al., 2020).

Implementing different livestock management approaches like land degradation, resources efficiency, and greenhouse gas emissions enhances the productivity, animal welfare, and environmental stewardship in livestock operations (Kleppel, 2020; Hassan et al., 2023).

Importance of Nanoparticles in Livestock Management

Nanoparticles in Feed Supplementation

A. Types of Nanoparticles Used in Feed

Depending on their composition and properties, different types of nanoparticles are used as feed additives to improve livestock digestion and absorption (Fig. 1).

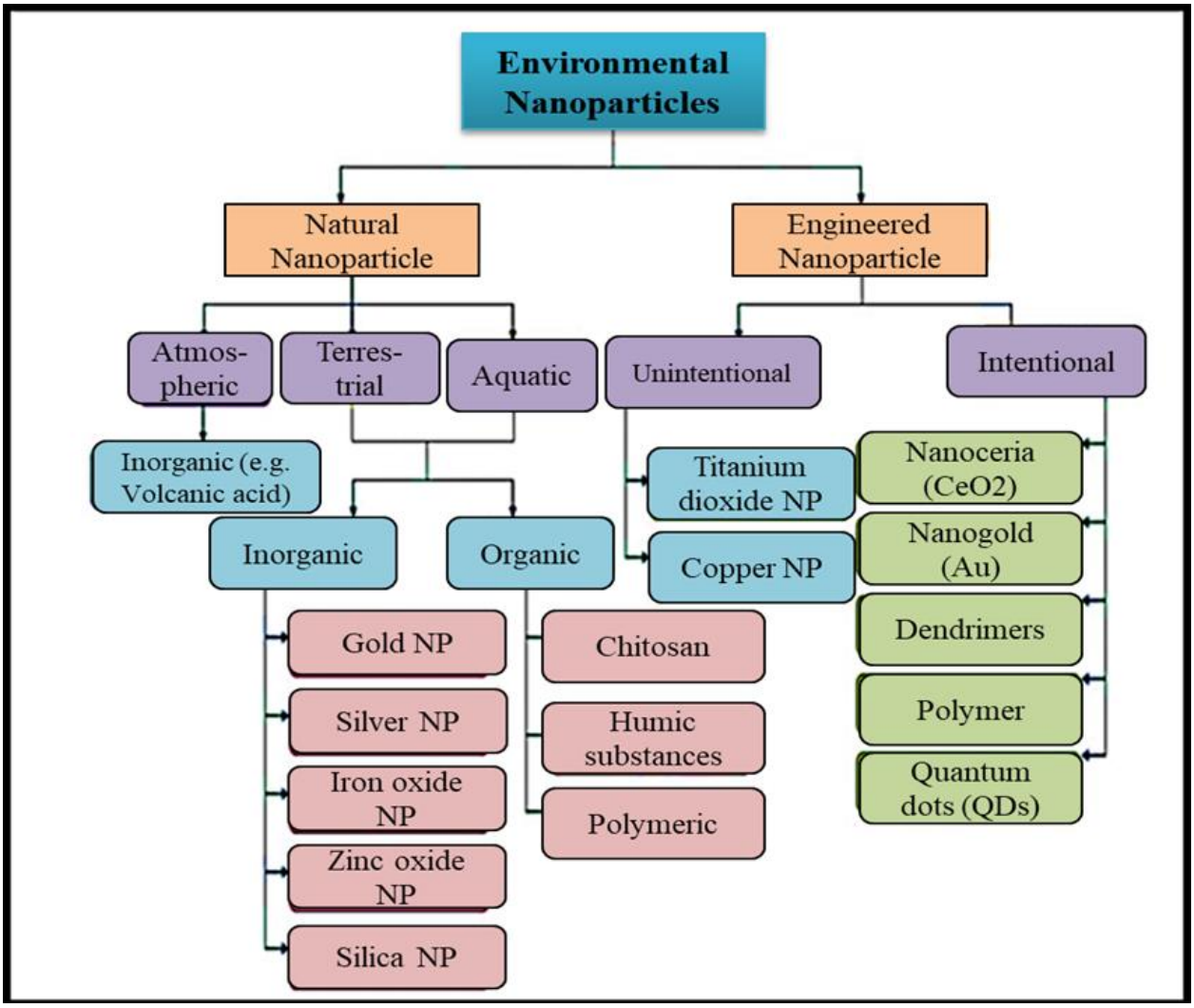

Fig. 1: Types of Environmental nanoparticles used in feed.

a. Nanocarriers: Nutrients like as vitamins, amino acids, and fatty acids can be condensed and delivered via Nano carriers (nanoparticles). These carriers enable the targeted transport of nutrients to specific areas for absorption while protecting them from breakdown in the digestive tract. Nutrient and bioactive material delivery solutions for animal feed are being demonstrated by Nano carriers such as ABA type tri-block copolymers (Mehrazar et al., 2015).

b. Nanominerals: These include nanoparticles of essential minerals such as zinc, copper, selenium, and iron. By increasing their bioavailability and absorption and nanoscale versions of these minerals an animal's development, immune system, and overall health can all be enhanced (Abdelnour et al., 2021).

c. Mettalic nanoparticles: Metallic nanoparticles like silver, copper, and gold, which have antibacterial qualities and can boost animal growth (Bunglavan et al., 2014; Scott et al., 2018).

d. Metal oxide nanoparticles: Magnesium oxide and zinc oxide frequently consumed in food formulations can enhance feed digestibility and nutrient utilization (Adegbeye et al., 2019; Mohd Yusof et al., 2019).

e. Nanoemulsions: Colloidal distributions of oil droplets in water, or vice versa, stabilized at the nanoscale by surfactants, are known as Nano emulsions. Encapsulating lipophilic materials in Nano emulsions can improve their solubility and absorption in the digestive tract. Examples of these materials include fat-soluble vitamins and bioactive compounds (Wilson et al., 2022).

f. Nanoclays: Several types of Nano clays, such as montmorillonite, bind mycotoxins and other contaminants in feed to lessen the animal's digestive tract's absorption of them (Nadziakiewicza et al., 2019).

g. Nanoparticles of plant extracts: Enzymes are encapsulated in nanoparticles to prevent degradation in the digestive tract and to increase the efficiency of the breakdown of feed components for improved nutritional absorption (Sorbiun et al., 2018).

h. Nanoparticles for enzyme delivery: Nanoparticles are used to encapsulate enzymes, protecting them from degradation in the digestive system and improving their efficacy in breaking down feed components for better nutrient absorption (Galliani et al., 2018)

B. Benefits of Nanoparticle Supplementation

Nanoparticles supplement provide number of advantages such as animal performance, production, and overall health. Nanoparticles given in the form of vitamin and minerals provide the better absorption and utilization by the animal's body and increase growth rates and feed efficiency (Alkhtib et al., 2020). Furthermore, the phytochemicals present on nanoparticles help in distribution of nutrients to specific tissues or organs, hence enhancing their effectiveness (Abdelnour et al., 2021). Additionally, the antibacterial property of nanoparticles maintains the gut health of cattle and help in treatment of microbial diseases (Baldissera et al., 2020). In animals nanoparticles stimulating the general health by reduce the oxidative stress and progresses their antioxidant state, and also increase the resistant to different stressor (Del Vento et al., 2019). There are number of different benefits of using nanoparticles as feed additives that livestock welfare and performance.

Nanoparticles in Disease Prevention and Control

A. Antimicrobial Properties of Nanoparticles

Due to their exceptional antibacterial abilities, nanoparticles have attracted a lot of attention from a variety of industries, such as agriculture and healthcare. The distinct physicochemical features of nanoparticles, counting their size, shape, and surface area to volume ratio, are the source of these attributes. Due to their strong antibacterial action against a variety of pathogens, including as bacteria, fungus, parasites, and viruses, metal nanoparticles—in particular, silver nanoparticles—have been the subject of substantial research (Hajipour et al., 2012). Nanoparticles combat bacteria by producing reactive oxygen species, break down microbial cell membranes, and changing microbial enzyme function and by altering their surface and addition functionality (Usman et al., 2013; Gharpure et al., 2020). Furthermore, green synthesis techniques conserving natural resources and lessening their negative effects on the environment by creating antimicrobial metal nanoparticles (Maťátková et al., 2022).

Nanoparticles, due to their unique physicochemical properties, offer numerous advantages in combatting infectious agents.

Functionalization of nanoparticles can improve their interactions with pathogens and increase the effectiveness of antimicrobial treatments (Look et al., 2010).

Nanoparticles are used in drug delivery vehicles, diagnostic instruments and immunotherapies; lets the medicine to be delivered to the infection zone, identification of infectious diseases which makes it easier to contain epidemics and intervene in a timely manner, and to strengthen immune responses against infectious diseases respectively (Torres-Sangiao et al., 2016; Singh et al., 2017; Kirtane et al., 2021).

B. Potential Applications in Vaccination

The major benefit of nanoparticle is to improve the efficacy and security of vaccination, offers a potentially new avenue in immunization.

The use of nanoparticles for transcutaneous vaccine delivery, in which the particles penetrate the skin to deliver antigens and possibly do away with the requirement for conventional injections, is one possible use (Kohli and Alpar, 2004). Due to their adaptable characteristics, polymeric micro/nanoparticles exhibit potential for vaccine delivery applications, providing regulated release and augmented immune responses (Yue and Ma, 2015). Furthermore,

nanoparticles can be created to function as artificial vaccinations, eliciting strong defenses against particular infections (Smith et al., 2015). Significantly, studies have looked into how well nanoparticles might penetrate antigen-presenting cells to increase vaccination effectiveness and uptake (Gregory et al., 2013).

Nanoparticles for Growth Promotion and Performance Enhancement

In plant development and agricultural production, nanopesticides, nanofertilizers, nanosensors, and nanobiotechnology are the uses of nanotechnology, which uses nanomaterials as carriers. The efficacy and durability of agrochemicals are facilitated by the distinctive architectures of nanomaterials, which include high specific surface area, centralized distribution size, and great biocompatibility (Chhipa and Joshi, 2016). Additionally, applying the right nanomaterials at the right times of plant development or under stressful circumstances helps plants thrive and become more resilient to adversity (Table 1). In order to improve crop yields and quality, nanotechnology has been applied to a different agricultural production processes, including seed germination and plant growth (Figure 2).

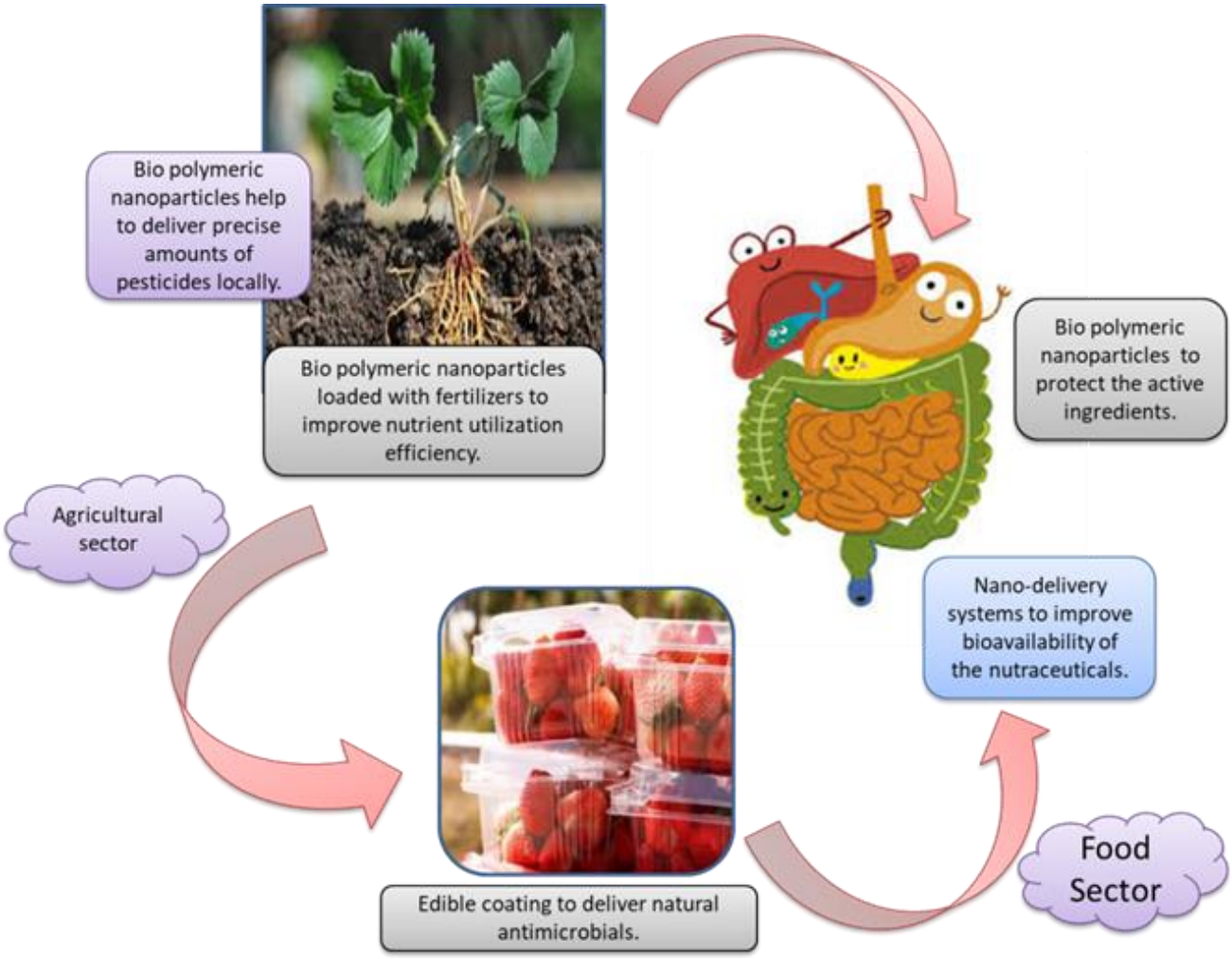

Fig. 2: Nanoparticles for Growth Promotion and Performance Enhancement.

Studies conducted recently have showed the beneficial impacts of nanoparticles (NPs) on seed germination in agricultural plants. Exogenous TiO2 NP treatment improves the seeds' absorption of water and oxygen, which shortens the germination period. TiO2 NPs are useful for boosting seed germination. For example, compared to the untreated control, tomato seedlings immersed in TiO2 NPs showed a germination percentage that was about 8% higher (Wang, 2014). TiO2 NPs have been shown in another work to promote seed germination and significantly shorten the mean germination time in wheatgrass. Furthermore, by improving the capacity of the seed to absorb water, nonmetallic NPs like multi-walled carbon nanotubes (MWCNTs) can promote seed germination in a variety of crops. As MWCNTs were sprayed by air over soybean, barley, and maize seeds, the germination rate of the seeds was successfully raised by at least 25% as compared to the untreated control. Subsequent tests demonstrated that MWCNTs were able to pierce the seed's surface. Furthermore, in soybean, barley, and corn seeds sprayed with MWCNTs, the relative gene expression of many genes associated to water channels increased dramatically (Lahiani et al., 2013).

Table 1: Types of nanoparticles and their role in Growth promotion.

Type	Nanoparticle	Experiment	Animal production application	References
METALS	Silver	Evaluation of antimicrobial activity of Alkali lignin bound silver nanoparticles to cellulose fibers.	Biocide and Veterinary Medicine	(Hu et al., 2015)
	Copper	copper's growth-promoting properties are enhanced with nanoscale copper.	Nutrient delivery and Biocide	(Gonzales-Eguia, et al., 2009)
	Gold	Use amoxicillin to functionalize in order to overcome the resistance of bacteria.	Biocide	(Kalita et al., 2016)
	Iron oxide	Applications of scanning in in vivo functional research.	Veterinary Medicine	(Soenen et al., 2010)
	Calcium carbonate and calcium citrate	Disparities in microparticle and nanoparticle bioavailability	Nutrient delivery	(Huang et al., 2009)
POLYMER	Polyacrylate	Assessing resistance to loaded penicillin and enhancing its antimicrobial efficacy.	Biocide	(Turos et al., 2007)
	Chitosan	Analyzing the effectiveness of drug dispensing and transferring.	Biocide	(Ghosh et al., 2010)
	qPDMAEMA-CNC	Examining the capacity of viruses to bind in order to collect and concentrate infections and particles resembling viruses.	Biocide	(Rosilo et al., 2014)
	Triclosan	Increasing organic compounds' antibacterial activity with aqueous nanodisperive methods	Biocide	(Zhang et al., 2008)
NANOSTRUCTURED	Carbon (glucose- and sucrose-derived)	Evaluating the activity of drugs against cancer.	Veterinary Medicine	(Ajmal et al., 2015)
	Mesoporous silica	Structural visualization of drug discharge in the body	Veterinary Medicine	(Croissant et al., 2014)
	Poly(L-lactide)- and Poly(D-lactide)-b-poly(acrylic acid)	Exploration of new number of therapeutic properties	Veterinary Medicine	(Sun et al., 2014)
	Albumin-dextran	Create aqueous solutions by Binding with hydrophobic drugs	Veterinary Medicine	(Li et al., 2009)
	Biocellulose	Wound dressing by stimulating of collagen	Biocide and Veterinary Medicine	(Napavichayanun et al., 2015)

C. Environmental Implications and Sustainability

When nanoparticles are added to a host polymer, two environmentally beneficial outcomes can occur: first, sustainable nanocomposites made of recycled or bioplastic materials could take the place of common petroleum-based polymers; second, significant plastic savings could be realized by taking advantage of the superior specific properties of the nanocomposites. However, the anticipated advantages may be jeopardized by nanoparticles' inherent environmental load. "Green" polymer nanocomposites made of recycled and bioplastics are environmentally sustainable. A scathing analysis of life-cycle assessment research on nanocomposites and their component parts is provided. Despite their often low concentration, nanoparticles have an amazing effect on the environment. The manufacture of typical nanofillers (nanocellulose, titanium dioxide, silver, and, most importantly, carbon nanotubes) generates significant amounts of greenhouse gases and consumes a lot of energy, negating the benefits of employing green polymer matrices, with the exception of organo-clays and graphene. Achieving optimal performance is therefore essential to genuinely sustainable polymer nanocomposites through material conservation. For this reason, adding more nanoparticles or functionalizing them to improve their dispersion in the host polymer may have unforeseen positive effects on the environment (Carroccio et al., 2022).

In agriculture, crop protection products such as insecticides, herbicides, and fertilizers are essential for maintaining crop growth. The development of sustainable nano fertilizers, nano insecticides, and nano herbicides is imperative due to the substantial losses in food and money caused by plant diseases and insect pests. Maintaining soil fertility is aided with nano fertilizers.

On the other hand, nano pesticides and herbicides improve solubility, prolong the duration of pest control, and shield plants against early deterioration. Plant diseases can be inhibited by directly applying pesticides to seeds and grains (Arora et al., 2024).

Nanoparticle stabilizers (NPS) find application in several domains such as food packaging, nanocoating (which

prevents scratches on surfaces), nanofiltration, nanodelivery systems for agriculture, and numerous agro-industries. In food sciences and food microbiology, NPs are essential because they help identify foodborne infections and prolong food shelf life. For root elongation and seed germination, NPS also garners a lot of attention. They are used in cosmetics like skin creams that fight skin aging by using proteins produced from stem cells (Figure 3).

NPs are used in wastewater treatment, a method that is used all around the world. To supply clean water for drinking and irrigation, they lessen pesticides, fertilizers, and heavy metals. This method is economical and ecologically friendly (Arora et al., 2024).

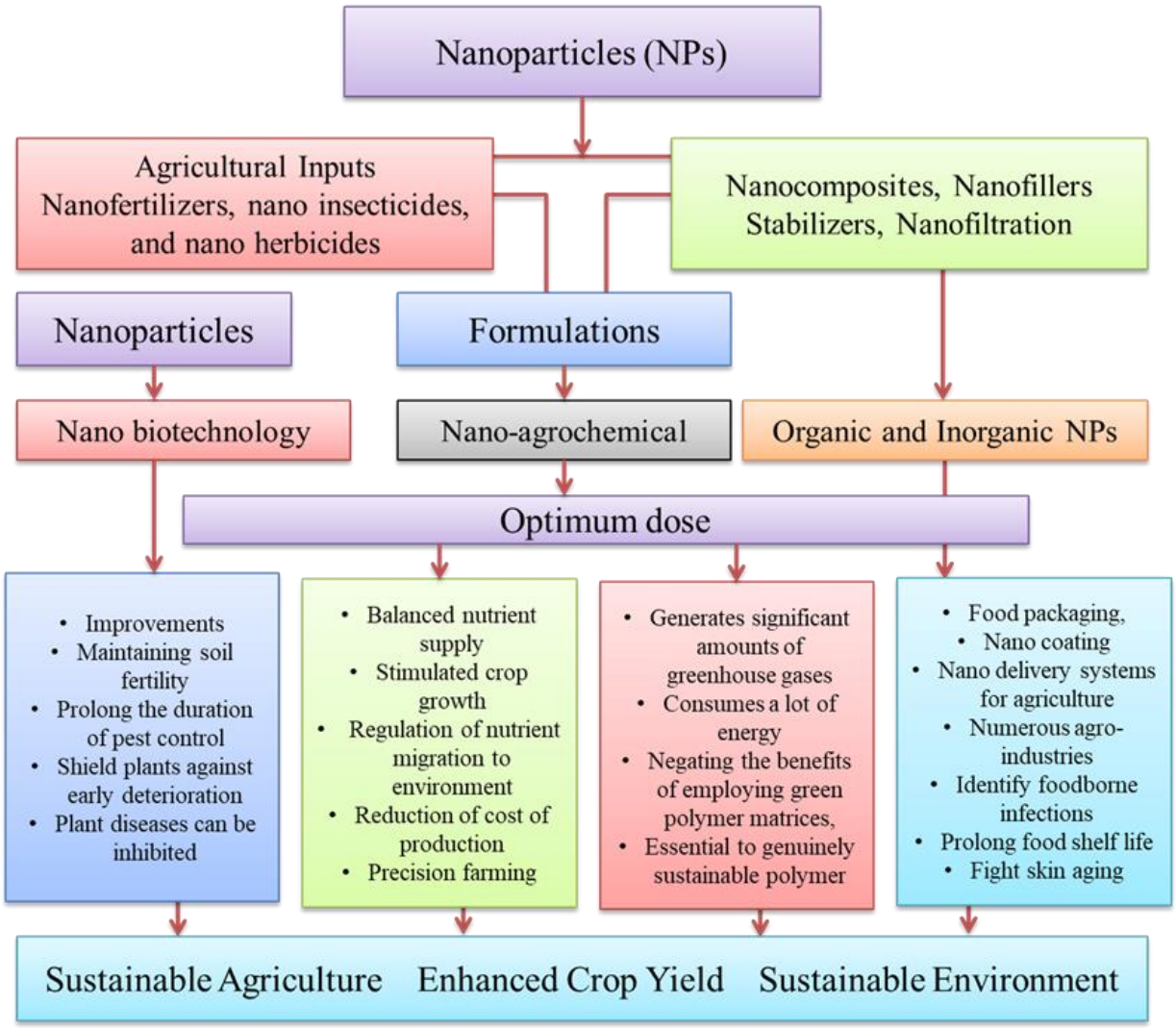

Fig. 3: Environmental Implications and Sustainability due to nanoparticles

Nanoparticles in Reproductive Management

A. Improving Fertility and Reproductive Efficiency

Nanotechnology used different techniques to improve fertility and reproductive efficacy. The use of nanotechnology has the potential to enhance both semen purification and sire fertility testing. The use of nanotechnology applications in cattle farming systems could offer novel and creative ways to address problems with reproductive control (Hill et al., 2017). Nanotechnology can give several pharmaceuticals (including hormones and antibiotics), biological molecules, and nutrients new physicochemical qualities. These include enhanced bioavailability, increased cellular absorption, regulated sustained release, and decreased toxicity as compared to conventional versions.

Nanoparticles improve the hormone based therapies and assisted reproductive techniques, ultimately enhancing fertility of farm animal (Hashem and Gonzalez-Bulnes, 2020).

B. Applications in Semen Quality Enhancement

Nanoparticles in semen extender improve the quality of semen and reproductive management. soybean lecithin nanoparticles and selenium nanoparticles in semen extender improved the quality of rooster frozen-thawed semen and bull sperm during cryopreservation leading to overall rise in progressive motility and viability (Khalil et al., 2019; Sun et al., 2021).

While adding thymoquinone nanoparticles GnRH-loaded chitosan nanoparticles to semen extenders boost the ability of buffalo bull spermatozoa to fertilize and cryotolerate and stimulatimg the LH secretion and viable ovulations in rabbits during artificial insemination protocols (Hassanein et al., 2021; Khalil et al., 2023).

Hence, the use of nanoparticle-based techniques proposing novel avenues for the regulation of reproduction and enhancing semen quality and fertility.

Advancement in Nanotechnology for Agricultural Innovation

a. Applications of Nanotechnology in Animal Science

Nanotechnology offers solutions for veterinary care, food production, and disease treatment in animal science. Nano-capsules protect enzymes and proteins in livestock feed, enhancing yield and effectiveness. Nanoparticles improve the efficiency of medications like antibiotics, vaccines, and probiotics, addressing infections and metabolic disorders. Silver nanoparticles disinfect livestock environments, while nanotubes track hormone levels for better breeding management (Chakravarthi and Balaji, 2010).

b. Applications of Nanotechnology in Pests and Plant Diseases Management

In order to manage pests and plant diseases, nanotechnology offers targeted and controlled delivery, revolutionizing chemical application procedures. Nanoparticles reduce environmental contamination while maximizing the effectiveness of fertilizers and insecticides. More precise diagnosis of illnesses like viral infections is made possible by nano-based diagnostic kits, which allow for prompt treatment (Sharon et al., 2010).

c. Applications of Nanotechnology in the Food Industry

In the food sector, nanotechnology improves safety, preservation, and packaging. While nanobarcodes track the safety and quality of food, nanocoatings stop oxygen from penetrating food packaging. Foodborne infections and pollutants are identified using biosensors, protecting consumers. Chemicals such as pest are absorbed by nanofibers, which also enable targeted delivery and lessen environmental pollution (Kuswandi, 2016).

d. Nanofiltration for Water Purification

In order to alleviate the shortage of freshwater, nanofiltration technologies enhance the desalination and water purification processes. Microbiological pollutants in water are identified by nano-based sensors, guaranteeing its safe ingestion (Khan et al., 2021).

e. Applications of Nanotechnology in Agronomy

Nanosensors are useful for precision agriculture because they maximize resource utilization and identify crop diseases and pests. Nanomaterials enhance crop resilience, soil fertility, and machinery durability, all of which support sustainable farming techniques. Food security, environmental sustainability, and agricultural output can all be improved with the help of nanotechnology (Yadav et al., 2023).

Hence, nanoparticles play important role in livestock management in many ways (Fig. 4).

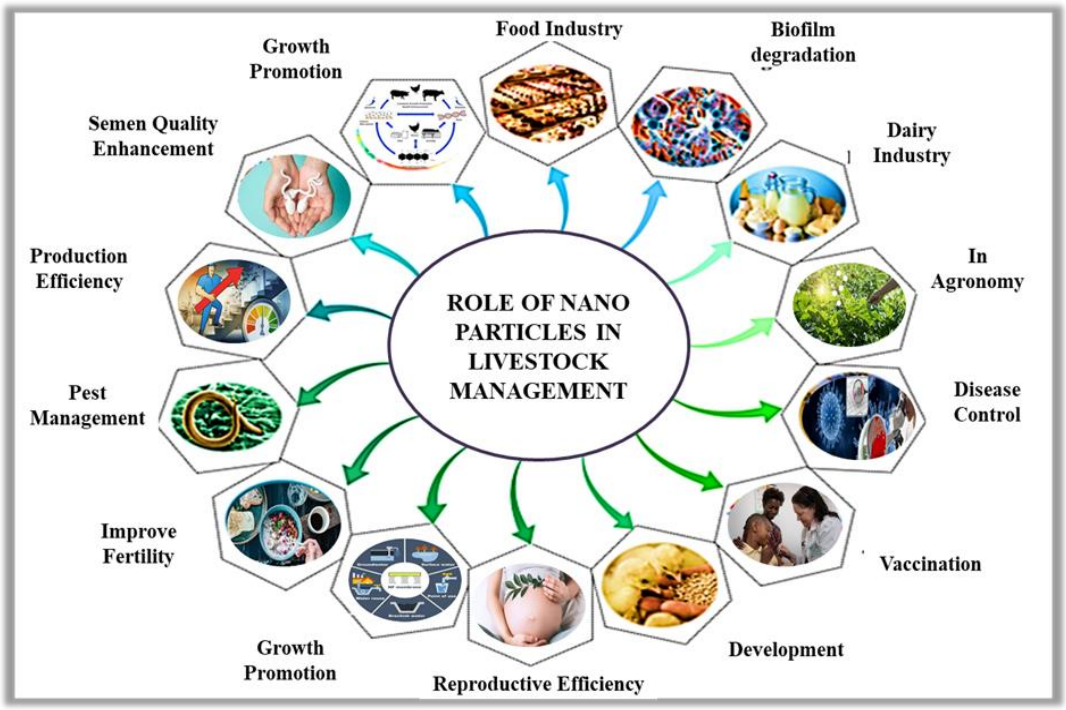

Fig. 4: Roles of nanoparticles in livestock management.

Nanoparticle Safety and Regulatory Considerations

An important part of nanotechnology is the safeness solicitude associated with the use of nanoparticles. And organizing structure and guidelines are essential to negiciated these issues. Laws are necessary to build protocols for handling nanoparticles and to ensure conformity to safety requirements (Isibor, 2024). A organized approach to criticizing possible risks and controlling the associated risks susceptibility of nanoparticles is presented through a risk assessment and risk management structure (Oomen et al., 2018). Assessing the executive structure to address nanoparticle-related issues and decide their relevancy and effectiveness is an essential step in nanomaterial resource assessment (Linkov and Satterstrom, 2008). Organize the risk control measures and telling decision-making processes is promoted by comparing appraisement of safety assessment factors and definitions of nanomaterials (Boverhof et al., 2015). Additionly, specific criteria for settling the presence of nanoparticles and assessing the risks related to the nanospecificity are provided by the instructions on Technical Requirements for controlled Food and Feed Products applications (EFSA, 2021). Overall, evaluation of risks and risk management techniques are integral and important in the normative framework to assure the safe execution of nanoparticles in various zone and applications.

Future Perspectives and Emerging Trends

The oncoming books opinions and arising Trends in Nanoparticles Research for farm animals' administration has great potential to improve farming practices. A notable progress is the combining of nanotechnology with perfection livestock farming that refine sustainability in smart farms by allowing precision sensing and biological heterogeneity (Zhang et al., 2021). These developments are predicted to enhance observing of livestock health and certainly reduce the industry's environmental effects. Real-time data collection is accelerating by advances in wearable sensors and biosensoing technologies that monitor animal health, and provides perceptive information about farm durability management (Neethirajan, 2017). Nanomaterials, nanominerals and nanofertilizers have the implicit to improve crop nutrition and productiveness, which will ultimately improve livestock nutrition and health (Ditta et al., 2015; Raliya et al., 2017; Bhagat and Singh, 2022). Moreover, the use of nanotechnology in stock raising also offers chhances to refine tissue-targeted therapies and mechanobiology that could transform animal care and livestock welfare (Wang et al., 2022). The livestock industry as a whole can greatly increase animal welfare and productivity by using nanotechnology in livestock management.

Conclusion

Finally, incorporating nanoparticles into livestock management techniques is a fanatical arrangement which extend many privileges in a field of agricultural setting. Livestock producers can promote animal health, production and welfare while reducing the environmental impact by exploiting the special properties of nanoparticles such as improved bioavailability targeted administration and antimicrobial action. Elevated opportunities to enhance agricultural practices originate from theoretic requisition of nanoparticles in model development, disease prevention, food supplementation, reproductive management, and environmental sustainability. Addressing safety concerns and establishing a strong regulatory framework are essential to ensure the ethical and sustainable use of nanoparticles in agriculture. Additional research and concoction are necessary to fulfill the promise of nanoparticles technology and to talk about new difficulties. This will eventually help create a more springy and viable livestock sector.

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