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Review Article

Nano-zinc: The smart nutrient that ensures better health and improved production performances

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Abstract

Zinc is a primary microelement essential for carrying out several activities within the body. Zinc enhances metabolic functions, the synthesis of vital enzymes, and the generation of hormones related to growth, reproduction, immunity, and antioxidative roles in aquatic organisms. Various zinc sources are routinely utilized in livestock and aquaculture, encompassing inorganic, organic, and nanoparticle forms. But bioavailability of nutrients seems to be the biggest hurdle in the nutrition sector. Nano-dimensional mineral particles, due to their intrinsic inertness, high surface to charge ratio are presumed to be non-reactive with antagonistic micronutrients and are thought to be absorbed through a changed pathway, suggesting increased bioavailability of these advanced minerals. The role of nano-zinc in animal and fish production, along with its qualities such as antibacterial characteristics and immune enhancement, is examined herein. Nano zinc has a positive effect on growth performance, nutrient digestibility, immune modulation, gut health, reproduction, etc. than its bulk counterparts (inorganic and organic zinc). Exploiting the use of nano zinc in livestock and aquaculture has the potential to improve production performance. This nutrient can be utilized for developing next-generation feed additives and promoting animal well-being.

Keywords: Antibacterial, Immunity, Nano zinc

Highlights

- Zinc is an essential element.
- The Nano form of zinc is more bioavailable.
- Nano-zinc delivers better antibacterial and immunity functions.
- Nano-zinc promotes growth more effectively.
- Nano-zinc is a smart nutrient for future farming.

INTRODUCTION

Micronutrients play a crucial role for maintenance of animal health and ensuring the quality products without compromising the feed safety. Zinc (Zn) is the second most abundant trace mineral in animal bodies, but because it cannot be stored, the body needs to regularly consume zinc-rich foods to meet its physiological requirements. It remains associated with a huge number of essential enzymes and body proteins such as carbonic anhydrase, carboxypeptidase-A, alkaline phosphatase, alcohol dehydrogenase, superoxide dismutase etc. Zn is an essential component of both DNA and RNA polymerases (Costa et al., 2023). Zn plays an important role in nucleic acid metabolism, protein synthesis, carbohydrate metabolism and cell division along with the regulation of genetic expression. It is crucial for spermatogenesis and is related with secretion of testosterone, insulin and corticosteroids. It is associated with collagen synthesis and hence prevents parakeratosis. Zn is necessary for vitamin A synthesis in the body from carotenoids and maintains the general epithelium of the ovary. Zn is a potent immunomodulator, as it can influence the production of B-cells and T-cells along with different cytokines. As an antioxidant, zinc can protect the sulfhydryl groups in the cell membrane. In the rumen, Zn is found to influence microbial growth. Zn absorption is highly challenging and differs with the age of the animal and the sites in the gastrointestinal tract. Different groups of cattle have varying zinc requirements, which range from 20 to 80 ppm. Zinc is absorbed in the small intestine as Zn ions, as a compound with amino acids or chelates, or, more recently, as Zn-nano particles.

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Antibiotic resistance appeared to be a major concern in today's animal production system, including aquaculture. Indiscriminate use of antibiotics in livestock and fishery sectors often leads to repeated exposure of the counteracting microbes and, in turn, increases the chances of developing resistance and thereby a higher mortality rate. To overcome this problem, antibiotics need to be replaced by safe alternatives (like nano-zinc molecules) that impart both antibacterial and antiviral properties. In the commercial sector, Zn is supplied as inorganic salts such as Zinc sulphate ($ZnSO_4$), Zinc oxide (ZnO), Zinc chloride ($ZnCl_2$) etc. in animal feed, from where the bioavailability of Zn is very poor (Zhao et al., 2014). Therefore, animal nutritionists are searching for a suitable alternative to enhance the bioavailability of this important mineral. Organic sources of zinc have been studied by several workers (Nagalakshmi et al., 2009; Hassan & Aarts, 2011; Mallaki et al., 2015; Sridhar et al., 2015) but not been adopted extensively. More recently, with the advent of nanobiotechnology, the concept of mineral nutrition has been reshaped. In order to increase the bioavailability, the dimensions of the minerals are brought down to less than 100 nm by applying soft chemistry or green synthesis. These nano-dimensional mineral particles by their inherent nature of inertness, are supposed to be non-reacting with so-called antagonistic micronutrients and believed to be absorbed via altered route (Abdelnour et al., 2021), indicating enhanced bioavailability of these smart minerals. The increased surface area to charged ratio potentiates the synthesized nano-dimensional particles and hence can be exploited for animal welfare. By virtue of increased bio-availability, dietary supplementation of these nano-particles might alter the excreta profile of animals and hence seems to be the least contaminant to the environment. This high bioavailability of different nano-mineral particles assumed to be due to its some novel characteristics, such as higher specific surface area and surface activity, high catalytic efficiency and stronger adsorbing ability (Schauermann et al., 2013). Due to the advantage of nano size and high surface reactivity, these nanoparticles may be used in drug designing and as targeting therapeutic agents to particular organs. Varieties of nano mineral particles show new characteristics of transport and uptake and thus exhibit higher absorption efficiencies reaching deeper into the tissues (Zhao et al., 2008). The present article depicted the role of nano zinc in animal husbandry and aquaculture by ensuring better health and improved production performances and for this, relevant researches of last fifteen years were evaluated.

Zinc sources and their efficiency

Sources of Zn can be divided into several groups according to their efficiency:

Inorganic Zinc compounds: Inorganic Zn (Zinc oxide, Zinc sulphate and Zinc phosphate) is not too biologically active. It accelerates oxidization processes in the organism and may cause health problems in higher doses. Most inorganic Zn is excreted from the body due to interactions with other trace minerals.

Organic Zinc compounds: Organic Zn compounds perform a key role in biological processes (Nagalakshmi et al., 2015). They are more active than the inorganic compounds. They are part of proteins, amino acids, carbohydrates and include Zinc-methionine (Zn- Met) and Zinc-glycinate (Zn-Gly). Zn-Met is quickly absorbed with the consequence of higher blood levels in comparison to inorganic Zn. Bioavailability of Zn depends on the chemical compound it is part of (Pal et al., 2010). Organically bound Zn is mostly used in the form of Zn- enriched yeast or other preparations. Zn-enriched yeast contains Zn in the form of Zn- Met (Singh et al., 2015). Zn in its organic form shows higher bioavailability than inorganic Zn (Star et al., 2012). This is manifested by higher levels of organic Zn in all tissues and anatomies. The activity of different enzymes in the serum remains almost the same in both the organic and inorganic forms.

Nano-zinc compounds: With the advent of nanotechnology, we have been able to synthesize nano minerals, which are gaining interest in the area of nutritional supplements and are becoming largely available and usable now. Nano-zinc is one of the most important nano minerals of present world with noted significant increase of chemical reactivity. Nano minerals can be synthesized by physical, chemical or biological methods, but the most commonly used is the chemical method. Though presently the biological method or the green synthesis is gaining popularity, as chances of toxicity could be highly reduced, and is an environment friendly method. The size of the nano-zinc particles is less than 100 nm and stable under high temperature and pressure. The bioavailability and activity of the nano-zinc particles are inversely proportional with the size. Due to small size the nano-zinc particles are easily absorbed in the gastrointestinal tract and are more effective than inorganic ZnO at very lower doses. The bioavailability may be increased to 1250 times in case of nanoparticles.

After absorption, the nanoparticles are evenly distributed in blood, brain, lung, heart, kidney, spleen, liver, stomach etc. and especially nano-ZnPs are retained in the liver for a long time (Sun et al., 2018).

Concept of nano-particles

A particle is defined to be nano-particle if one of its dimensions is less than 100 nanometers (nm). It has been reported that the physical, chemical, electrical, optical, mechanical and magnetic properties of nano-particles are quite different from those present at a greater scale (Casals et al., 2012). The stability of the nano-particles decreases since the energy required to join adjacent atom is less and thus results in change of point of the given element (Jamkhande et al., 2019). The behavior of nano-dimensional particles is similar to that of a single atom. The surface area also increases many folds and thus increases the rate of the reaction (Casals et al., 2012).

The smaller the nano-particles, the faster they can diffuse through the mucosa of the gastrointestinal tract (GIT) to reach the cells of the intestinal lining, passing through the GIT barrier, and ultimately reaching the blood. Uptake occurs variously by passive diffusion across the mucosal cells, and smaller particles are absorbed deeper into the tissue. The nano-particles may directly enter the bloodstream and then predominantly scavenged by the liver and spleen (Qin et al., 2020). In the 21st century, nano zinc has received a lot of interest due to its features which are unusual (Younas et al., 2023). ZONP has the efficiency to modulate the immune mechanism of body, growth-promoter, and antimicrobial properties in poultry birds. It has increased bioavailability as compared to their other dietary forms, producing better results in terms of productivity and reduces ecological harm in the poultry sector (Fatima et al., 2024). ZONP can enhance the intestinal microbiota by favouring beneficial bacteria and inhibiting harmful bacteria (Samy et al., 2025). Supplemental ZONP has the potential to improve growth, feed utilization, amylase and lipase enzymes activity, intestinal morphology, hemato-biochemical, and oxidative response biomarkers of Nile tilapia (Ibrahim et al., 2022).

Influences on supplementation of nano-zinc

Growth: Zinc is very much essential for growth and the use of organic Zn and nano-zinc are giving better results than inorganic Zn-compounds. Organic Zn-compounds (e.g., Zinc-methionine) and Zinc oxide nanoparticles (ZONP) have been reported to enhance growth performance, improve feed utility and provide economic benefits in weaning piglets and poultry (Mishra et al., 2014; Denny et al., 2015). Zinc oxide nanoparticles (ZONP) have been found to improve the production performance and dressing performance of broilers on 42 days of feeding at the level of 40 mg/kg in the diet (Lina et al., 2009). Even at a concentration of 1/500 of the basal dose of nano-zinc, Mishra et al. (2014) found that layer chicks' development rate was significantly enhanced compared to inorganic Zn. At this dosage of nano-zinc supplementation, they also found that serum glucose and alkaline phosphatase (ALP) levels were higher, whereas alanine aminotransferase (ALT) levels were lower. Zinc supplementation within a specified limit often stimulates growth both in ruminants and in poultry (Sun et al., 2019). Using lower dosages of ZONP (200, 400, 600 mg/kg) instead of higher doses of inorganic ZnO (3,000 mg/kg), they studied the effect of ZONP on the growth performance and diarrhoea incidence in weanling piglets. The researchers reported that whereas piglets supplemented with 3,000 mg/kg of ZnO had a much lower rate of diarrhoea (49.1% reduction), but when the basal diets were supplemented with 400 mg/kg of ZONP, no discernible effect was recorded.

Immunity: Gharibzahedi and Jafari (2017) found that zinc deficiency reduces immune responses and disease resistance in both experimental animals and humans. There has been a significant uptick in research into zinc's antioxidant role in the brain and the rest of the central nervous system. Many proteins, including those involved in regulation, structure, and enzyme activity, rely on zinc for their proper structure and function. As a neurosecretory chemical or cofactor, zinc has an ancillary role in the central nervous system. For this task, a certain group of neurons found only in the forebrain, called "zinc-containing" neurons, must have a high concentration of zinc in their synaptic vesicles (Benarroch, 2023). Substituting 0.06 mg/kg of ZONP into broiler meals improved the birds' health (lower blood cholesterol levels and raised ALT) and immunity compared to the conventional dosage of 15 mg/kg of organic and inorganic Zn in the base diet (Sahoo et al., 2014). The brain has relatively high amounts of zinc compared to other soft tissues. In a study conducted by Sun et al. (2019), it was found that supplementing basal meals with 400 mg/kg ZONP reduced the diarrhoea rate by up to 49.1%, whereas 3,000 mg/kg ZnO only reduced it by 21.6%.

Reproduction: The use of nano sensors could lead to new insights into the causes of abortion. Using nano

antioxidants to combat infertility, post-calving reproductive problems, including retained placenta, and other similar disorders, is an emerging area of study. As an essential component in the neutralization of reactive oxygen species, zinc also has antioxidative properties. An increase in oxidative damage due to zinc deficiency may have a negative impact on sperm quality (Colagar et al., 2009). Zinc controls spermatozoa movement by regulating energy consumption through the ATP system, which is critical for contraction and the control of phospholipid energy reserves (Kerns et al., 2018). Goat sperm motility is controlled by zinc, which influences sperm tail flagella production (Liu et al., 2020). As an energy source for the migration of spermatozoa, zinc is involved in lipid breakdown in the middle area of the sperm. Idiopathic male infertility and poor sperm quality are both linked to zinc deficiency (Colagar et al., 2009). Implanting nanotubes under the skin to allow real-time blood estradiol level measurement is a novel use in animal production systems. Abortions and stillbirths are more common in women who do not get enough zinc in their diet. Potentially improving agricultural profitability, ZONP administration to animals may correct these reproductive abnormalities. The possibility of ZONP improving animal reproductive performance warrants more investigation in this area.

Rumen fermentation: Supplementing rumen fermentation with ZONP (0, 50, 100, 200, and 400 mg/kg of DM) altered the fermentation pattern, according to research by Chen and Liu (2011). It has been found that adding ZONP to ruminal microorganisms *in vitro* improves their growth, protein synthesis, and energy usage efficiency in the early phase of incubation (6 to 12 hours). At 6 and 12 hours of incubation in the *in vitro* study, 100 and 200 mg/kg of ZONP led to an increase in volatile fatty acid concentration, microbial crude protein production, and organic matter fermentation, but a decrease in ammonia nitrogen concentration and an adverse effect on the acetate to propionate ratio.

Blood biochemical profile: Broiler birds supplemented with 60 ppm or 90 ppm of ZONP in diet had decreased ($P>0.05$) triglyceride values, total cholesterol, LDL-cholesterol and increased ($P<0.05$) HDL-cholesterol in comparison to control (Ahmadi et al., 2013). Organic Zn and nano-zinc supplemented at 15 ppm and 0.06 ppm, respectively, to the basal diet in broilers ($P<0.05$) altered the serum cholesterol, SGPT and ALP levels (Sahoo et al., 2014). Broilers supplemented with 20 ppm ZONP tended to increase serum cholesterol and ALP activity but had no significant effect on ALT, CK or AST activities. Levels above 50 mg/kg of ZONP induced oxidative stress and increased plasma levels of ALT and AST (Sharma et al., 2009). The organic and nano Zn groups of laying hens showed higher ($P<0.05$) carbonic anhydrase activity (Tsai et al., 2016). Serum glucose and alkaline phosphatase levels were increased, and alanine amino transferase levels were decreased among ZONP-supplemented birds (Mishra et al., 2014). In a recent study, supplementation of ZONP (@20 ppm) resulted in a decrease ($P<0.05$) in serum uric acid and triglyceride levels and an increase in high- density lipoprotein (HDL) in broiler (Mahmoud et al., 2020). Kidd et al. (1996) stated that feeding of ZONP (0.2 to 0.3 gm/kg diet) dramatically reduced the cholesterol level and the level of low -density lipoprotein (LDL) in serum and enhanced the level of HDL in growing Japanese quail. Some researchers found that the enhancing dose of ZONP at a level of 20 or 40 mg/kg in diet decreased the level of cholesterol, triglycerides, creatinine and uric acid and increased the HDL (El-Bahr et al., 2020). Bashar et al. (2023) reported that there is a reduction in serum uric acid, AST, ALT and glycerides levels in rabbits treated with nano minerals. When ZONP was supplemented to laying hens and broilers, the level of serum cholesterol was decreased (Attia, 2020). Zn has the ability to prohibit cholesterol from being absorbed in the intestine and that uplifts the development of lactic acid bacteria in the GI tract and thereby reduces the production of cholesterol in the body (Liao et al., 2020).

Carcass traits: ZONP particles had no significant effect on digestive and visceral organs of broilers compared with the control and other treatments (Ahmadi et al., 2013). No obvious difference was observed in organ weights (liver, kidney and brain) of control mice and ZONP-treated mice (Sharma et al., 2012). The weight of abdominal fat and small intestine was lower in broiler birds supplemented with 60 mg/kg and 90 mg/kg of ZnO nano-particles in the diet compared to control and other treatments (Ahmadi et al., 2013). Rossi et al. (2007) stated that carcass and cut-up (drumstick, thigh and breast) yields were not influenced by the addition of increasing levels of dietary organic Zn in broilers. Carcass yield of broiler birds fed 80 ppm Zn nanosulphate and control groups were dramatically reduced with increased abdominal fat (%) as compared to inorganic Zinc sulphate, Zinc methionine and ZONP (Mohammadi et al., 2015).

Bone strength: Broilers supplemented with 80 ppm nano-zinc sulphate had significantly higher tibial Zn concentration compared to control and inorganic zinc sulphate treated groups (Mohammadi et al., 2015). Zn content in tibia ash had significantly ($P<0.05$) increased in broiler birds supplemented with at least 15 ppm of Zn as zinc sulphate or 10 ppm of Zn as organic zinc compared to the unsupplemented control group (Star et al., 2012). The concentration of Zn in tibia increased ($P<0.001$) linearly with Zn intake in broilers (Bao et al., 2007).

Anti-bacterial activity: The antibacterial properties of metal oxide nanoparticles have been noted by numerous researchers. A substance with antibacterial action is one that, without harming nearby tissues, either kills germs locally or inhibits their growth. Both Gram-positive and Gram-negative bacteria are susceptible to the bactericidal effects of zinc oxide nanoparticles (Arabi et al., 2012). They are also efficient against spores that are resistant to high pressure and high temperature. ZONP significantly increases the permeability of bacteria, which interferes with normal transport through the plasma membrane and causes cell death (Auffan et al., 2009). Surface area and concentration determine ZONP's antibacterial activity, but particle shape and crystalline structure have less bearing (Arabi et al., 2012). However, some researchers discovered that the antibacterial property and size are inversely related, meaning that the smaller the ZONP, the more effective the antibacterial activity (Shrivastava et al., 2007). Nanoparticles can increase their bactericidal impact by interacting with the bacterial surface due to their cytotoxicity to microorganisms and having a greater surface area than big particles (Reijnders, 2012). ZONP'S antibacterial activity is concentration-dependent (Arabi et al., 2012). However, it is still unclear how exactly ZONP breaks through the bacterial cell wall. ZONP works against harmful germs through a variety of methods, according to numerous scientists (Siddiqi et al., 2018; Krishnamoorthy et al., 2022; Mendes et al., 2022; Tah et al., 2025). According to Raad et al. (2005), ions released by nanomaterials interact with the thiol groups (eSH) of proteins found on the cell surface. These proteins pierce the cell wall to facilitate nutrient transfer. Proteins are rendered inactive by ZONPS, which reduces membrane permeability and ultimately results in cellular death (Rajendra et al., 2010). According to Padmavathy and Vijayaraghavan (2008), minerals in nanoform also prevent bacteria from adhering to surfaces and forming biofilms. By interacting with substances like DNA that contain phosphorus and sulphur, ZONPS can also enter bacterial cells and harm them (Arabi et al., 2012). Another explanation for ZONP's antibiotic properties suggests that because metal oxides have a positive charge and microbes have a negative charge, there is an "electromagnetic" attraction between the treated surface and the germ. The microorganism is oxidized and dies instantaneously upon touch. Nanoparticles are excellent candidates for antibacterial treatments because of their nonspecific mode of action against bacteria, which eliminates the possibility of bacterial resistance. The quantity of bacterial cells and the ZONP concentrations determine total bacterial inhibition. Therefore, it is clear from the literature that ZONP has outstanding antibacterial qualities and can be added to animal feed to promote growth or stop illnesses from developing. To cut down on the use of in-feed antibiotics and provide additional advantages, future research should concentrate on using ZONP as an alternative to traditional Zn sources in animal feed.

Milk production: When compared to more traditional sources of zinc oxide, nano-zinc has been found to improve milk output and decrease somatic cell counts in cows suffering from subclinical mastitis. Therefore, nano-zinc has the potential to be utilized as a therapeutic and preventative measure for the management of subclinical mastitis in cattle (Rajendran et al., 2013).

Fish nutrition and health: The physiological and biological functioning of aquatic animals as well are impacted by zinc deficiency. The role of zinc for improving the production performances and optimizing the health is of recent interest. Dietary supplementation of zinc proved its efficacy for augmenting the production performances and ensured optimum fish health. ZONPS as supplements can be an additional strategy to treat zinc shortage. The growth and well-being of fish could be improved by nanoparticles. The nano-structures ensure the adequacy at tissue level and hence nano-zinc appeared to be more potent for immunomodulation in fish. Supplemental nano-zinc seems to have more potency to improve the growth rate, physiological status and overall health in different species (Jewel et al., 2024). Highest weight gain and specific growth rate (SGR, % per day) were obtained in zinc oxide nanoparticle-supplemented group in comparison to organic or inorganic source of zinc-upplemented groups in rohu (*Labeo rohita*) (Mondal et al., 2020; Swain et al., 2019); Nile tilapia (*Oreochromis niloticus*) (Ghazi et al., 2021); Asian catfish (*Clarias batrachus*)

(Jewel et al., 2024) and in Mrigal (*Cirrhinus mrigala*) (Rajan & Rohini, 2021). Considering the bioavailability issue nano-structured zinc is being more preferred for dietary fortification in fish and in their study (Swain et al., 2019). Not only they observed an improved performances in terms of growth, but also improved performance of lysozyme, myeloperoxidase activities, SOD and acetylcholine esterase activity when rohu (*Labeo rohita*) was fed a diet fortified with nano-zinc at 10 mg/kg feed. Organic Zn in nano particles was reported to improve innate defense significantly during bacterial infection in Nile tilapia (*O. niloticus*) (Silva et al., 2024). Kumar et al. (2018) reported that ZONP supplementation has a cumulative impact on the reduction of biotic and abiotic stress, as well as an improvement in health and oxidative stress response in *Pangasius hypophthalmus* (Kumar et al., 2018). The zinc in its nano-form is believed to be an excellent stress modulator and can enhance the non-specific immunity and antioxidant status of fish exposed to multi-stressors (Kumar et al., 2023). Dietary nano-zinc can increase the immunoglobulin level and upregulate the IL1 beta expression (Hafez et al., 2020). Higher immunomodulation is linked to increased number of thymocytes and peripheral T cells which in turn induce the production of interferon and IL-2. The ZONP proved to be a potent immunomodulator even at lower doses compared to inorganic and organic Zn (Hafez et al., 2020; Tah et al., 2025). ZONP can also promote the extra thymulin activity to enhance the maturing of T-lymphocytes and the activation of B lymphocytes by T-helper cells (Bonaventura, 2015; Abedini et al., 2017). Dietary nano-zinc can trigger the lymphocyte count and phagocytic activity (Hafez et al., 2020). In a recent study, a special variety of ZONP was devised to potentiate its antimicrobial activity (Mahato et al., 2024). The synthesized nano-zinc proved to be a good preservative to extend the refrigerated shelf life of fish. Supplemental zinc often combats the stress as observed by the reduction of serum glucose, cortisol, and HSP70 levels and concomitant increase in serum total protein, albumin, and globulin levels (Kumar et al., 2018). Feeding of nano-zinc at 60 mg/kg diet found to have a positive influence on the survival rate, growth and immunity of *Macrobrachium rosenbergii* (Muralisankar et al., 2014). Supplemental nano-zinc even at lower levels (20 mg/kg) might improve the weight gain and specific growth rate along with imparting extra innate immune response (higher phagocytic and respiratory burst activities). Precise supplementation of dietary nano-zinc seems to be more efficient to improve the production performances, imparting gut health and to overcome the issues of environmental footprint.

Conclusion

Zinc is an important essential trace element that plays some crucial roles for sustaining the life processes that includes nutrient metabolism, component of numerous metallo-enzymes and transcription factors. It is important for growth, development of bones and immunogenic make up of an individual. But zinc absorption is again highly challenging and bioavailability of most of the inorganic supplements is meager and used to antagonize with other dietary micronutrients at GIT level. In addition, the fact that the animals that were given the supplement had higher amounts of zinc excreted has brought to light concerns regarding the pollution of the environment. Therefore, we need to figure out how to exactly apply zinc supplements so that we can satisfy the physiological requirements and enhance the immune system without putting the sustainability of the soil at risk. Nano-sized zinc, also known as nano zinc, has the potential to serve as an alternative to both organic and inorganic Zn sources. It possesses a high bioavailability and may also exhibit other antibacterial and antiviral effects. Nano-minerals by their inherent nature of inertness, are supposed to be non-reacting with so-called antagonistic micronutrients and are believed to be absorbed via an altered route, indicating enhanced bio-availability of these smart minerals. Due to the higher bioavailability of nano-zinc than its other form, it can augment the growth potential and also can optimized the gut health. The antimicrobial property of nano-zinc makes it a safe alternative to commonly used antimicrobials, and recent studies have also established the antiviral potential of nano-zinc. The unique nano-dimensional particles of nanostructured zinc can further be exploited for devising it to next generation feed additives for ensuring animal welfare.

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