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Nano-Minerals in Animal Nutrition: Precision, Promise and Safety

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INTRODUCTION

Trace minerals are small in dietary quantity but large in biological importance. Zinc supports enzyme systems, epithelial integrity, immunity and reproduction. Selenium is part of antioxidant selenoproteins such as glutathione peroxidase. Copper is required for haemoglobin formation, connective tissue metabolism, pigmentation, immune function and antioxidant enzymes. Deficiency of these minerals can reduce productivity, fertility, product quality and health.

Mineral supplementation is not simply the addition of more mineral to the diet. In the digestive tract, minerals may interact with phytate, fibre, calcium, iron, sulphur, molybdenum and other dietary components, reducing availability and increasing faecal loss. Over-supplementation also increases feed cost and environmental mineral loading. The future of mineral nutrition therefore lies in improving mineral efficiency: the right source, right dose and right purpose.

Nano-minerals, generally defined as particles within the 1-100 nm range, offer one such possibility. Their higher surface area per unit mass may improve dissolution, mucosal contact and biological response. Still, the word "nano" alone does not guarantee superior nutrition. Each product requires characterization, dose validation and safety assessment.

What makes nano-minerals different?

Nano-minerals differ from bulk mineral particles mainly because of their smaller size, larger surface area and higher reactivity. These features may improve apparent availability, tissue mineral status and functional biomarkers such as antioxidant enzyme activity or immune response. In some cases, lower doses of nano-minerals may produce responses comparable to higher levels of conventional salts.

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They can be produced by top-down approaches, where larger particles are reduced to nanoscale, or by bottom-up approaches, where particles are built from atoms, ions or molecules. Biological or green synthesis using plants, microbes, fungi or algae is gaining interest because it may reduce chemical residues and improve biocompatibility. However, particle size, shape, surface charge, purity, crystallinity, solubility and stability must be verified using methods such as X-ray diffraction, scanning electron microscopy and transmission electron microscopy.

How may nano-minerals work?

The proposed action of nano-minerals is linked to better dissolution, closer interaction with intestinal mucosa and possible cellular uptake. Some formulations may also protect minerals from antagonistic interactions in the gut. However, true targeted delivery should not be assumed for all nano-mineral products; it generally requires specific particle engineering, coating or carrier systems.

The practical response should be judged through measurable outcomes such as serum or plasma mineral concentration, tissue retention, enzyme activity, antioxidant status, immunity, growth, reproduction, product quality and mineral excretion. Improved mineral status does not always mean improved body weight gain, especially when the basal diet already meets the requirement.

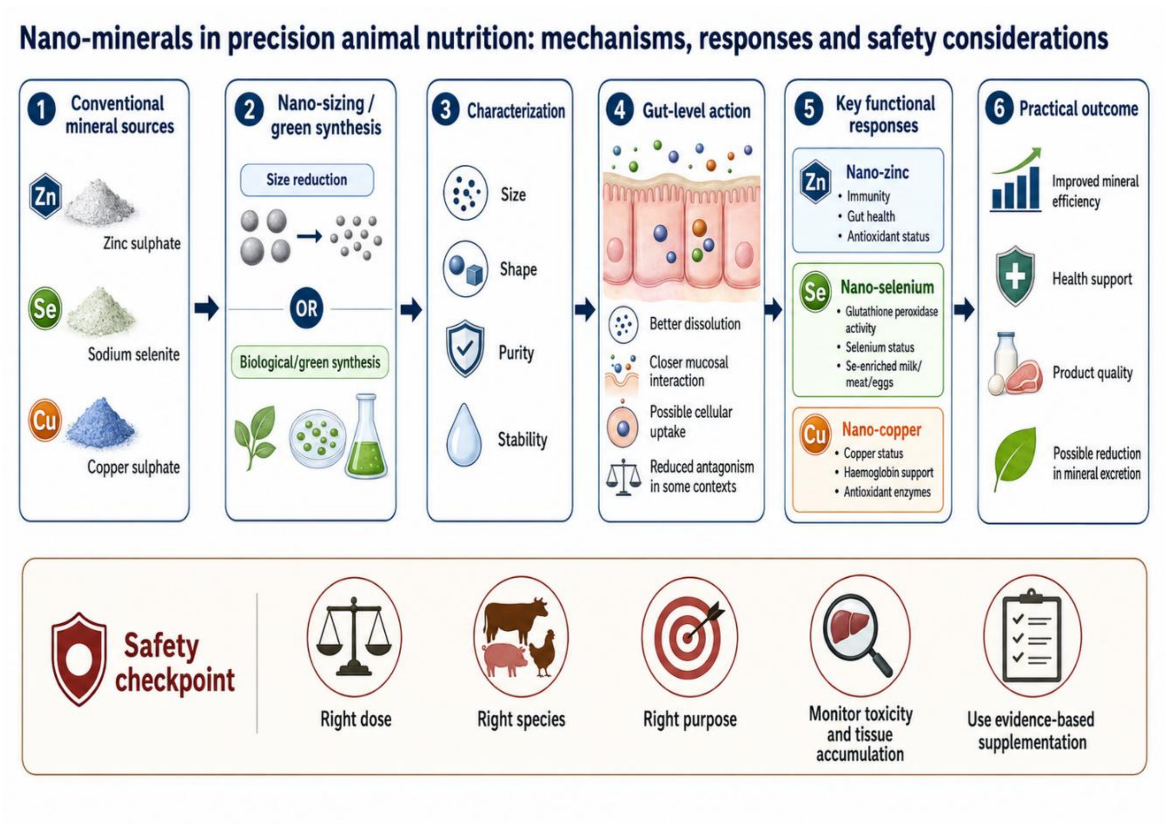

Figure 1: Nano-minerals in precision animal nutrition: potential mechanisms, functional responses and safety checkpoints. Beneficial effects depend on particle characterization, dose, species, physiological status and toxicity monitoring.

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Nano-zinc: growth, immunity and gut function

Zinc is one of the most studied nano-minerals. Swain et al. (2016) reviewed nano-zinc oxide as an alternative zinc source and highlighted its growth-promoting, antibacterial and immunomodulatory potential. They also emphasized that zinc cannot be stored in large amounts in the body and regular dietary supply is required.

Nano-zinc has shown promise for mineral status, immune function, antioxidant activity and gut health. In ruminants, it may influence fermentation, microbial biomass and nutrient utilization. However, improved zinc retention does not always translate into higher growth, particularly when the basal diet already supplies adequate zinc. Thus, nano-zinc should be considered a precision supplement rather than a universal growth promoter.

Nano-selenium: antioxidant defence and enriched animal products

Selenium is essential for antioxidant defence, immunity, thyroid hormone metabolism, fertility and product quality. Nano-selenium is of interest because it may improve selenium status and antioxidant response, although safety still depends strongly on dose and duration.

In dairy cows, Han et al. (2021) compared nano-selenium with sodium selenite at 0.30 mg Se/kg dry matter. Dry matter intake, milk yield and milk composition were unaffected, but nano-selenium increased plasma selenium, plasma glutathione peroxidase activity, milk selenium and milk glutathione peroxidase activity. This suggests a stronger functional role than a direct production response.

In broilers, Khajeh Bami et al. (2022) reported that green synthesized nano-selenium did not significantly change growth performance, but improved meat selenium content, beneficial intestinal microflora, intestinal morphology and immune response. Therefore, nano-selenium may be most valuable when the aim is antioxidant support, gut health, immunity or selenium-enriched animal products.

Nano-copper: useful but safety-sensitive

Copper is essential for haemopoiesis, connective tissue metabolism, pigmentation, antioxidant defence and immune function. However, it requires special caution, especially in sheep, because chronic hepatic copper accumulation can cause toxicity. Nano-copper should therefore not be used routinely without mineral diagnosis.

Min et al. (2022) studied nano-copper oxide in copper-deficient Kazakh sheep and reported improved blood copper, haemoglobin, erythrocyte count, packed cell volume and antioxidant enzyme activities, along with reduced oxidative stress indicators. These findings support its use mainly under confirmed copper-deficient conditions.

In young dairy calves, Pandey et al. (2023) reported that combined nano-copper and nano-zinc improved immune response and antioxidant status and reduced diarrhoea frequency and incidence, although growth performance was not significantly affected. This indicates that the value of nano-minerals may be more visible in health protection than in simple weight gain.

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Table 1. Evidence-based relevance and caution points for major nano-minerals in animal nutrition.

Nano-mineral	Best-supported response	Species evidence	Main caution
Nano-zinc	Mineral status, immunity, antioxidant activity, gut health and possible growth response	Calves, sheep, poultry and experimental models	Response depends on basal zinc status and dose
Nano-selenium	Selenium status, glutathione peroxidase activity, immunity and selenium-enriched milk/meat	Dairy cows and broilers	Narrow margin between requirement and excess
Nano-copper	Copper status, haemoglobin, antioxidant enzymes and immunity under deficiency	Copper-deficient sheep and young calves	High toxicity risk, especially in sheep
Other metallic nanoparticles	Experimental metabolic, antimicrobial or mineral-retention effects	Mostly poultry and laboratory studies	Limited routine feeding evidence and safety concerns

Safety and toxicity concerns

The same properties that make nano-minerals biologically active may also create safety concerns. Small size, high reactivity and deeper tissue interaction can increase the risk of oxidative stress, membrane damage, mitochondrial injury, DNA damage, inflammation and bioaccumulation when dose or exposure is inappropriate.

Safety evaluation should include animal performance, tissue deposition, milk/meat/egg residues, environmental excretion, worker safety and regulatory approval. Metallic nanoparticles with antimicrobial properties should also be evaluated for effects on beneficial gut microbes and environmental microbial ecology. Field use should wait for clear safe-dose recommendations.

Practical way forward

Nano-minerals may be useful where conventional minerals are poorly utilized, mineral antagonism is high, young animals require immune support, oxidative stress is a major challenge, or enrichment of milk, meat or eggs is desired. If lower nano-mineral inclusion maintains mineral status, environmental excretion may decrease, but this must be proven through mineral balance and excretion studies.

The practical rule should be: right nano-mineral, right dose, right animal and right purpose. Nutritionists should consider basal diet composition, deficiency status, species, age, production stage, mineral interactions, safety and cost-effectiveness before recommending nano-mineral supplementation.

CONCLUSION

Nano-zinc, nano-selenium and nano-copper have opened a new window in precision animal nutrition. Evidence from calves, dairy cows, broilers and sheep indicates potential benefits for mineral status, antioxidant defence, immune response, gut health, disease resistance and product enrichment. Yet, responses are not universal and safety cannot be ignored. In practical feeding systems, nano-minerals should be introduced only after considering basal mineral adequacy, antagonistic interactions and species-specific toxicity limits. With proper characterization, dose optimization and toxicity monitoring, nano-minerals may become valuable tools in sustainable livestock and poultry nutrition.

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REFERENCES

- Abdelnour, S. A., Alagawany, M., Hashem, N. M., Farag, M. R., Alghamdi, E. S., Hassan, F. U., Bilal, R. M., Elnesr, S. S., Dawood, M. A. O., Nagadi, S. A., Elwan, H. A. M., Almasoudi, A. G., & Attia, Y. A. (2021). Nanominerals: Fabrication methods, benefits and hazards, and their applications in ruminants with special reference to selenium and zinc nanoparticles. Animals, 11(7), 1916. https://doi.org/10.3390/ani11071916
- Khajeh Bami, M., Afsharmanesh, M., Espahbodi, M., & Esmaeilzadeh, E. (2022). Effects of dietary nano-selenium supplementation on broiler chicken performance, meat selenium content, intestinal microflora, intestinal morphology, and immune response. Journal of Trace Elements in Medicine and Biology, 69, 126897. https://doi.org/10.1016/j.jtemb.2021.126897
- Han, L., Pang, K., Fu, T., Phillips, C. J. C., & Gao, T. (2021). Nano-selenium supplementation increases selenoprotein (Sel) gene expression profiles and milk selenium concentration in lactating dairy cows. Biological Trace Element Research, 199(1), 113–119. https://doi.org/10.1007/s12011-020-02139-2
- Min, X., Yang, Q., & Zhou, P. (2022). Effects of nano-copper oxide on antioxidant function of copper-deficient Kazakh sheep. Biological Trace Element Research, 200(8), 3630–3637. https://doi.org/10.1007/s12011-021-02975-w
- Pandey, P., Kumar, M., Kumar, V., Kushwaha, R., Vaswani, S., Kumar, A., Singh, Y., & Shukla, P. K. (2023). The dietary supplementation of copper and zinc nanoparticles improves health condition of young dairy calves by reducing the incidence of diarrhoea and boosting immune function and antioxidant activity. Biological Trace Element Research, 201(8), 3791–3803. https://doi.org/10.1007/s12011-022-03481-3
- Swain, P. S., Rao, S. B. N., Rajendran, D., Dominic, G., & Selvaraju, S. (2016). Nano zinc, an alternative to conventional zinc as animal feed supplement: A review. Animal Nutrition, 2(3), 134–141. https://doi.org/10.1016/j.aninu.2016.06.003