Emerging Trace Minerals in Animal Nutrition: New Frontiers in Feed Sciences

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ABSTRACT

Nowadays feeding of trace mineral like zinc and copper to animal feed is changing. Instead of just meeting basic nutritional needs, scientists are using advanced delivery methods—like organic, hydroxy, and nano-minerals—to boost animal health, improve product quality, and protect the environment. Because animals absorb these new formats so well, farmers can use smaller amounts without slowing down animal growth, which leads to much less mineral waste in manure. While organic and hydroxy minerals are reliable and ready to use right now, nano-minerals still need more testing to ensure they are safe long-term. Moving forward, the industry's main goals should be to standardize these new supplements and thoroughly test their safety and effectiveness on real commercial farms.

INTRODUCTION:

Even though animals only need tiny amounts of trace minerals, nutrients like zinc, copper, manganese, iron, and selenium are vital for their bones, immune systems, and the quality of their meat, milk, and eggs. Because modern farm animals grow so fast and face high stress, they often struggle to absorb enough minerals from their meals—especially when other natural compounds in the feed block that absorption. To prevent deficiencies, farmers usually add extra

minerals to the diet, but this excess just ends up in the manure and pollutes the environment.

Traditionally, the go-to solution was using cheap, basic mineral salts. However, these break apart too quickly in the gut and interact poorly with other food parts. To solve this, scientists created better delivery methods: organic minerals (which attach metals to proteins), hydroxy minerals (which stay intact until they reach stomach acid), and nano-minerals (ultra-tiny particles that are easier to absorb).

From mineral salts to engineered delivery systems

Organic chelates and complexes

"Organic trace minerals" is a broad term, not a single specific product. The mineral might be attached to a single amino acid, a mix of them, or a protein. Just calling a supplement "organic" doesn't tell you exactly how it is built. For example, a 2023 pig study used a specific product where minerals were attached to 18 different plant-based amino acids (Y. Xiong *et al.*, 2023).

The main benefit of these organic minerals is that their coating protects them in the gut, making them much easier for the animal to absorb. One study showed that broilers digested organic copper, iron, zinc, manganese, and selenium much better than traditional cheap salts (nano-minerals performed just as well) (J. Lee and M. Kim 2025). However, we can't assume this exact result will happen on every farm, since this test was done under strict lab conditions with young birds on a very specific diet.

Because of this, the best real-world reason to use organic minerals is to feed animals *less*, rather than expecting them to magically boost production. For instance, when researchers replaced a full dose of standard minerals with just 30–60% of an organic version, pigs grew just as well and had better antioxidant levels. Even better, they pooped out far less mineral waste. Interestingly, feeding the pigs extra organic minerals beyond what their bodies actually needed didn't make them grow any faster (Y. Xiong *et al.*, 2023).

This is a crucial point. If farmers just use organic minerals as a pricey way to over-feed their animals, they lose both the economic and environmental benefits. But if they use them to safely lower the amount of minerals mixed into the feed while keeping the animals perfectly healthy, organic minerals become a smart, precision tool.

Hydroxychloride minerals

Hydroxychloride Minerals often called the "third generation" of trace minerals, hydroxy minerals (like copper, zinc, and manganese hydroxychloride) feature a unique crystal structure. This gives them a smart-release ability: they stay intact in the neutral environment of a cow's first stomach (the rumen), but break down and dissolve exactly when they need to in the acidic conditions further along the digestive tract (B. Reddy *et al.*, 2021).

This special chemistry solves two big problems at once. First, out in the feed bag, they are less dusty, don't clump up from moisture, and won't aggressively destroy added vitamins or fats like cheap mineral salts often do. Second, inside the animal, their slow-release design means they don't get tangled up with other food particles early on, leaving more of the mineral available for the animal to actually absorb (B. Reddy *et al.*, 2021).

The real-world results are promising, though perhaps not quite as perfect as the marketing suggests. In a study with young beef steers, hydroxy minerals were absorbed very effectively. More importantly, farmers were able to use a lower dose without hurting the

steers' overall growth, meat quality, or liver health (B. Reddy *et al.*, 2021).

However, a study on dairy cows shows why it is risky to crown any one mineral as the absolute "best." Dairy cows fed hydroxy minerals right before calving held onto their body weight better than cows fed traditional mineral salts. But surprisingly, their overall antioxidant levels were actually *lower* than the cows eating the basic salts (B. Reddy *et al.*, 2021).

This dairy study highlights an important lesson: a specific mineral supplement might be great for keeping a cow's weight up, but fall short on a different health marker. Hydroxy minerals are incredibly stable in feed and release smartly in the gut, but they don't automatically guarantee a superior outcome for every single health test.

Nano-minerals

Instead of attaching minerals to proteins, nano-minerals are simply engineered to be incredibly tiny. This massive surface area helps them dissolve and absorb much faster. In a 2025 broiler study, testing particles around 84–107 nanometers, researchers found that birds digested both nano and organic forms of copper, iron, zinc, manganese, and selenium much better than standard salts (with the nano and organic forms performing about equally well) (J. Lee and M. Kim, 2025).

While this direct comparison is helpful, it doesn't mean all nano-minerals are identical. Details like a particle's specific size, coating, and how it is manufactured can completely change how it acts inside the body.

A 2022 broiler trial showed how this technology impacts actual farm production. Researchers tested nano versions of zinc, manganese, and copper at 25%, 50%, and 100% of the standard required dose. The 50% and 100% nano doses successfully boosted the birds' body weight and feed intake. At a scientific level, they also improved key health markers by increasing the activity and expression of important antioxidant proteins (like superoxide dismutase, metallothionein, and ceruloplasmin) (B. Gowtham *et al*., 2022).

Impressively, the authors noted that feeding just a 25% nano dose maintained the exact same growth as a full 100% dose of standard salts, while the 50% nano dose produced the best overall growth (B. Gowtham *et al*., 2022). This is highly promising for reducing mineral doses on farms. However, we shouldn't assume a quarter-dose works perfectly everywhere based on one commercial trial. Also, because three minerals were tested together, we can't tell if the boost came from the zinc, the manganese, the copper, or the combination of all three.

The biggest hurdle right now is safety. Even the studies praising their high absorption admit that the long-term safety of nano-minerals is still unknown (J. Lee and M. Kim 2025). Yes, higher absorption means less mineral waste in the manure. But we don't yet know if these tiny particles build up unsafely in animal tissues, transfer to offspring, disrupt gut bacteria, or behave unpredictably once they hit the soil. Because of this, nano-minerals need to be judged on total biological and environmental safety, not just on how fast they make an animal grow.

What improves in the animal?

Mineral digestibility and retention

Across all the recent studies, the most consistent benefit of these new alternative sources is higher bioavailability—meaning the animal actually absorbs the nutrient instead of passing it through. For example, both organic and nano forms improved ileal digestibility in broilers compared to standard inorganic minerals. Similarly, a pig study showed that organic minerals not only reduced mineral

waste in the manure, but they also improved the animal's overall ability to digest energy, dry matter, and crude protein (Y. Xiong *et al.*, 2023), (J. Lee and M. Kim 2025).

The pig study perfectly illustrates this: researchers found that reducing the mineral dose didn't hurt the pigs' performance, but they also noticed that feeding them *excessive* amounts of organic minerals didn't make them grow any faster, either (Y. Xiong *et al.*, 2023). Because of this, the true goal for these advanced minerals is achieving the "same output with less input," rather than expecting more output from the same amount of feed.

Growth, immunity, and antioxidant status

When it comes to actual farm production (like growth and weight gain), the results are a bit more of a mixed bag. For example, the broiler study using nano-minerals saw improved body weight and feed intake when birds were given 50% and 100% doses. Meanwhile, another broiler study using advanced chelated (organic) minerals tested 25%, 50%, and 100% doses, but focused more on measuring growth, bone (tibia) health, mineral absorption, and antioxidant levels (B. Gowtham *et al.*, 2022), (H. A. Ghasemi *et al.,* 2020).

The chelate study had some impressive results: feeding just a 25% organic dose improved the birds' ability to digest phosphorus, zinc, manganese, and copper compared to a standard dose of cheap inorganic salts. Even more notably, a 50% organic dose resulted in better zinc and manganese absorption than a full 100% dose of traditional minerals. The researchers believe this success comes from the organic minerals remaining stable in the gut and avoiding tangles with other food particles. However, they admitted they still don't fully understand exactly how every mechanism works (such as how it affects the way the bird uses phosphorus) (H. A. Ghasemi *et al.,* 2020).

It makes perfect biological sense that these advanced minerals boost immune and antioxidant health, since zinc, copper, manganese, iron, and selenium are crucial building blocks for the body's defence systems. However, it is vital to remember that seeing a better biomarker on a blood test doesn't automatically mean the animal is fully disease-resistant.

For instance, the nano broiler study showed positive changes in antioxidant enzymes (like superoxide dismutase) and mineral-related gene expression. This proves the minerals successfully altered the bird's internal chemistry, but the study didn't actually prove that the birds were better at surviving, fighting off real-world pathogens, or staying healthy on a commercial farm (B. Gowtham *et al.*, 2022).

Product quality and reproduction

Alternative trace minerals don't just affect the animal's growth; they can actually improve the final food products. They do this by changing how minerals are deposited in the body, boosting antioxidant protection, strengthening bones and tissues, or improving eggshell formation.

A recent review highlighted that organic minerals (specifically amino-acid and peptide-complexed minerals) improved eggshell thickness and color, increased broiler meat quality, and boosted antioxidant capacity in pigs—all while reducing mineral waste in their manure (H. Cardoso, 2025). However, because this paper was a "narrative review" (a summary of other people's work), we should treat these claims as a helpful overview rather than a replacement for the original, hard data from the individual trials.

The evidence also shows that results depend heavily on the specific animal species:

In laying hens: The review noted that using a lower dose of organic zinc, copper,

manganese, and iron put just as much (or even more) mineral into the egg yolk compared to standard sulfate salts. It also improved the antioxidant response in the bird's shell gland. Remarkably, feeding the hens just 50% of the standard mineral dose positively activated the specific genes responsible for organizing eggshell crystals (H. Cardoso, 2025).

In pregnant sows: Replacing a portion of their standard zinc, copper, and manganese with organic chelates improved both the physical appearance and the microscopic cellular health (histology) of their hooves (H. Cardoso, 2025).

While these findings make product quality an exciting frontier, they also highlight a frustrating, recurring problem in the research: every study measures something completely different, at different stages of the animal's life, using different mineral combos. You simply cannot lump things like eggshell strength, bone (tibial) density, pork loin quality, liver mineral levels, and antioxidant gene expression into one generic, one-size-fits-all "quality improvement" claim.

Methodological Comparison

Study	Design or method	Animal and comparison	Main finding	Limitation for interpretation
(J. Lee and M. Kim 2025)	Controlled ileal digestibility and bioavailability experiment	480 Ross 308 male broilers; inorganic, organic, and hot-melt-extruded nano premixes	Nano and organic Cu, Fe, Zn, Mn, and Se had higher apparent and standardized ileal digestibility than inorganic forms; nano and organic forms were similar	Young broilers and a controlled metabolism design may not predict commercial performance or long-term safety
(H. A. Ghasemi *et al.*, 2020)	Randomized feeding experiment measuring growth, mineral digestibility, tibia, and antioxidant status	625 male broilers in 25 pens; no mineral, inorganic mineral, and chelated mineral at 25%, 50%, and 100% of inorganic level	Lower chelated inclusion improved selected mineral digestibility; 50% organic supplementation increased Zn and Mn absorption relative to full inorganic supplementation	Several minerals were changed together, and the mechanistic explanation for phosphorus responses remained uncertain
(Y. Xiong *et al.*, 2023)	Growing-finishing pig feeding trial measuring performance, carcass traits, digestibility, antioxidant capacity, and fecal excretion	Pigs receiving full inorganic minerals or 30–60% amino-acid-chelated minerals	Reduced organic inclusion-maintained performance and reduced fecal mineral excretion; 30–60% organic minerals improved antioxidant capacity and apparent digestibility	Product contained a specific multi-amino-acid chelate, so results cannot be generalized to all organic minerals,
(B. Gowtham *et al.*, 2022)	35-day commercial broiler feeding trial with performance, serum biomarkers, antibody titers, and gene expression	150 broilers; inorganic 100%, organic 100%, and nano Zn–Mn–Cu at 25%, 50%, and 100%	The 50% and 100% nano treatments improved growth-related outcomes; nano treatments increased selected antioxidant and mineral-status biomarkers	The combined nano treatment prevents attribution to one mineral; the study does not resolve long-term safety
(B. Reddy *et al.*, 2021)	Review of hydroxy Cu, Zn, and Mn chemistry and livestock studies	Ruminants, pigs, and poultry; hydroxy compared with inorganic and organic sources	Hydroxy forms were described as stable in feed, less soluble in rumen-like conditions, and potentially effective at lower doses	Review-level evidence and heterogeneous cited trials limit direct comparison across species and endpoints

Research Gaps

To move this science forward, the industry needs to address six major blind spots:

1. Define "Bioavailability" Consistently Right now, researchers measure completely different things—like blood levels, liver stores, digested amounts, or overall growth – and treat them as if they mean the exact same thing.

2. Demand Exact Chemical Identities Broad labels like "organic," "hydroxy," or "nano" aren't good enough anymore because they each cover dozens of different technologies. Companies need to reveal their exact chemistry – like the specific binding structures for organic chelates, the crystal structures for hydroxy minerals, and the exact particle sizes and coatings for nano-minerals.

3. Real-World Testing for Lower Doses We need to prove that feeding animals less actually works on real commercial farms.

4. Tailor Safety Tests to the Technology You cannot test a high-tech nano-mineral the same way you test a basic salt.

5. Look at the Big Environmental Picture Claiming a product is "eco-friendly" just because it creates less waste in the manure isn't enough.

CONCLUSION

Ultimately, the future of trace-mineral nutrition isn't about discovering new nutrients—it is about delivering the familiar ones with extreme precision. Advanced formats like organic complexes, hydroxychloride minerals, and nano-engineered particles give us the power to control exactly *where, when, and how* minerals dissolve and absorb inside the animal's body.

In the end, the winning mineral supplement won't just be the one that boasts the highest absorption rate. The true winner will be the one that reliably allows farmers to put *less* mineral in, get *equal or better* animal growth out, and do it all without passing hidden risks onto our food, our soil, or the wider environment.

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