



Positive and Negative Effects of Using Nanotechnology in Animal Health and Production: A Review Article

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ABSTRACT

Nanotechnology has made a big difference in animal production and health. This review study looks closely at both the good and bad sides of using nanotechnology in raising livestock. For animal feed special nano-formulated additives have shown they can help animals use their food better, keep them growing steadily, and make nutrients easier for them to absorb. This could mean more food production, healthier animals. The review also discusses the potential problems that come with using nanotechnology widely with animals. It raises concerns about nanoparticles possibly being toxic, to make sure nanotechnology does help animals stay healthy and productive in a sustainable way, we need to do our research thoroughly, have strong rules in place and be careful how we develop new technologies. Nanotechnology has great potential in enhancing animal health and productivity through animal feed efficiency, targeted delivery of drugs and better diagnostic tools. But we should be cautious around issues of toxicity how these materials may accumulate in the environment, and regulatory challenges. To reap all that nanotechnology has to offer and minimize risks in veterinarians and animal applications we need a comprehensive approach which includes continued study combined with rigorous safety measures. This review article aim is to assess the advantages and disadvantages of applying nanotechnology to animal productivity and health

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INTRODUCTION

Nanotechnology is the ability to see, modify and produce materials at a very small size called the Nanoscale [1]. This scale typically includes substances in the range 1-100 nm, and occasionally smaller than 1 μ [2]. The stakes are high among the global challenges of raising animals is protecting the environment, ensuring there's sufficient food, keeping diseases in check and safeguarding human health. Nano biotechnology is a rapidly expanding work area and holds several tangible advantages in animal and veterinary sciences, such as medical applications,

diagnostics, nutrition [3,4]. They received considerable attention due to the small size (1-100 nanometer or less) and potential for replacement of other common minerals in animal feed [5]. The small dimensions of nano-minerals enable them to enhance animal mineral uptake through their extensive surface area and consistent distribution patterns and reactive physical properties [3,6]. Animals stand to gain advantages from nanoparticle biological characteristics that promote enhanced tissue distribution together with improved growth outcomes and optimized feed efficiency and superior overall health [3,7]. Animals require smaller mineral doses and experience fewer negative reactions along with quicker absorption rates when nanoparticles are used [3]. The use of essential minerals in their nano form results in increased weight gain and superior daily growth and improved feed conversion ratio (FCR) [8,9]. Not only do nanoparticles assist animals in achieving their nutritional requirements, they also help improve their gut health and immunity, productivity and reduce the potential for them to experience disease. Nanoparticles are such potent tools to combat bacteria, fungi, viruses as well as protozoa and they also serve as antioxidants as reported by many [4,6,8-14]. Among others, nanoparticles of Silver, copper, zinc, and selenium are also used as alternatives to antibiotics. The superoxide dismutase enzyme, a crucial antioxidant defense against oxidative stress, can also be activated by nano-copper and nano-zinc [15,13]. However, it's vital to remember that small nanoparticles may increase cellular absorption and translocation inside the animal's body, which could affect their toxicity [16]. A high surface-to-volume ratio, improved reactivity, stability, functionality, bioavailability, controlled drug arrival, and drug delivery at the precise target site are just a few of the unique physicochemical properties that set nanoparticles apart from bulk materials

[17,18]. Nanoparticles can overcome high toxicity and poor bio-accessibility since they find it easier to enter cells, tissues, and organs when compared to Macroparticles [19,20]. Nanotechnology, which manipulates materials with diameters between 1 and 100 nanometers, has become popular in a variety of industries, including agriculture and food systems. It can be applied to enhance agricultural nutrient utilization efficiency and animal nutrition and health. making advantage of current technical surveys and scientific research. By discussing the potential benefits and drawbacks of nanotechnology treatments, the discussion emphasizes the need for a comprehensive, evidence-based approach.

Nanoparticle types

Nanoparticles with a diameter of less than 1,000 nm can be broadly classified into a number of categories based on their origin, size, shape, and chemical characteristics [21-23]. A wide range of components and an increasing number of innovative, state-of-the-art nanomaterials, including polymers, carbon nanotubes, silicon oxides, inorganic materials, quantum dots, and liposomes have been used to find nanoparticles in recent decades [24]. Based on their chemical properties, nanoparticles are said to be classified as Inorganic nanoparticles which includes Numerous nanomaterials fall within this category including silver and iron oxide, bucky balls, carbon nanotubes, quantum dots and nano shells and organic nanoparticles that are characterized by Colloidal materials exhibit certain size-dependent physicochemical features, including optical, magnetic, catalytic, and electrochemical ones [25,26]. Minerals and other inorganic nanoparticles are used in the nutrition, feed, and packaging industries for a number of purposes, such as feed storage, water purification, feed packaging, and antimicrobial packaging [25,26]. Organic nanoparticles increase feed functionality, nutritional value, and bioavailability by

encapsulating proteins, fats, and sugars. They are used in feeds as liposomes and small particles, and in feed packaging methods as biosensors, identification markers, shelf-life extenders, and antimicrobials [27].

There are nanoparticles available, and as technology advances, their properties will change to enable a greater variety of uses. In many developing countries, the demand for animal products is rapidly increasing. Nanomaterials offer a wide range of uses in the ever-expanding realm of daily life. These methods of NP uptake may be deliberate or unplanned. The respiratory system, the gastrointestinal tract, infusions, skin pores, and sensitive tissues are all possible entry points for these nanoparticles. Health effects could

result from their entrance and accumulation within the cells. According to [28] the livestock, agricultural, and poultry industries have recently made substantial use of nanomaterials to increase the freshness and shelf life of food products. According to [29] they are also used to boost animal immunity, oxidation resistance, and output while reducing the need for antibiotics in cattle. According to recent research, nanoparticles had a usage coefficient of approximately 100%. whereas inorganic trace elements had a utilization coefficient of about 30%. In addition to promoting growth and increasing feed conversion rate, selenium nanoparticles may also improve the health of fish, poultry, and livestock

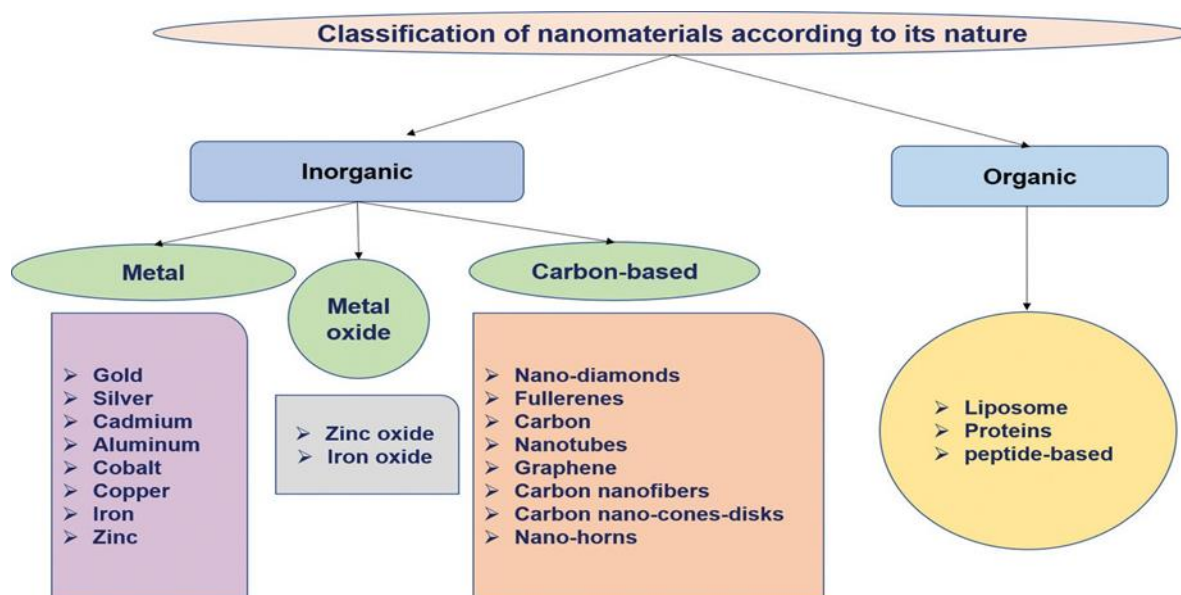


Fig. 1. Classification of NPs according to their nature [30]

NANOTECHNOLOGY APPLICATIONS IN THE FIELD OF ANIMAL SCIENCES

1-Technology for assisted reproduction:

By using assisted reproductive methods, breeders have been able to produce offspring with acceptable traits in agricultural animals that were previously believed to be sterile through standard breeding operations.

The ability of farm animals to reproduce has a major influence on the productivity and profitability of livestock agriculture systems. The field of reproduction has benefited greatly from nanotechnology, and the best way to control reproduction is to use a variety of exacting techniques that also consider the effects on the environment and cost [31].

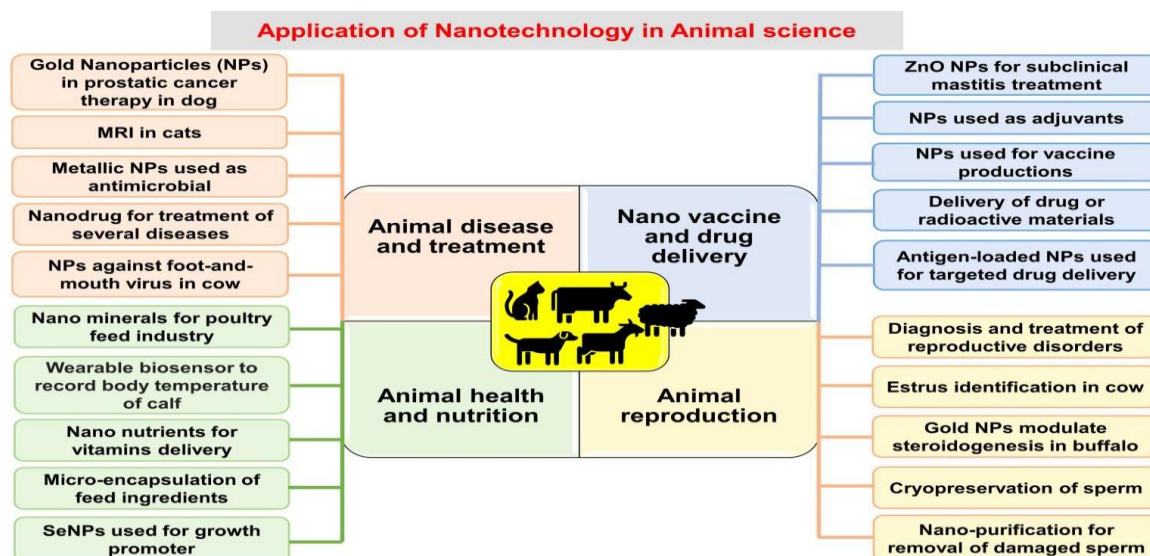


Fig. 2. Applications of nanotechnology in animal research appear in the schematic picture [32]

2-Feed additives of nanoscale size:

As stated by [33] there are two primary groups of feed additives used in animal nutrition.: the first category comprises nutrients such as vitamins, minerals, and amino acids, while the second category includes non-nutrients, which encompass hormones, antibiotics, prebiotics, enzymes, pellet binders, yeast cultures, antioxidants, and others. Feed additives are primarily used to safeguard animal health, boost production, maintain feed and nutrient quality while increasing the nutritional value of feeds, and provide feeds a certain form. The animal feed industry strategically uses these additives which are integrated into feed formulation and manufacturing processes to maximize production efficiency and support animals' healthy growth and development [34]. Because of their surface effects nanoparticles differ from bigger materials in that they require less energy for atoms to join making them less stable altogether. For instance, gold nanoparticles of a specific size have a lower melting point than the same element in a bigger structure. In contrast, nanostructures at the nanoscale exhibit behavior akin to that of a

single atom in terms of quantum effects [35]. When compared to particles of conventional size, the specific surface area of nanoparticles with sizes in the nanometer range is greater.

Higher surface efficiency, higher catalytic efficiency, and a greater capacity for absorption. According to [36] and [37] nanoparticles also possess special physical, chemical, and biological characteristics, including higher conductivity, improved solubility, improved material strength, optical qualities, thermal dynamics, and catalytic effectiveness. Numerous aspects, including immune system function, growth and development, digestibility, and nutrient absorption, can benefit from the increased surface area of nanoparticles [38,39]. These advantages, along with the size impact and high surface reactivity, are used to increase the bioavailability of meals. Because NP-sized minerals can pass through the gastrointestinal barrier and enter the body's cells more quickly than bigger particle sizes, they can improve absorption rates when used as feed supplements [26,40]. Feed additives are crucial for enhancing the animals' growth performance, but there are drawbacks as well

like the possibility of decreased nutritional absorption because to interactions with natural nutrients and the development of endotoxins. Numerous macronutrients may be transformed or digested by rumen bacteria as a result of this decrease in food absorption [41]. In this context, however, it is crucial that nutrients be preserved for small intestine absorption. Feed additives are more easily identified and used when they are combined with nanoscale encapsulation. Nanotechnology has truly made a mark on animal productivity and health, bringing with it both exciting opportunities and significant challenges. It's seen as a fundamental part of what could be a major leap forward in veterinary care, animal welfare, and other areas related to animal production. For instance, nanoparticles can make nutrients work better and be more easily absorbed by animals, whether they're monogastric or ruminants. Nanomaterials, for example, can help animals get more out of their feed, leading to better productivity and health. Plus, because they allow for more effective drug delivery and help cut down on infectious diseases in herds, nanoparticles are showing great promise as treatments for various conditions. These advancements are key to boosting financial outcomes and cutting down on the losses caused by animal illness.

3- Application of Nanotechnology in Animal Nutrition:

Nanotechnology is bringing a fresh perspective to how we feed animals. This innovative approach shows real promise for boosting their immune systems, improving their overall health, making their food production more efficient, and making sure they get the most nutritional value from their feed. Think of feed additives shrunk down to the nanoscale they're incredibly tiny. Because of their small size, these additives have a much larger surface area compared to regular-sized ones. This means they can be absorbed much more easily by the animals, making the feed itself more nutritious [42]. Adding these tiny boosters to animal diets can really help improve how well they absorb nutrients, which in turn benefits their general health and productivity. There are actually quite a few different nanoscale feed additives that can be used in animal nutrition [43,44]. These include things like nano-sized minerals, vitamins, enzymes, prebiotics, antioxidants, and even herbal extracts. Much of the research so far has focused specifically on using nanoparticles to make mineral supplements work even better for animal.

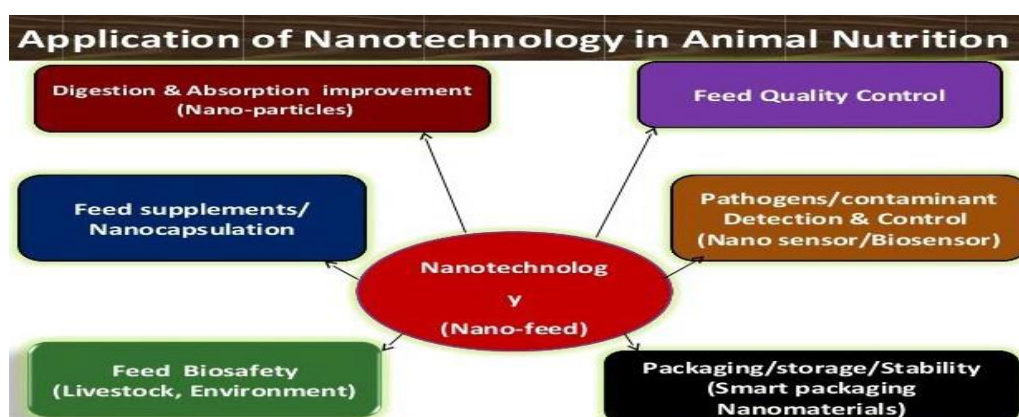


Fig. 3. Animal Nutrition within the Use of Nanotechnology [44]

THE APPLICATION OF NANO FEED ADDITIVES IN ANIMAL NUTRITION

Reports have indicated that nano additives are present within protein micelles, capsules, and within some natural feed constituents [45]. To prevent minerals and micronutrients from oxidizing and to lessen their disagreeable taste, encapsulating nanoparticles was employed. According to [46], Liposomal nanovesicles are said to carry antibacterial agents, tastes, enzymes, and minerals in food. To encapsulate nano-additives in micelles and oil spheres coated with bipolar molecules, proteins and other materials are also expressed [20]. These can be encapsulated in oil or suspended in water, as mentioned by [47]. One of the components of nano-capsules is omega-3 fish oil, which has an unpleasant taste. In order to improve nutritional content, raise animal production efficiency, promote health, ensure cost-effectiveness, and improve product quality, feed additives are essential fundamental ingredients utilized in the modern feed industry [48]. The application of enzyme nanoparticles in animal nutrition is highlighted by [49]. Enzyme nanoparticles are clusters resembling proteins, with sizes varying from 10 to 100 nm, offering conductivity, sensitivity, stability and biocompatibility.

APPLYING NANOTECHNOLOGY TO POULTRY NUTRITION

Smaller nanoparticles are able to better penetrate intestinal wall cells [35,50]. Also, by increasing their surface area and which in turn extends their time in the intestine's environment we see that nanoparticles play a role in enhancing intestinal cleaning action and also in to improve tissue penetration [51]. Nanoparticles play a role in improving tissue penetration and in supporting active intestinal cleansing by means of increasing their surface area and extending their residence time in the tissue [51]. Allowing to transported to lymph

nodes before reaching liver and spleen after gastrointestinal absorption of the nanoparticles [35,52]. In contrast to antibiotic supplements, nanoparticles such as possess higher surface to volume ratio and absorption allaying against quick degradation and microbial resistance development [53,54]. Application of nanotechnology in nutrition is more predictable science and have many benefits, according to researches [53,55]. Nanotechnology has been very promising in showing how it can positively influence the nutrition sector, by dealing with such issues as production, processing, storage, transportation, traceability, security, and food safety [55]. Moreover, food can be required in smaller portions by employing nanotechnology, which is instrumental in lowering pollutant emissions and thus has a positive environmental impact. At the same time, it assures increased production efficiency, animal health, and food safety in the poultry sector [52].

Nanotechnology can do a number of impressive things: (1) enhance the quality of feed (2) increase the availability of nutrients, micronutrients, and bioactive compounds for more effective delivery (3) make subtle adjustments to feed texture to improve qualities like color and flavor (4) create biosensors that can detect pollutants and pathogens; and (5) revolutionize feed packaging by stabilizing nutrients and bioactive compounds within the feed matrix. Recent advancements are making a significant difference in feed safety and enhancing the antibacterial properties of feed. When it comes to poultry, selenium is a rare but essential micronutrient. This mineral plays a crucial role in forming the enzyme glutathione peroxidase, which is vital for stimulating thyroid hormones, managing energy metabolism, and boosting the immune system. Selenium acts like a pseudo-antioxidant, helping the body combat cellular damage and neutralize free

radicals, especially during stressful conditions. Research indicates that adding selenium to the diet of broiler chickens can lead to better production performance and improved health indicators, such as blood composition, antioxidant levels, and gastrointestinal health. Interestingly, the benefits of selenium supplementation are particularly pronounced in younger birds [56]. According to [12] the inclusion of selenium nanoparticles in a layer diet can improve the balance of intestinal microbial flora, immunological modulation, antioxidant status, egg quality, reproduction, egg production, FCR and selenium. Selenium is also required for producing follicles and viable eggs in hens' reproductive physiology. According to [57] laying hens that ingest 0.25 ppm of nano selenium exhibit increased glutathione peroxidase activity and enhanced production efficiency, the eggs produced are also rich in selenium, in poultry, the use of inorganic copper sulfate and copper oxide nanoparticles improves immunity and growth performance while reducing inflammatory responses. It has been established that the diets with copper nanoparticles lowered feed intake, but they did not affect the mass, body weight, productivity, or egg quality of laying hens. Iron nanoparticles in hens' diet boost growth performance owing to improved hematological and immunological indicators.

THE BIRD'S GENERAL NANOPARTICLE MECHANISM

When it comes to poultry nutrition, nanoparticles can be inhaled or ingested. Although there are other biochemical and physiological issues with the way that nanoparticles work, their size is generally the most crucial factor in how well they work [58]. Particles smaller than 100 nm have been shown to penetrate tissues, and particles smaller than 300 nm have been shown to spread throughout the circulation [59]. For instance, clinical studies have demonstrated that adding trypsin and peroxidase enzymes to

magnetic iron nanoparticles can significantly extend their lifespan (from a few hours to several weeks). Making protein enzymes more stable by nanotechnology and nanoparticles enhances their impact on nutrient absorption, digestion, and metabolism [35]. In general, smaller particles can penetrate deeper into the biological system and are more absorbable. The performance, absorption, and elimination of nanoparticles are affected by various factors, including solubility and particle charges. Based on their physical properties like size, charge, and solubility, the avian body will absorb, distribute, degrade, and expel nanoparticles [60,61].

BENEFITS OF NANOTECHNOLOGY FOR ANIMAL PRODUCTION AND HEALTH

1- Increased Feed Efficiency and Further Nutrition:

Advances in nanotechnology have shown great potential in the field of animal nutrition. Adding nanoparticles to animal feed can enhance general health and weight gain by raising the bioavailability of nutrients [62]. Research shows, for instance, that nanoscale chemicals like zinc and selenium can help to boost immune response and feed efficiency, both of which are absolutely required for cattle health [62]. Moreover, assisting more exact animal feed composition, nanotechnology enhances its nutritional content and minimizes resource waste in the agricultural sector. Using nanoscale feed supplements that let animals more efficiently transform grain into energy has been shown to dramatically increase animal feed efficiency. Optimizing nutrient absorption and utilization increases growth rates and FCRs [63]. Adding nanoparticle additions to animal feeds is one crucial approach to improve feed efficiency and so profitability in animal agriculture. Using By using nano feed additives to improve feed efficiency, quality and quantity of animal

products can be increased while feed costs are lowered [64]. Increasing feed efficiency may somewhat improve the quantity and quality of the product. Actually, research reveal that including nano feed supplements to the diet through feed and water greatly enhances the quality of chicken meat and eggs and improves the yield properties of the meat, milk, and other products of cattle and sheep [65,61]. Nanoparticles also reduce the need for feed preservatives and aid to get rid of unpleasant odors animals find offensive [66]. Furthermore, nanoparticles treat Nanotechnology helps in the treatment, diagnosis, tissue engineering, and vaccine development of animal diseases.

2- Nanotechnology's antibacterial and immunomodulatory properties

They have been investigated by researchers. Metal oxide nanoparticles like copper oxide (CuO NPs) have been shown to have potent antibacterial effects against dangerous bacteria that cause illness in animals [67,68].

3- Advances in Immunization and Illness Management:

Nanotechnology has played a major role in the development of vaccines against zoonotic diseases that affect both people and animals. More effective vaccinations that can trigger stronger immune responses have been made possible by advancements in nanomaterials [69].

4- Minimization of Environmental Impact:

Nanotechnology can support sustainability by lowering the quantity of nutrients lost to the environment. Controlled-release nano fertilizers and feed additives reduce the excretion of nitrogen and phosphorus, which in turn reduces environmental contamination from animal excrement [70].

5- Food Safety and Disease Prevention:

In the realm of cattle production, the antibacterial properties of certain nanoparticles present viable alternatives to traditional antibiotics. Specifically, nanoparticles composed of copper and silver have demonstrated potential in decreasing the occurrence of diseases, thwarting bacterial infections, and enhancing the overall wellbeing of animals [20].

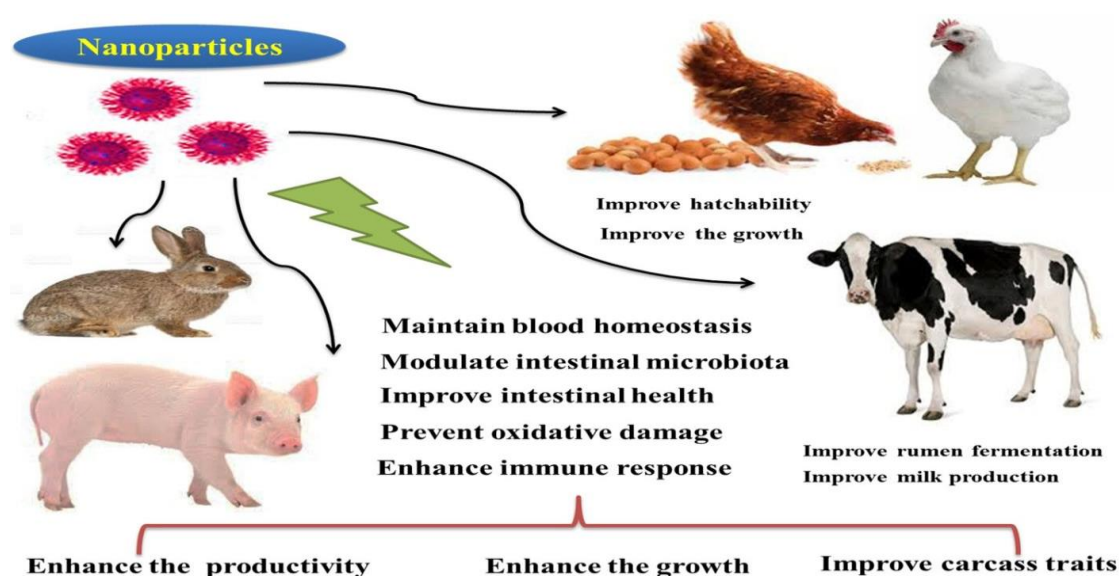


Fig. 4. The positive impacts of nanoparticles on animal health and performance [71]

NEGATIVE EFFECTS OF NANOMATERIALS

Although nanoparticles have exciting potential in framing benefits to animal health and production, these approaches are tainted by drawbacks. Nanoparticles can cross biological membranes leading to tissue build-up resulting in cytotoxicity, they can induce oxidative stress of cells by producing reactive oxygen species (ROS) that damage cellular components such as lipids, proteins, and DNA, in addition, oxidative damage can interfere with normal cellular function [84]. At high concentrations nanomaterials can harm the growth and structure of living organisms, nanoparticles may damage DNA and proteins [72]. Oxidative stress is a common sign of toxicity causing tissue damage and disrupting metabolic regulation, it happens when oxidant production outpaces available antioxidants which can trigger cell apoptosis or degeneration, often this imbalance stems from a rise in ROS that lowers antioxidant levels [73]. Toxicity of the nanoparticles is a multi-step process, in which cellular metabolism is disturbed by interference with biochemical processes, at the same time, the nanoparticles amplify overproduction of ROS further disturbing the balance of the antioxidants and causing oxidative stress [72]. Oxidative stress causing tissue damage and disrupting metabolic regulation, it happens when oxidant production outpaces available antioxidants which can trigger cell apoptosis or degeneration, often this imbalance stems from a rise in ROS that lowers antioxidant level [73]. Such oxidative stress caused by excess ROS is a prime culprit responsible for various liver diseases like hepatitis, liver failure [74]. Exposure to nanoparticles (NPs) can cause oxidative stress in hepatic tissues by several processes because Oxidative stress results from the interruption of antioxidant enzyme activity brought on by MNPs collecting in the liver, nanoparticles also greatly lower

antioxidant levels, including those of hepatopancreatic glutathione-S-transferases. Studies have demonstrated that these nanoparticles can even damage DNA in liver cells, for example, exposure to causes ZnO NPs causes cluster in the liver, which results in pathological changes by increasing serum levels of ALT and ALP. Induction of inflammation is one of the most obvious body effects of MNPs, in experiments on Wistar rats exposed to ZnO, TiO₂ noted inflammatory cell infiltration in the livers of the afflicted animals together with necrosis in the central region of the hepatic lobule and steatosis in liver cells. Kupffer cells, found in the liver, serve as natural macrophages, when MNPs penetrate the liver, they are largely consumed by Kupffer cells and some hepatocytes and increases the release of IL-1 β , which then sets off inflammation [75]. The research represented by [76] also involved injecting rats with ZnO-NPs at a dosage of 300 mg/kg for 30 days which shows a liver damaged rat model demonstrated with elevation of liver function tests such as AST and ALT. MNPs have a greater ability to develop ROS in the form of free radicals, oxygen ions and peroxides, which can all induce oxidative stress in cells through multifaceted mechanisms that can damage important biological macromolecules like fats, proteins [77].

Interactions between nanoparticles with cell membranes, organelles, and biomolecules like proteins and DNA can induce considerable cell damage, such damages can cause cell death, as apoptosis, or even cause genetic changes in the cells [78]. The exposure of certain nanoparticles can alter or inhibit immune responses in animals, possibly leading to increased vulnerability to infections, decreased vaccine response or abnormal immune responses which all detrimentally impact the health of animals [85]. Through several routes, MNPs can be toxic, for example, some may cause acute

toxicity by injuring the cell membrane because of their abrasive nature. When the cell membrane is destroyed, the contents of the cell can escape eventually killing the cell. Unicellular organisms show clearly this kind of membrane damage especially because of their small size and large surface-to-volume ratio. Exposure to NPs can cause a range of negative consequences on male reproductive organs, spermatogenesis, and hormone levels ratio, and increased chemical reactivity [79,80] nanoparticles can impact reproductive organs and functions, they may reduce the ability to reproduce, disrupt hormone levels, or produce developmental defects in progeny which reduce reproductive efficiency and sustainability of the herd, nanoparticle can also enter the airways deeply and aggravate disorders including bronchitis, and pulmonary disease [81]. A disease known as atherosclerosis, plaques that develop within blood vessels depend in part on nanoparticles, this increases the possibility of heart-related problems [82]. Nanoparticles may bioaccumulate into animal tissues including muscles, liver, and kidneys, mammary gland which raises concern about residues in products of animal origin (such as meat, milk) with the potential to affect human health and safety of food [83,84].

RECOMMENDATIONS FOR FUTURE USE OF NANOTECHNOLOGY:

The recommendation includes strict safety and environmental assessments, standardized regulations, and the feasibility of large-scale production. There should also be multidisciplinary research and development to maximize positive impacts like improved nutrition and targeted disease control while reducing risks such as toxicity and resistance.

CONCLUSION

The analysis reveals that nanotechnology offers significant benefits for animal health and production, including better

nutrient delivery, improved disease diagnostics, and targeted therapies, which can lead to increased efficiency and welfare. Nevertheless, it also highlights possible disadvantages, such as nanoparticle toxicity, environmental buildup, and unknown long-term health effects on both animals and humans.

CONFLICT OF INTEREST

The authors affirm that there are no conflicts of interest.

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