Transforming Animal sciences and it's Advances in Nanotechnology and their implications in production of poultry

AUTHORS DETAIL

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Abstract

The cutting-edge, multidisciplinary field of nanotechnology combines computer science, engineering, and biology. The goal is for large chemical molecules to be disassembled into smaller ones, with new properties such as enhanced reactivity and cellular absorption being endowed to them. In fields like genetics, nutrition, and medicine, new avenues for animal scientific research will be opened up. Nanotechnology focuses on controlling matter at the nanoscale, which is characterized by dimensions of around 1 to 100 nanometers. The poultry industry might be transformed by recent developments in nanotechnology. Nanotechnology, for example, can improve the absorption of chicken feed, clean farm water, lessen chemical pollution, and encourage quicker development. Using small particles of copper, zinc, and silver, which have potent antibacterial qualities, it can also aid in the prevention of illnesses in poultry. Antibiotics can be used less often if these nanoparticles are introduced to chicken feed and water to shield them against dangerous pathogens like Salmonella and E. coli. Furthermore, by enhancing waste management and water purification, nanotechnology can help reduce environmental impact and enhance vaccine development. However, issues like cost and safety must be resolved.

Keywords: Nanotechnology, Nanoscale, Poultry farming, Antibacterial properties, Feed absorption, Water purification

Introduction

Richard Feynman, a physicist from the US, is often called the father of nanotechnology (Pisano & Durlo, 2023). Fifteen years later, the Japanese scientist Norio Taniguchi was the first to use the term "nanotechnology" in 1974 (Guin & Singh, 2023). The word "nano" is derived from the Greek word meaning "dwarf," indicating something extremely small. Nanotechnology refers to the science and technology of studying and creating materials at the nanoscale, typically ranging from 1 to 100 nanometers. It helps the environment by cutting down waste and making feed more efficient (Saritha et al., 2022). It involves manipulating materials at the nanoscale to improve various processes, such as boosting poultry production. Nanomaterials are produced using two methods: "top-down" and "bottom-up" (Sadr et al., 2023). The top-down approach involves breaking larger materials into

smaller particles, while the bottom-up approach builds nanomaterials by assembling molecules or atoms into larger structures (Tripathy et al., 2023).

1. Classification of Nano materials

1.1 Polymorphic Nanoparticles: Utilized in the oral vaccination of poultry flocks, these nanoparticles enhance both humoral and cellular immunity. They also provide controlled and sustained release of antigenic loads. As explained in figure 1 (Renu et al., 2020).

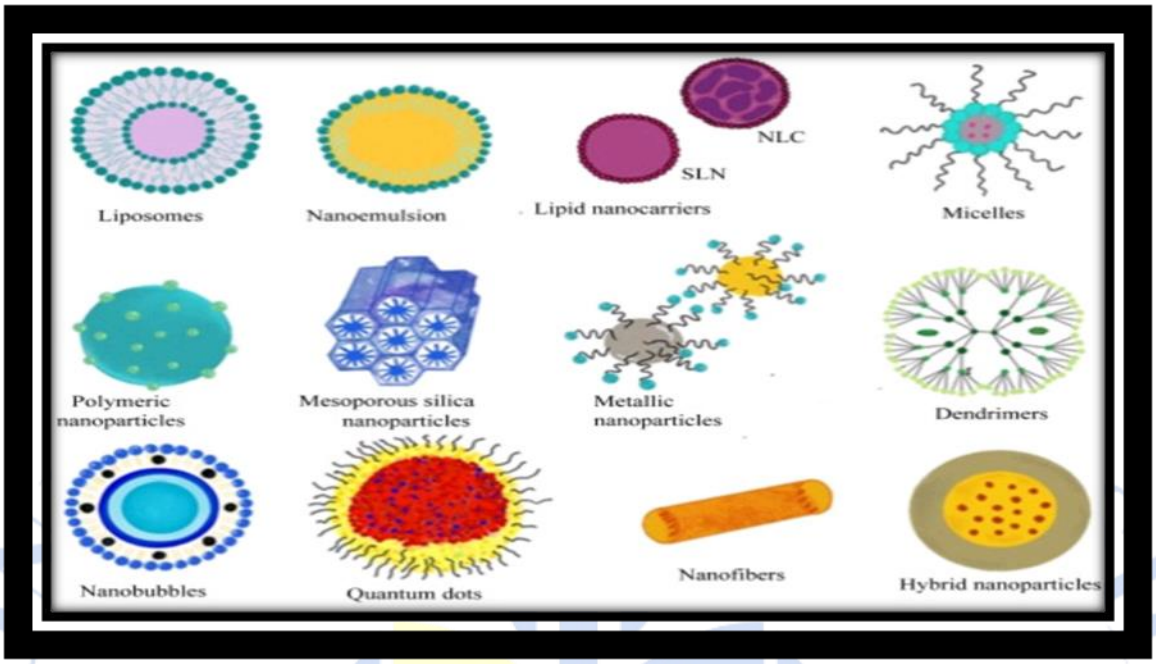

Fig. 1: Variation of Nano minerals

1.2 Solid Lipid Nanoparticles: These nanoparticles reduce toxicity, protect entrapped drugs from sensitive environments, and improve the bioavailability of poorly water-soluble and active molecules (Kumari et al., 2023).

1.3 Quantum Dots: Quantum dots are employed for the detection and eradication of poultry-associated Salmonella. Carbon-based quantum dots are particularly effective in managing bacterial diseases. Additionally, they are used to develop intelligent indicators for monitoring food freshness (Alavi et al., 2021).

2. Application of Nanotechnology in Poultry

Nanotechnology has a wide range of applications in the poultry industry (Hassan et al., 2020). It can be used for diagnosing diseases through advanced techniques, disinfecting, preparing vaccines and stimulating the immune system (Trovato et al., 2020). It also helps to overcome challenges related to antibiotic resistance. Nanoparticles are utilized as antimicrobial agents, including anti-parasitic and antifungal applications (Sadiq et al., 2023). Bio functionalized nanoparticles can remove bacteria from chickens before they pose a risk to humans. It is explained in figure 2 (Sui et al., 2022).

Fig. 2: Nanotechnology in Different food varieties

Feed additives are enhanced with nanotechnology to improve digestion and nutrient absorption (Hanif et al., 2024). Nano biosensors are used to monitor water quality and detect diseases, such as avian influenza. Nanoparticles made from minerals are added to poultry feed to support immune system modulation, promote growth, enhance metabolic and physiological processes, and resolve mineral conflicts in the intestines (Pandey et al., 2023). They also improve embryo development and bioavailability, allowing for lower doses, reduced feed costs, higher product quality, better growth rates, increased egg production, reduced gut pathogens, and improved feed conversion ratios. In water purification, biosensors detect contamination and water quality, while nanoparticles remove heavy metals using nanoscale metal oxides (Heras et al., 2024). To extend the shelf life of meat, nanotechnology has introduced Nano chitosan films, which delay spoilage. Silver nanoparticles inhibit the growth of lactic acid bacteria, while TiO2 nanoparticles (TiO2NPs) are used in food packaging polymers to block UV radiation and act as coloring agents (Sani et al., 2022). Adding selenium nanoparticles (Se-NPs) to chicken feed has been shown to increase the growth rate of broilers (Nabi et al., 2020).

3. Nanotechnology in Animal Nutrition

Animal nutrition has seen revolutionary changes because of nanotechnology, which has greatly improved product quality, feed efficiency, and immunity (Abbas et al., 2022). Nanoparticles are used to supply vital nutrients, including nano zinc oxide, which boosts growth rates and immunity. They can be eaten on their own or be added to feed formulations (Patra & Lalhriatpuii, 2020). Targeted immunization administration enabled by nanotechnology improves bulk embryo development (Das et al., 2021). The need for additives like salt, oil, and preservatives is reduced, digestion is improved, and the growth of beneficial bacteria is promoted, while the formation of harmful ones is prevented (Melaku et al., 2021).

3.1. Nanotechnology in Enhancing Feed Efficiency

Chicken feeding has been revolutionized by nanotechnology, with boosted production and better health promotion in birds. Because the immune system is boosted and digestive efficiency is improved, growth performance is enhanced by nanoparticles (Ahmad et al., 2022). A better intestinal environment is provided by them, as the growth of beneficial bacteria is encouraged and harmful bacteria in the chicken's micro biome are reduced (Khan et al., 2021). The overall absorption of nutrients is enhanced by this improvement in intestinal health. Additionally, certain nanoparticles are designed to be bound to and removed from the digestive system, protecting birds and preventing the transfer of illnesses to humans (Yue et al., 2024). Furthermore, a safe alternative to antibiotics is provided by nanoparticles because residues are not left in animal goods, ensuring that human food is safer (Qadeer et al., 2024).

3.2. Inclusion of Nanoparticles in Animal Feed

Because of their unique properties, such as their high surface area-to-volume ratio, absorption is enhanced by nanoparticles and they can be considered as a beneficial addition to poultry diets (Evci, 2024). When added to drinking water or chicken feed, nanoparticles that are easily ingested by the birds are used. Additionally, food packaging that might include nanoparticles to increase the feed's shelf life and ensure its security is employed, giving the best nutrition possible to the chickens (De Vries, 2021). Feed should be balanced with no pathogens like Salmonella and E. coli, as well as toxins like ochratoxins and trypsin inhibitors. Proper storage methods are required to maintain feed quality, and moisture content should be kept below 10% to avoid mold formation and nutrient loss (Shastak & Pelletier, 2023). Unlike ruminants, fowl rely solely on their feed for vital nutrients, including vitamin B complexes and fat-soluble vitamins. Feed components must be utilized in appropriate proportions to avoid negative consequences (Vlaicu et al., 2023).

4. Nanominerals

Intestinal interference is reduced by nanominerals, improving the bioavailability of nutrients. Meat quality, microbiological resistance, hatching rates, and egg weight are all enhanced by these minerals (Abbas et al., 2022).

Types of Mineral Nanoparticles

4.1. Nanoclays

It includes kaolinite and hectorite, categorized based on chemical composition and morphology. Organ clays are hybrid organic-inorganic nanomaterials with applications rheological modification and polymer composites (Rana, 2021).

4.2. Organic Nanoparticles

Materials that are both biocompatible and biodegradable are employed in biomedical applications, including medication administration. A few examples are liposomes, dendrimers, and micelles (Das et al., 2021).

4.3. Inorganic Nanoparticles

The increased permeability, controlled release, and stability are characteristics of metal-based nanoparticles. These are perfect for vaccinations that deliver antigens (Selim et al., 2023).

Factors Influencing Nanoparticle Efficacy

The Size and Shape of particles is significantly influencing their physical and chemical properties. Smaller particles have a higher surface area to volume ratio. The Surface Properties refer to characteristics like surface charge, roughness and the presence of functional groups. These properties determine how particles interact with their environment. Particle-Particle and Particle-Solvent Interactions play a crucial role in dispersion, stability and aggregation behaviour. Attractive or repulsive forces between particles can lead to clumping or dispersion (Abbas et al., 2022).

5. Applications in Animal Nutrition

Digestion and Absorption are essential processes that determine how effectively nutrients in feed are broken down and utilized by an animal’s body. Proper digestion ensures that feed components are converted into absorbable forms. The Feed Quality Control involves monitoring and evaluating the composition, safety and nutritional value of animal feed. Biosafety refers to practices that minimize the risk of biological hazards in feed such as bacteria, viruses or toxins. Packaging and Storage play a key role in preserving the quality and safety of feed. Proper packaging prevents contamination and moisture absorption (Pandey et al., 2023). Animal nutrition might be completely transformed by nanotechnology, ensuring that improved production, sustainability, and health are guaranteed.

5.1. Advantages of Nano Feed

1. Cost-effectiveness is provided by nano feed as a reasonably priced and effective way to enhance the nutrition of chickens.
2. The digestive tract is rid of dangerous materials by the particular purging agent as a focused agent.
3. The risk of bacterial foodborne illnesses in hens is lowered by Nano feed.
4. Drug residues in meat are reduced, improving food safety for consumers.
5. A powerful substitute is provided by Nano feed in the battle against bacteria that are resistant to antibiotics.
6. Biological threats may be neutralized through surface decontamination.
7. Hazardous bacteria in Nano feed can be identified using agglutination tests based on certain criteria (Bist et al., 2024)

6. Effects of nanoparticles on poultry products

Nanoparticles are considered as the key to increasing poultry production and product quality. In order to improve growth, reproduction, egg production, and feed efficiency, nutrient utilization is improved and oxidative stress is reduced by selenium nanoparticles (Se-NPs) (Selim et al., 2023). The quality of meat and eggs is also enhanced by the increase in antioxidant levels and the enhancement of traits like eggshell strength and yolk color. The immunity is increased, healthy gut flora is supported, and harmful infections like Salmonella and E. coli are reduced by the antibacterial properties of silver and gold nanoparticles (Michalak et al., 2022). Environmental pollution is also reduced by the improvement of nutrient uptake and the decrease of waste. Nutrients are stabilized by feed containing nanoparticles, enhancing feed quality over time. However, negative effects, including toxicity and risks to the liver and kidneys, can be caused by excessive usage (Rajendran et al., 2022). These issues are avoided by the appropriate dosage and management. When used appropriately, poultry health and productivity have the potential to be significantly enhanced by nanoparticles (Scott et al., 2018).

6.1. Sustainable poultry farming

Water-saving gadgets, such as breast-drinkers, ensure that people have access to clean water while reducing waste. Energy-efficient lighting improves poultry health and increases resource efficiency. Reusing chicken litter as fertilizer reduces pollution and encourages the reuse of nutrients (Bist et al., 2024).

Nanotechnology lowering the demand for and cost of supplements, and boosting development. Nanoparticles offer an antibiotic substitute, promoting healthier chickens without the development of resistance. It reduces environmental contaminants and improves waste management. Example: Selenium nanoparticles reduce environmental contaminants and improves waste management (Filmer, 2024).

6.2. Waste management in Poultry farms

Effective waste management investigates environmental problems and enhances sustainable chicken production. Poultry farms generate a considerable amount of waste and litter, which can cause water and soil contamination (Attia et al., 2024). Farmers use chicken litter to generate organic matter, fertilizer, and bio char, resulting in a creative strategy to convert waste into valuable resources. Pillarization, biogas production, and the burning of poultry litter for energy generation all ensure efficient waste utilization and are becoming increasingly popular. Cutting-edge treatment methods seek to mitigate the negative impacts of raw chicken manure, which includes ammonia, heavy metals and other pollutants that are damaging to both humans and the environment (Swain et al., 2021).

Poultry Waste Processing Using Nanotechnology:

Nanotechnology holds revolutionary promise for effectively treating and digesting poultry manure. Nanoparticles like silver, copper, and zinc oxide are used by researchers to manage microorganisms during the waste treatment process because of their antibacterial properties (Scott et al., 2018). Photo catalytic chemicals such as titanium dioxide and nano-filtration technologies can render wastewater ecologically benign and recyclable by removing organic pollutants and heavy metals. Nanotechnology enhances biogas production by acting as a catalyst during anaerobic digestion, increasing the energy output from chicken faeces

(Au et al., 2023). Nanoparticles accelerate composting and enhance pyrolysis processes to produce biochar, which helps turn waste into useful soil nutrients. These innovations enable the sustainable recycling of chicken waste into fertilizers and biofuels and the recovery of nutrients (Mohana et al., 2020).

6.3. Reduction of Ammonia Emissions and Environmental Impact

Ammonia emissions from chicken manure cause serious health and environmental issues for both humans and animals, including soil erosion, air pollution, and respiratory illnesses (Kumar & Patyal, 2020). Nanotechnology can reduce ammonia emissions by using zeolites and nanoparticles coated with burning charcoal to absorb it. These materials improve the air quality in chicken homes, which benefits animal health. Nanotechnology lowers greenhouse gas emissions and the environmental effect of chicken production by increasing feed efficiency and boosting waste management (Mohana et al., 2020). These ground-breaking advances in chicken farming meet global sustainability criteria by maximizing resources and reducing pollution (Kumar & Patyal, 2020).

7. Methods of Nanoparticle Production

There are several ways to create nanoparticles but they may be broadly divided into two categories: top-down and bottom-up (Ji, 2022).

7.1. Top-Down Approaches

Top-down methods involve breaking down bulk materials into nanoscale particles through mechanical, physical, or chemical techniques. These approaches are often used for sculpting materials into desired nanoscale shapes (Sani et al., 2023).

7.1.1 Mechanical Milling:

This method employs a planetary ball mill where steel or refractory balls grind powders to nanoscale sizes. The energy transmission depends on factors like:

- Rotational or vibration speed
- Ball size and quantity
- Ball-to-powder mass ratio
- Milling duration
- Milling environment

Grinding induces shear forces, producing nanoparticles. Mechanical milling is widely used to modify properties of powders, such as altering particle shapes and surface characteristics (e.g., in silver powders) (Sani et al., 2023).

7.1.2 Laser Ablation: A laser beam irradiates a solid surface, removing material. Material evaporates or sublimates due to heat absorption. Material transitions to plasma. Laser ablation enables the precise removal of material, making it effective for fabricating nanoparticles (Guo et al., 2022).

7.2. Bottom-Up Approaches

Bottom-up methods focus on assembling nanoparticles atom by atom or molecule by molecule, allowing precise control over size, shape, and composition. These approaches are widely applied in nanotechnology and materials science is illustrated in figure 3 (Mala et al., 2021).

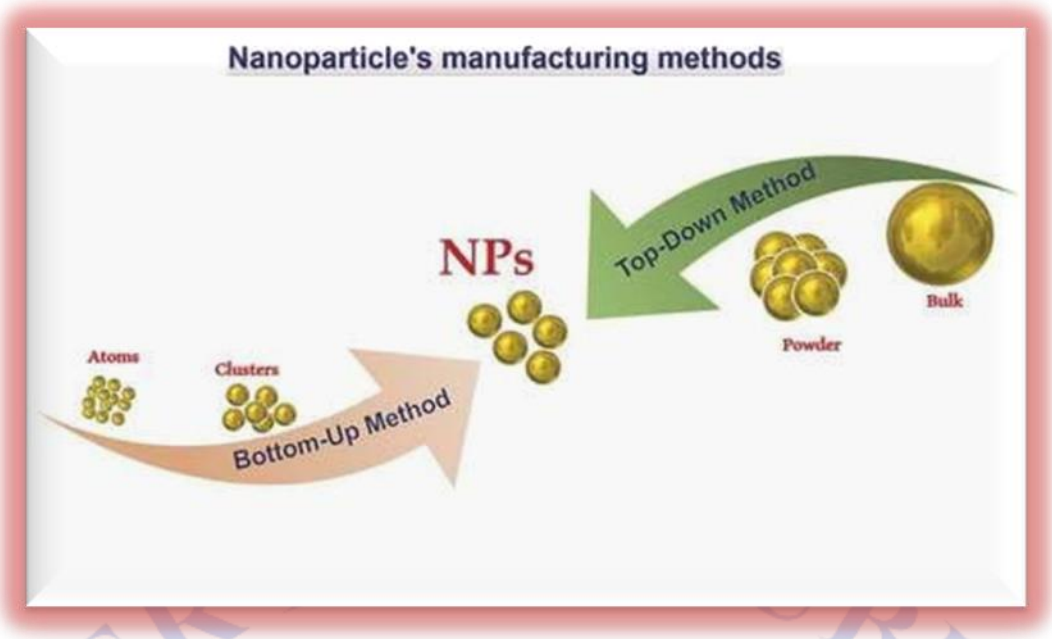

Fig. 3: Manufacturing of Nanoparticles

77.2.1. Self-Assembly

Nanoparticles spontaneously organize into structured patterns when dispersed in a liquid medium, such as water. Magnetic or attractive forces between nanoparticles drive their assembly into organized structures. This method is used to create well-ordered and functional nanomaterials (Musgrove et al., 2024).

7.2.2. Sol-Gel Method

A sol (colloidal suspension of nanoparticles) is formed by dissolving metal cation precursors in a solvent. Hydrolysis breaks down precursors into hydroxides (Musgrove et al., 2024). Condensation of hydrolyzed particles forms a gel. The gel is dried carefully to remove the solvent, leaving behind Nano powder. These are commonly used for synthesizing metal oxide nanoparticles and other nanomaterials (Njoku et al., 2021).

8. Synthesis of Nano minerals

Nanominerals can be synthesized using physical, chemical, or biological methods, each with unique characteristics the syntesis of Nanoparticles is sketched in figure 4.

8.1. Physical Methods

- Evaporation and condensation
- Pyrolysis
- Electric discharge
- Gas-phase synthesis
- Ball milling and annealing
- These methods produce nanoparticles with a wide size variation (Sani et al., 2023).

8.2. Chemical Methods

- Reduction of mineral salts using chemical agents, such as in titration.
- Simple setup with no need for sophisticated equipment or highly trained personnel.
- Use of chemicals raises environmental concerns (Guo et al., 2022).

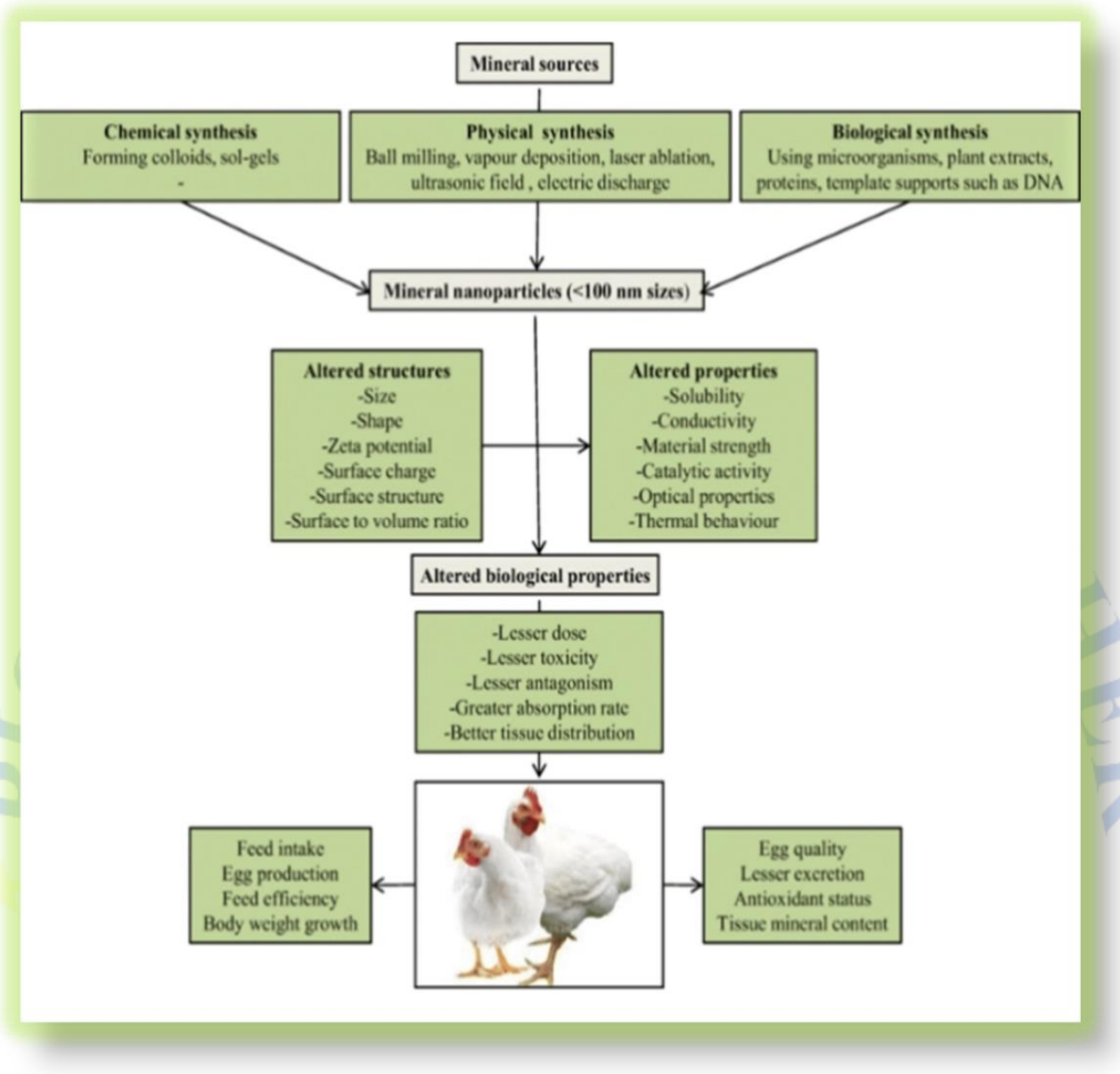

Fig. 4: Representation of Synthesis of Nanominerals

8.3. Biological Methods

- Use of microorganisms (e.g., bacteria, fungi, algae, and viruses) or plant extracts to synthesize nanoparticles.
- Low cost
- Energy-efficient
- Environmentally friendly and non-toxic

- Requires careful maintenance of microbial cultures.
- This rephrased and structured content provides a concise and clear overview of nanoparticle production methods while improving readability and eliminating errors (Table. 1) (Musgrove et al., 2024).

Table. 1: Challenges and Limitations in Nanotechnology in Poultry Production

Challenges and Limitations	Details
Potential Toxicity	Nanoparticles may harm animals and impair their immune systems, with concerns over their ionic or nano form remaining unresolved.
Complex Risk Assessment	Due to the diverse nature of nanomaterials, risk assessment must be conducted on a case-by-case basis, making it difficult.
Manufacturing Challenges	Producing nanoparticles requires intricate engineering and design to ensure uniformity, which is a significant challenge.
Food Safety Concerns	Contaminants and variations in feed composition may pose health risks to humans and animals.
Lack of Long-Term Studies	Insufficient research on the long-term effects of nanotechnology on humans, birds, and the environment raises uncertainties.
Environmental Impact	Improper disposal of nanoparticles may harm soil, water, and non-target organisms.
Farmers' Ignorance	Lack of knowledge about nanotechnology, especially in rural areas, limits its adoption.
Cultural and Ethical Concerns	Resistance from cultural skepticism, cynicism, and ethical issues reduces market acceptance of nanotechnology in poultry production.
Consumer Resistance	Concerns over the safety and ethics of nanotechnology among consumers hinder its acceptance in the market.

Cost and Accessibility of Nanotechnology in Poultry

The development and manufacturing of nanoparticles is currently very expensive, which is a major barrier to their use in chicken production, especially by small-scale or underfunded farms (Jarman et al., 2023). Because large, well-funded companies are the only ones to have access to nanotechnology, its wider use is occasionally limited. The industrial production of nanoparticles from laboratory settings is increased in complexity and cost (Gadel Hak et al., 2023). The requirement for complex infrastructure to preserve nanoparticle performance and stability in a range of environmental and storage circumstances further increases costs. Collaboration among scholars, industry executives, and policymakers can result in scalable and cost-effective nanotechnology solutions for these issues (Singh et al., 2023). The safe use of nanomaterials for people, animals, and the environment may be guaranteed by setting up exact regulatory frameworks. Public education increases awareness of how nanotechnology benefits chicken production and builds trust in its potential (Kopler et al., 2023).

Conclusion

Nanotechnology might revolutionize chicken production by enhancing animal health, lessening its negative effects on the environment, and boosting feed efficiency. It offers long-term solutions to the chicken industry's problems by enhancing nutrition absorption, controlling diseases, and replacing antibiotics. It offers long-term solutions to the chicken industry's problems by enhancing nutrition absorption, controlling diseases, and replacing antibiotics. Moreover, nanoparticles can boost vaccination delivery, enhance the quality of chicken products, and aid in disease prevention. Regulatory frameworks and public education crucially depend on the safe and effective integration of nanotechnology in chicken production. Nanotechnology could overcome these challenges potentially revolutionizing chicken farming, enhancing sustainability, and benefiting farmers.

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