Chapter 22

Trends in Application of Nanotechnology for Poultry Production

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ABSTRACT

Nanotechnology, an innovative technology operated at the nanoscale that has a great scope of applications as well as a socioeconomic potential in the poultry sector. This chapter provides an overview of nanotechnology and provides the basic concepts about nanotechnology, nanoparticles, nano-biosensors, nano-carriers vaccines, nano-minerals, essential oils, and nano-emulsions. Moreover, nanotechnology is an emerging field in poultry science, it plays a vital role in poultry nutrition. Nano-minerals and nanoencapsulation can improve the bioavailability and absorption of essential nutrients and improve the gut health and immunity of broiler birds with disease resistance to antimicrobial meat packaging and overall flock health. Nano-carriers are used for the targeted delivery of vaccines and antibiotics described with problems and solutions of nano-carrier based vaccine in poultry, moreover, nano-carriers play a vital role in early chick detection. This chapter highlights the nanoparticles improve the hygiene of poultry houses, challenges, prospects, and recent emerging trends like gene editing and target genes. The advantages of nanotechnology as traditional methods are described as well.

KEYWORDS
Nanotechnology, Poultry, Nanoencapsulation, Nanosensors, Nanoemulsions, Nanovaccines

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INTRODUCTION

Nanotechnology is widely regarded as one of the most promising technologies in the 21st century. Nanotechnology is an emerging field in poultry sciences and can be possibility defined as the process of designing, characterization, producing, and application of structures, by controlling shape and size at the nanoscale (1-100 nm) at least in one dimension (Bayda et al., 2020). Nanotechnology is commonly associated with nanoparticles which are antimicrobial activity, cytotoxicity from reactive oxygen species (ROS), and genotoxicity. Various factors, such as size, shape, dose, and concentration, have been shown to influence the effects of nanoparticles (Rawat et al., 2018). The mode of action associated with nanoparticles in poultry is as explained Fig 1.

The two approaches used to form nanoparticles are top down and bottom-up (Sadr et al., 2023). In the Bottom-Up approach (Fig 2), Plasma arcing is used which relies on ionized gas atoms, which require a high energy level to remove an electron from its valence shell and create a positively charged atom. This process ensures an overall state of neutrality. Another method in bottom-up is the Chemical vapor deposition process in which the Reactants are transported onto the growth surface and chemical reactions take place on the growth surface and by-products formed by the gas-phase reaction are removed and the nanoparticles are generated. In Molecular beam epitaxy thermal molecular and atomic beams are directly onto a heated substrate under ultra-high vacuum conditions to produce nanoparticles. In Self-assembly bottom-up method atoms or molecules come together under equilibrium conditions to form a stable and well-defined nano-phase through non-covalent bonds to form nanoparticles (Kumar et al., 2018). Different type of material is used in the preparation of nanoparticles which include polymers such as copper particles, zinc oxide particles, gold, silver, chitosan, polyethylene glycol, and inulin are effectively used. The materials such as liposomes, fullerenes, solid lipids, nanoemulsions, bulky tubes, magnetic ions oxide, and metallic particles also play a carrier role in the field of nanotechnology (Sadr et al., 2023).

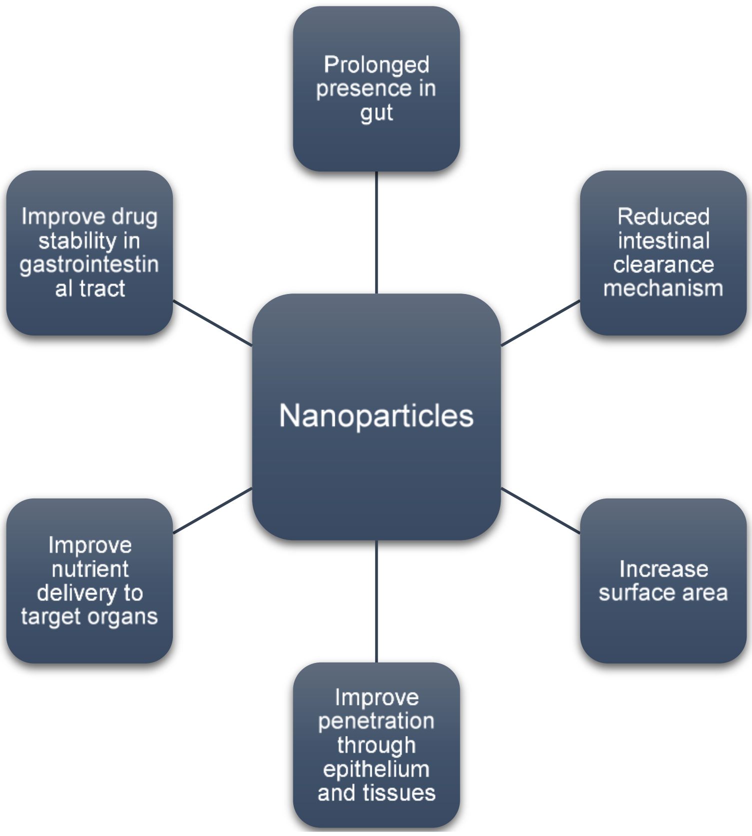

Fig. 1: Mode of Action of Nanoparticles (Suk et al., 2016).

The top-down method (Fig 2) begins with macroscopic structures that are converted to nanoparticles through a series of activities. The method includes material grinding by externally controlled tools to cut, grind, and shape materials into nanoscale structures except for soft materials. There are different methods of top-down approach but Mechanical milling is a widely used method in which the rotatory tools are used to generate shear force which produces nanoparticles. Nano-lithography is another process that uses optical, electron-beam, multi-photon, nano-imprint, and scanning probe lithography to break large particles into nanoparticles another method used is the Arc Discharge method in which a chamber containing 2 graphite rods, and helium pressure is used to produce nanoparticles from larger molecules. In sputtering nanoparticles are produced by hitting solid particles with high energy (Kraft et al., 2014) particles such as plasma or gas. As the advances continue in nanotechnology laser ablation method also gets it ground in which nanoparticles are produced by striking the target material with a strong laser beam another method that is effective works in the field is the Pulse wire discharge method in this method metal wire is exposed to pulsing current which evaporated and vapor is cooled by ambient gas to produce nanoparticles (Altammar, 2023).

Nanotechnology is becoming more popular in modern animal production systems than traditional methods due to several advantages. The nanotechnology has provided efficient drug delivery compounds with better safety profiles, better quality of feed additives with no drug resistance complications, and minimized the usage of antimicrobials. The nanotechology-based compounds are an eco-friendly and economically viable options for animal production industry (Malik et al., 2023) as discussed in Table 1.

Role of Nanoparticles in Poultry Nutrition

The feed additives used in the poultry industry are costly and good quality ingredient availability is a challenge (Sayee et al., 2019). The anti-nutritional factors present in feed ingredients cause low utilization of nutrients and most nutrients are excreted undigested (Kiarie and Mills, 2019). Nanotechnology is opening an exciting possibility in the field of nutrition by enhancing nutrient delivery and bioavailability by improving the digestion of nutrients. Some nutrients are poorly soluble and some are highly degradable losing their nutritional potential to resolve this issue and improve their absorption nanoparticle play a role as nano-carriers such as liposomes which increase the solubility of a nutrient and increase their absorption, they also protect against degradation of nutrient by forming a protective covering around them and deliver them to a particular site for absorption in this way they carry a particular nutrient to a specific site without being wasted or utilized by other organ (Van Tran et al., 2019).

Role of Nanotechnology in Bioavailability and Nutrient Utilization of Essential Nutrients

Nano-encapsulation aims to enhance the solubility of insoluble ingredients by binding them, protecting highly degradable nutrients with a covering, and transporting them to the absorption site intact. This process increases surface area for optimal absorption, ensuring prolonged availability. The nano-encapsulation can pass from small capillaries and barriers and then reach the brain and groan region. They remain longer in birds due to their small size and slow metabolism excretion (Barua and Mitragotri, 2014).

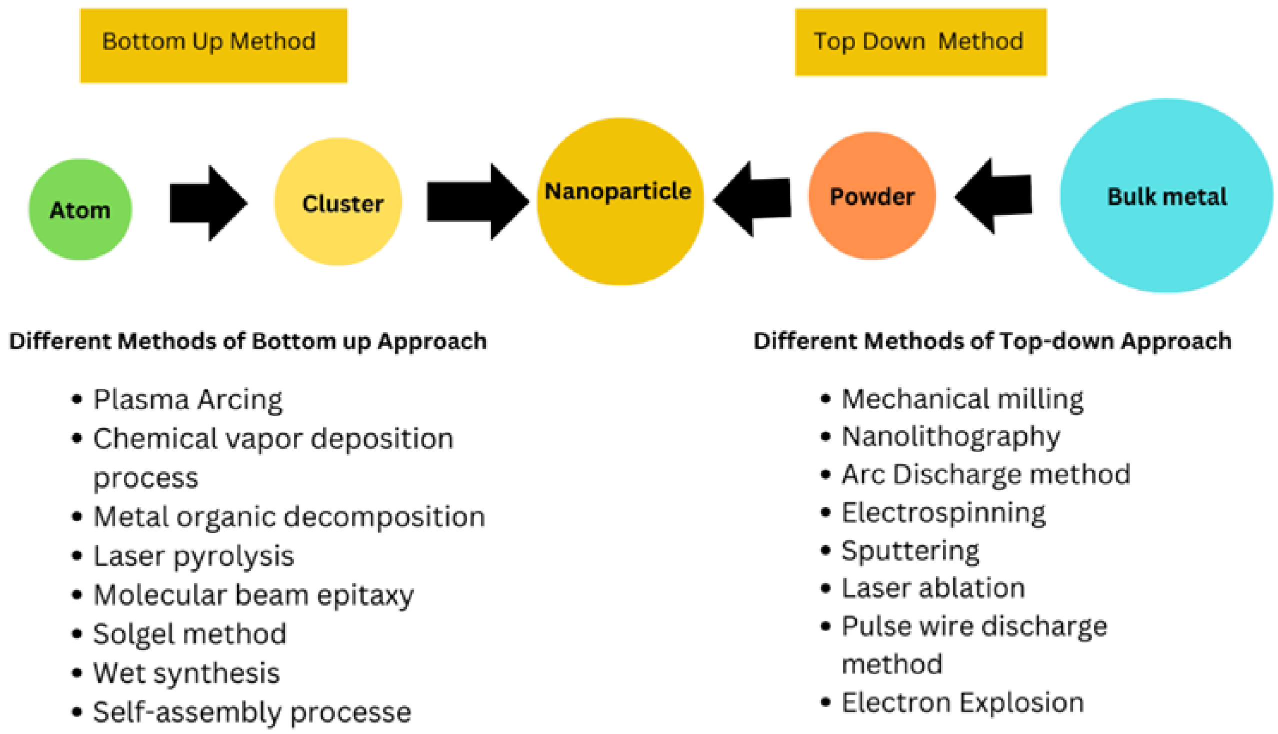

Fig. 2: Nanoparticles production approaches through bottom-up and top-down methods (Kumar et al., 2018).

Table 1: Advantages of using Nanotechnology over Traditional Methods

Sr #	Usage of Nanotechnology	Nanotechnology advantages	Traditional Methods limitations	Reference
1	Drug Delivery	Enhance solubility, absorb-ability, bio-availability, and half-life of products.	Limited by Conventional formulations	Danchuk et al., 2023
2	Disease Prevention	Smart technology for diagnosis and treatment of poultry diseases.	Relies on traditional Vaccines and medications.	Danchuk et al., 2023
3	Growth Promotion	Nanoparticles are used as an alternative to antibiotics as growth promoters.	Dependence on antibiotics can lead to resistance.	Gelaye, (2023).
4	Feed Additives	Improve growth rate, performance, immunity, and resistance to pathogens.	Less targeted and efficient feed additives.	Gelaye, (2023).
5	Animal Product Quality control	It enhances meat quality and can reduce supplemental doses of minerals.	Animal product quality depends on varied factors, therefore less controlled.	Mekonnen, G. (2021).
6	Environmental Impact	Nanoparticles are used without affecting animal health and welfare.	Greater environmental footprint.	Poddar and Kishore, (2022).
7	Cost Efficiency	Potential to reduce costs and enhance final product quality.	Higher costs due to less efficient processes.	Malik et al., 2023

Role of Nanominerals in Poultry Production

In poultry, dietary minerals are essential for immune function and gastrointestinal health. They function as vital components and mediators of numerous physiological processes, influencing everything from the formation of immune cells to the integrity of the gut barrier. Minerals like zinc, calcium, and magnesium contribute to maintaining the tight junctions between intestinal cells, fortifying this barrier. Minerals like copper, manganese, and selenium are essential co-factors for enzymes involved in digestion. They help break down complex nutrients in feed for proper nutrient absorption and gut health. Minerals like manganese or chromium can promote the growth of beneficial bacteria, creating a healthy gut environment. Zinc, iron, and selenium are crucial for the development and function of immune cells. Selenium and manganese act as antioxidants which neutralize harmful free radicals. Zinc and copper have anti-inflammatory properties (Sadr et al., 2023). Selenium nanoparticles improve growth performance, egg production, feed conversion ratio, immune response, and antioxidant status which enhance meat quality and intestinal microbiota (Abdel-Moneim et al., 2022).

How Nano-minerals can Improve Mineral Absorption and Utilization?

Regular dietary minerals have low absorption and utilization in the body which encourages scientists to explore the potential of nano-minerals to increase digestion. Essential minerals like iron, calcium, and magnesium often have low solubility and absorption in the digestive system. Nano-minerals, ranging from 1-100 nanometre, such as; silver, copper, and zinc (Vazhacharickal and Thomas, 2022) interact more effectively with water due to their smaller size, improving solubility and bioavailability (Table 2). To protect minerals from degradation by stomach acid, enzymes, or other factors, nano-minerals can be encapsulated in carriers such as liposomes or nanoparticles. Nano-minerals also offer targeted

Table 2: Effect of various types of nanoparticles on poultry production

Sr #	Nano- encapsulation	Dose	Output/impact	Reference
1.	Silver- NPs	900 ppm/ kg diet	Body weight gain and feed intake increase and FCR value decreases	(Anwar et al., 2019)
2.	Gold- NPs		Growth performance increases	
3.	Copper-loaded chitosan	100 mg/kg diet	Increased growth performance, Immunity improved, Protein synthesis increased, Beneficial cecal microbiota population increase	
4.	Zinc oxide- NPs	20 mg/kg diet	Growth performance improves Anti-oxidative bio-marker increases	
5.	Montmorillonite- NPs	3 g/kg feed	Decrease the toxicity of aflatoxins	
6.	Zinc- NPs	80 mg/kg diet	Increased egg production, Size, and shell quality of egg improve, Culminates oxidative stress	(Abedini et al., 2017)
7.	Nano-encapsulated Ginger essential oil with chitosan	100 mg/kg feed	Improved weight gain, Growth of Lactobacilli population ileo-caecum appreciates, Mucin2 gene expression	(Amiri et al., 2021)
8.	Curcumin-cinnamon essential oil nano-emulsion	Sprinkled on meat	Decrease the total plate count (TPC), psychrophilic bacteria, yeast, and mold growth, and preserve the broiler meat from spoilage.	(Abdou et al., 2018)
9.	Curcumin-garlic essential oil nano-emulsion	Sprinkled on broiler meat	The lowest values of total volatile nitrogen (TVN) show meat is fresh and protein does not degrade Low thiobarbituric acid (TBA) value which shows low lipid oxidation. Showed the best values for water-holding	
10.	Eugenol nano-emulsion (E. coli challenged)	400 mg/kg feed	BWG, FI, and livability, digestive enzyme level increases, Lactobacillus species count in cecum increases, E*nterobacteriaceae* and *Bacteroid* count decrease, Bird challenged with E.coli strain show reduction in APEC O78 loads with downregulation of *papc, iron, iuta*, and *iss* virulence genes	(Ibrahim et al., 2022)
11.	Encapsulated trace mineral premix containing Zn, Cu, Mn, Fe, Se and I	250mg/kg 375mg/kg feed	Same effects on poultry as organic and inorganic minerals but less excretion of mineral	(Ramirez et al., 2022)
12.	Encapsulated form of lactic acid VS encapsulated form	0.6%	Improved broiler performances Reduced intestinal pH, Increased intestinal villi length and reduced only the number of S*almonella* sp	(Natsir et al., 2010)
13.	Fe- NPs	100mg/kg feed	Egg quality traits, immune response and biochemical blood indices without negatively affecting productive performance traits in laying hens, Increase the per-oxidation of egg lipids at this level.	(Javadifar, et al., 2020)

delivery in the intestine by attaching specific ligands to the nano-carrier for maximum absorption. These controlled release mechanisms optimize mineral efficacy (Barua and Mitragotri, 2014). The encapsulated nano-minerals improve the absorption and utilization of nutrients than traditional minerals (Sadr et al., 2023).

Role of Nanotechnology in Poultry Health Management

Challenges of Maintaining Hygiene in Poultry Houses

Maintaining hygiene in poultry houses is a complex task that involves addressing various challenges such as bio-security, waste management, ventilation, water quality, cleaning and disinfection, pest control, and worker hygiene practices (Pagar et al., 2020). Nanoparticles with antimicrobial properties, such as silver, copper, zinc oxide, titanium dioxide, and chitosan, have shown potential in surface disinfection due to their small size and high surface area-to-volume ratio. These nanoparticles can disrupt microbial membranes, interfere with cellular processes, and generate ROS that damage microbial DNA (Rai et al., 2009). TiO_2 nanoparticles exhibit photo-catalytic activity when exposed to UV light, effectively killing bacteria and viruses. Airborne nanoparticles are also used for surface disinfection (Lara et al., 2010).

Early Disease Detection Challenges

Early disease diagnosis in poultry flocks is crucial for timely intervention and disease control, but it presents several challenges due to factors such as asymptomatic carriers, limited diagnostic tools, and the rapid spread of pathogens within flocks. Numerous diseases that affect poultry, like avian influenza and infectious bronchitis, can appear as sub-clinical infections, meaning that even if the birds carry the pathogens, they only exhibit minimal or no symptoms (Brown et al., 2006). Numerous pathogens, such as bacteria, viruses, and parasites, may cause poultry diseases; precise identification of each requires specialized diagnostic testing (Bello et al., 2018). Particularly in the early stages of infection, traditional diagnostic methods like culture-based methods and serological assays may lack sensitivity and specificity, causing false-negative or inconclusive results (Stärk et al., 2014).

Role of Nano-sensors in Early Disease Detection

Nano-sensors, have rapid and sensitive detection capabilities and have a lot of potential for in-field disease monitoring in poultry (Dhumpa et al., 2011). Nano-sensors generate a detectable signal such as fluorescence, electrochemical, or colorimetric changes that can be quantitatively evaluated after the target pathogen binds to the sensor surface (Lee et al., 2007). Early diagnosis and intervention are made possible by the sensitive detection of infections at low concentrations enabled by the signal transduction pathways (Stephen Inbaraj and Chen, 2016). Although nano-sensors can be reduced to micro or nanoscale dimensions, portable and point-of-care devices for pathogen detection on-site can be created (Yetisen et al., 2013). Portable nano-sensor platforms are suitable for environments with restricted resources or field applications because they offer rapid results and enable decentralized testing. Through the use of multiplexed detection techniques or arrays of different recognition elements, nano-sensors can be designed to detect multiple pathogens simultaneously. Multiplexed nano-sensor platforms enable comprehensive pathogen screening, identification of multiple infections, and efficient use of resources in diagnostic work flows (Guo et al., 2020). Bio-sensors can identify poultry products parameters like freshness, spoilage, and nutritional content in chicken meat which will ensure the quality of poultry products. Nano-biosensors are used in monitoring physiological parameters (Fig 3) including heart rate, temperature, and stress level (Sadr et al., 2023).

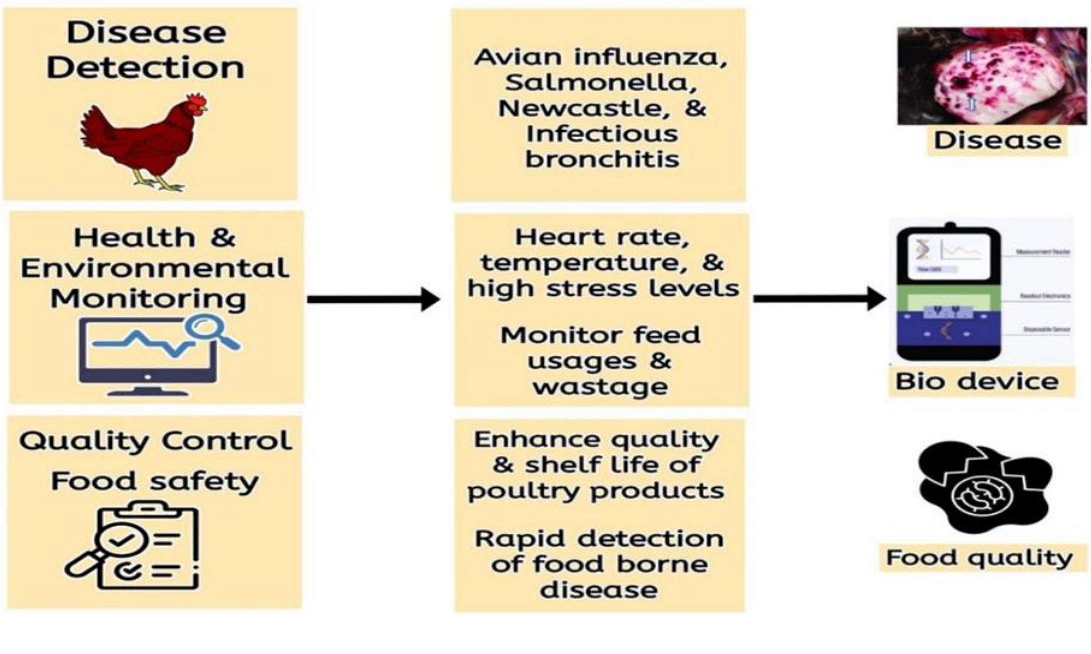

Fig. 3: Nano-biosensors application quality control, food safety, disease detection and environment monitoring (Sadr et al., 2023)

Nano-carriers for Targeted Delivery of Vaccines and Antibiotics

Challenges with Conventional Vaccines and Antibiotics

Conventional vaccines and antibiotics are used extensively in poultry production to prevent diseases and treat bacterial infections but there are several limitations that lower their efficacy and sustainability. Conventional vaccines may produce sub-optimal immune responses in poultry due to factors such as antigen degradation, poor immunogenicity of antigens, and interference from maternal antibodies (Marangon and Busani, 2007). Many conventional vaccines require strict temperature control throughout storage and transportation, posing logistical challenges in regions with limited access to the cold chain. Traditional vaccines often target a single antigen, limiting their ability to provide broad-spectrum protection against diverse pathogens or emerging strains. The onset of immunity after vaccination with conventional vaccines may be delayed, leaving poultry susceptible to infections during the vulnerable period post-vaccination (Rauw et al., 2009). Continuous misuse of antibiotics in poultry production has developed antibiotic-resistant bacterial strains, posing a significant threat to both animal and human health (Zhu et al., 2013). Conventional antibiotics can disrupt the gut microbiota of poultry, causing dysbiosis, poor nutrient absorption, and increased susceptibility to opportunistic pathogens (Oakley and Kogut, 2016).

Nano-carriers as a Promising Solution to Conventional Vaccines and Antibiotics Challenges

Nano-carriers offer significant advantages for enhancing drug delivery to specific target sites within the body, including good vaccine delivery, improved targeting capabilities, and controlled release profiles. Nano-carriers can protect drug molecules from degradation in the body, leading to increased bioavailability and prolonged circulation in the bloodstream (Torchilin, 2014). The danger of systemic toxicity and adverse effects can be decreased by encasing antibiotics inside nano-carriers, which will enhance antibiotics effectiveness (Anselmo and Mitragotri, 2019). By responding to particular stimuli at the target region, such as pH, temperature, or enzyme activity, nano-carriers can be made to release encapsulated drugs in a regulated manner (Meng et al., 2014)

In 2014, Chinese scientists explored the encapsulation of the Newcastle disease virus (NDV) vaccine in chitosan nanoparticles, demonstrating enhanced mucosal immune responses and protection against NDV infection in chickens (Sun et al., 2014). Nanoemulsions and nanoparticles have shown promise in delivering poultry vaccines via oral or intranasal routes, offering convenient and effective administration in poultry farming (Jazayeri et al., 2021).

Ongoing Research on Nano-carrier based Vaccines against Poultry Diseases

In 2017, Indian scientists investigated the development of polymeric nanoparticles as carriers for the Marek's disease virus (MDV) vaccine in poultry. The study focused on evaluating the immunogenicity and protective efficacy of the polymeric nanoparticle- encapsulated MDV vaccine in chickens (Reddy et al., 2017). In Iran, explored the use of chitosan nanoparticles as carriers for the NDV vaccine in poultry. The study investigated the immunogenicity and protective efficacy of the chitosan nanoparticle- encapsulated NDV vaccine in chickens (Mohammadi et al., 2021). Most recently, the liposome-based vaccines for AIV in poultry showcased the increased stability and better immune responses elicited by the liposome-encapsulated AIV vaccine in chickens (Elbohy et al., 2024).

Improved Bio-security and Sanitation

Antimicrobial nano-materials have demonstrated significant potential to enhance poultry premises hygiene by efficiently inhibiting the growth of microorganisms that may infect poultry. Antimicrobial nanoparticles have the ability to reduce bacteria's adherence to surfaces, which reduces their ability to colonize and form bio-films (Sonawane et al., 2022). Metal and metal oxide nanoparticles are good antimicrobial agents i.e. Titanium dioxide and Zinc oxide (Elbourne et al., 2017).

Antimicrobial Meat Packaging

A tremendous increase in the population and growing demand for meat has taken the poultry industry to the sky heights. Industry focused on the quality production and packaging of meat. Nanotechnology is used in food packaging which enhances antimicrobial properties, microbial barrier, and chemical, thermal, and mechanical properties of packaging materials. Nano- composites are used for packaging meat. Natural or synthetic bio-polymers like chitosan, cellulose, polyvinyl alcohol and polylactide nanoparticles are used in biodegradable packaging. Nano device-combined polymers such as bio-sensors are able to detect microbes and toxins in the packaging (Ramachandraiah et al., 2015).

Emerging Trends and Future Prospects

Research on gene editing using nanoparticles for improving poultry traits, such as disease resistance and feed efficiency, is promising. CRISPR/Cas9 technology allows for precise gene editing by targeting specific DNA sequences. Nanoparticles, like liposomes and polymeric nanoparticles, can efficiently deliver CRISPR/Cas9 components into poultry cells (Khwatenge and Nahashon, 2021). Gene editing can enhance disease resistance by modifying immunity genes, such as the CD163 gene, and improve feed efficiency by targeting genes involved in nutrient metabolism and utilization (Cheng et al., 2019). Nano-material coatings are being developed to improve hygiene, reduce disease transmission, and enhance poultry production efficiency. These coatings consist of nanoparticles dispersed in a matrix, such as titanium dioxide ($TiO2$), zinc oxide (ZnO), and silver nanoparticles. These coatings have antimicrobial properties and photo-catalytic activity, which can inhibit the growth of bacteria, viruses, and fungi on poultry house surfaces. Nano-material coatings also contribute to improved air quality by reducing dust accumulation. Research is focused on developing environmentally friendly coatings that do not leach into the environment. Although initial costs may be higher than traditional methods, the long-term benefits, such as reduced cleaning and maintenance requirements, improved poultry health, and increased productivity, make them cost-effective in the long run (Lead et al., 2018). Nano-biosensors are a revolutionary approach to personalized nutrition in poultry, enabling real-time monitoring of physiological parameters and nutrient levels. These sensors can be integrated into feed delivery systems or implanted in birds to continuously monitor bio-markers. By analyzing these parameters, personalized feed formulations can be created to meet individual nutritional needs, leading to improved growth performance, feed efficiency, and overall health. By detecting early signs of health problems or nutrient deficiencies. Nano-biosensors can help prevent disease outbreaks and reduce antibiotic needs (Hill and Li, 2017).

Nanotechnology in poultry production poses potential environmental and health risks, including toxicity, environmental release, and unintended consequences. If not managed properly, nanoparticles can cause environmental contamination, persist in soil, water, and air, and potentially enter the food chain. They may also contribute to antibiotic-resistant bacteria. To mitigate these risks, responsible development and application of nanotechnology in poultry production are essential, including thorough risk assessments, regulation of nanoparticles use, and best practices (Li et al., 2017).

Conclusion

Nanoparticles are highly promising technology with a wide range of applications in the poultry industry. However, their optimal usage still needs to be studied. Common modes of action associated with nanoparticles include antimicrobial activity, cytotoxicity induced by ROS, and genotoxicity. It is crucial to study how nanoparticles can effectively reduce disease prevalence in the poultry industry in order to achieve better growth, production, and the production of healthier and safer products. A recent study has shown that adding various dietary nanoparticles to poultry feed significantly improves growth, production, and the quality of meat and eggs. Additionally, incorporating these particles during the processing and storage of meat products enhances and maintains their quality. However, further research is needed to investigate the correct dosage, sizes, and shapes of these materials. It is also important to study the accumulation of nanoparticles in the body, the number of residual particles in body tissues, and the potential toxic effects.

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