Progress in the Application of Nano-trace Elements in Animal Husbandry

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Abstract Nano-trace element additives, with a particle size of 1–100 nm, are absorbed directly by osmosis in animals without ion exchange. When added to the feed, they can not only promote the growth by own nutrition at the conventional size, but also greatly improve the utilization and absorption rate of additives by animals. In this paper, the researches on micro-element feed additives such as nano-selenium, nano-copper, nano-zinc and nano-chromium were reviewed, which will provide basis for breeding production.

Keywords Nano; Trace elements; Animal husbandry; Application

Nanometer materials are composed of nano-level particles, which are in the intermediate region between macroscopic substances and microscopic atoms and molecules, and are characterized by excellent small-size effect, surface effect, volume effect and quantum size effect [1]. Florence *et al*. [2] suggested that the particle size of nutrient is a key factor affecting its absorption by gastrointestinal tract. Jani *et al*. [3] reported that when polystyrene particles of 50, 500 nm and 1μm were orally administered by mice, 50 nm particles appeared in lymph nodes and were maximumly absorbed within 6 h; 500 nm particles appeared in liver and spleen 18 h after oral administration; and only a small amount of 1 μm particles were absorbed. Desai [4] pointed out in the study on mice that the absorption rate of 100 nm particles was 10–250 times higher than that of other large particles. Other reports put forward that particles smaller than 5 μm can pass through the lung; particles smaller than 300 nm can enter the blood circulation and; particles smaller than 100 nm can enter the bone marrow. Therefore, nanoparticles can more easily pass through gastrointestinal mucosa, thus improving their bioavailability [5]. At present, nano-level trace element additives mainly include nano-selenium, nano-copper, nano-zinc and nano-chromium.

1 Nano-selenium

1.1 Improve animal growth and reproduction performance Appropriate nano-selenium can improve the growth and reproductive performance of animals, and the effect of nano-selenium is better than that of sodium selenite at the same supplemental level. Hu *et al*.[6] showed that the growth performance of piglets was at the peak when sodium selenite was added at the concentration of 0.2–0.5 mg/kg selenium, and the growth performance of piglets added with 1 mg/kg selenium was significantly lower than that added with 0.2–0.4 mg/kg selenium, while the growth performance of piglets remained at the peak when nano-selenium was added at the concentration of 1mg/kg. Xia *et al*.[7] reported that nano-selenium and sodium selenite had significant impacts on the growth, liver deiodinase I activity and serum thyroid hormone of broilers; when nano-selenium was added at the concentration of 1 mg/kg, the growth performance, liver deiodinase I activity and serum T3 level of broilers remained at the peak, while the serum T4 level remained at a low peak.

1.2 Enhance the body immunity Nano-selenium can significantly stimulate the cellular, humoral and non-specific immune functions of organism, so as to improve the ability of disease prevention and resistance. It is proved that nano-selenium can sensitively improve the immune function of mice. Gao *et al*.[8] studied the regulatory effect of nano-selenium on immune function through animal tests; compared with the control group, the organ weight and organ index of mice in nano-selenium and sodium selenite dose groups did not change significantly; in the nano-selenium group, the cellular immune function, humoral immune function and macrophage phagocytic function of mice were significantly increased in the high-dose group, while the above immune indexes did not change significantly in the sodium selenite groups, indicating that nano-selenium had significant regulatory effect on the im-

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mune function of mice.

1.3 Anti-oxidation effect The most important biological effect of selenium lies in its antioxidant activity, which mainly targets at reactive oxygen species and their derivatives. Nano-selenium is a tiny unit formed by tens of thousands of selenium compounds, which has stronger antioxidant and free radical scavenging ability, and can well inhibit free radicals and protect cells from damage[9]. The existing experiments manifest that the scavenging efficiency of nano-selenium against hydroxyl radical *in vitro* is 5 times of that of inorganic selenium and 2.5 times of that of organic selenium.

Zhang *et al.*[10] evaluated the anti-oxidation and survival time extension effects of nano-selenium using D-galactose mice aging model and *Drosophila melanogaster* survival model; the results demonstrated that nano-selenium significantly reduced the malondialdehyde content and increased the activity of glutathione peroxidase in the whole blood of mice, and significantly prolonged the survival time of *D. melanogaster*, indicating that appropriate dose of nano-selenium had anti-aging effect. Song *et al.*[11] found that nano-selenium could regulate the stability of cGPx mRNA in broiler liver and improve its enzyme activity. Xu *et al.*[12] proved that when nano-selenium was added at the mass concentration of 1 mg/kg, the activity of GSH-Px could remain at peak.

1.4 Improve breeding performance of livestock and poultry Selenium is essential for sperm production in male animals. Selenium in male semen can protect sperm cell membranes from damage through the antioxidant effect of GSP-Px. Adding nano-selenium to the diet can protect sperm cells from damage and improve sperm motility, thus improving fertilization ability and embryo development. Marin-guzman *et al.*[13] added 0.50 mg/kg nano-selenium to the basal diet, and found that the sperm motility, normal sperm content and fertilization rate of boars in the experimental group increased by 27.5%, 27.7% and 25.1%, respectively, compared with the control group. Gong *et al.*[14] reported that adding 0.10 mg/kg nano-selenium to the diet of laying hens with low selenium (0.015 mg/kg) could increase the laying rate by more than 75% and keep egg hatching rate above 90%.

1.5 Improve the quality of livestock and poultry products Xia *et al.*[15] studied the effect of nano-selenium on muscle quality of fattening pigs with sodium selenite as the control; the results demonstrated that the optimum Weinberg dose-response range of nano-selenium was wider than that of sodium selenite, and nano-selenium at high dose could improve the antioxidant capacity of muscle tissue and reduce the drip loss of meat, with superior selenium deposition rate of muscle than sodium selenite. Studies on broilers proved that compared with sodium biselenate, nano-selenium could better improve the antioxidant capacity of muscle tissue, reduce drip loss and improve selenium deposition in muscle when selenium was added at a high dose[16].

2 Nano-copper

Nano-copper oxide, with a particle size of 1–100 nm, has better catalytic activity, selectivity and other application properties than large-size copper powder[17]. Compared with ordinary copper oxide, it has superior properties such as surface effect, quantum size effect, volume effect and macroscopic quantum tunneling effect [18]. Nano-copper oxide shows unique physical and chemical properties in magnetism, light absorption, chemical activity, thermal resistance, catalyst and melting point [19]. The effects are mainly manifested in the following aspects.

2.1 Improve apparent digestibility Tian *et al.*[20] added 8 mg/kg copper in the form of copper sulfate, copper oxide, nano-copper oxide and nano-copper to the basal diet of 20-day-old healthy AA broilers; the results showed that compared with copper sulfate and copper oxide, adding nano-copper oxide extremely increased the apparent digestibility of copper ($P<0.01$), and adding nano-copper significantly increased the apparent digestibility of copper ($P<0.05$); adding nano-copper oxide significantly increased the apparent digestibility of zinc and manganese($P<0.05$); and adding nano-copper oxide and nano-copper had no significant impact on the apparent digestibility of crude protein ($P>0.05$), indicating that the apparent digestibility of copper of nano-copper oxide and nano-copper was significantly higher than that of copper sulfate and copper oxide, and adding nano-copper oxide could significant increase the apparent digestibility of zinc and manganese.

2.2 Improve production performance Tian *et al.*[21] added copper in different forms to the basal diet of 1-day-old healthy AA broilers, and found that adding 16 mg/kg nano-copper oxide significantly increased the daily gain and reduced the feed/gain ratio of broilers. Compared with copper sulfate, adding nano-copper in the diet had multiple functions, such as significantly improving piglet feed intake, reducing feed/gain ratio, improving the growth rate, decreasing the diarrhea rate of piglets, improving the apparent digestibility of crude protein, crude fat and calcium in weaned piglets, increasing spleen weight, significantly reducing the serum urea nitrogen values, significantly increasing the SOD activity in liver, and elevating serum GH concentration[22], as well as promoting protein synthesis and deposition and inhibiting protein degradation[23]. For growing pigs, the addition of nano-copper in the

diet tended to decrease the feed intake, probably because nano-copper was absorbed by passive diffusion in the body, which not only improved the absorption and utilization efficiency, but also reduced the need and consumption of carrier and energy and reduced the energy consumption of the body, so that lower feed intake can meet the needs of animals for various nutrients[24].

2.3 Improve immunity Nano-copper oxide can significantly improve the activity of ceruloplasmin in mouse plasma[25]. Ceruloplasmin (CP), as a scavenger of superoxide anions, can inhibit the reducing action of ferricytochrome C and reduce the generation of superoxide anion free radicals induced by this process, which has a similar effect to copper and zinc superoxide dismutase. Moreover, it significantly increases the activity of cytochrome C oxidase (CCO) and decreases the content of malondialdehyde (MDA) in plasma.

Nano-small peptide chelated copper significantly increased the contents of immune proteins IgG, IgM, IgA, insulin-like growth factor-1 (IGF-1) and interleukin-2 (IL-2) in the serum of mice, thus exerting a powerful immune-promoting effect[26]. It has been reported that compared with copper sulfate and copper oxide, adding equal amount of nano-copper oxide to the feed can improve the immune organ index of broilers. Nano-copper oxide can improve humoral immunity and cellular immunity of broilers, and the addition of nano-copper oxide can significantly improve the lymphocyte conversion rate of broilers[27]. Adding nano-copper in the diet of piglets can increase the spleen weight, significantly reduce the serum urea nitrogen value, significantly increase the SOD activity in liver and the serum GH concentration[22].

3 Nano-zinc

Nano-zinc oxide is featured by good fluidity, less additive amount, convenient use, high biological activity and absorption efficiency, and low cost in feed. Meantime, due to small amount of addition, it can reduce the antagonistic effect on other mineral elements, improve animal absorption and utilization of nitrogen by affecting the synthesis level of hormones and zinc finger protein, and reduce environmental pollution and improve the quality of livestock and poultry products[28].

3.1 Improve production performance The mechanism of zinc improving animal performance may be that high zinc stimulates the synthesis of metallothione protein (MT) in intestinal mucosa, and MT regulates zinc intake and zinc metabolism in the body, thus promoting the growth of piglets[29]. Xu *et al.*[30] suggested that there might be two reasons: (1) zinc could enhance the sensitivity of taste buds and increase appetite and; (2) zinc supplementation may increase the activity of alkaline phosphatase in saliva and carboxypeptidase A in the pancreas, thereby promoting appetite. Afterward, it was reported that the growth-promoting effect of high dose zinc on piglets seems to be a holistic effect: promote growth by increasing appetite and increasing feed intake and digestibility; improve immunity, promote the synthesis and secretion of insulin and IGF-I, and strengthen anabolism by eliminating free radicals in the body[31].

In 2009, Tian *et al.*[32] added 40 mg/kg nano-zinc oxide to the diet of 1-day-old AA broilers; compared with the blank control group, the feed consumption and feed/gain ratio of broilers in the addition group were significantly reduced, and the slaughter rate and semi-eviscerated rate were significantly increased, thus playing a role in improving growth and slaughter performance. Wang *et al.*[33] showed that nano-zinc oxide could significantly increase the daily gain of piglets by more than 10%, significantly reduce the feed/gain ratio and diarrhea rate, and achieve better economic benefits than ordinary zinc oxide. Liao *et al.*[34] showed that the daily gain, feed/gain ratio and diarrhea rate of piglets supplemented with 300 mg/kg nano zinc oxide reached or exceeded the effect of 3 000 mg/kg zinc oxide. Yu *et al.*[35] found that nano-zinc oxide significantly increased the daily gain and reduced the diarrhea rate of piglets.

3.2 Improve immunity Nano zinc oxide promoted the growth of duodenum and jejunum epithelial cells in mice and improved their antioxidant capacity, but high concentration had the opposite effect[36]. Xu *et al.*[37] showed that dietary supplementation of 40 mg/kg nano zinc oxide had no effect on serum zinc content and activities of GLU, AKP, AST and ALT in broilers; and supplementation of 200 mg/kg nano zinc oxide rice increased the serum zinc content of broilers; supplementation of 80 and 200 mg/kg nano zinc oxide affected serum glutamic oxalacetic transaminase activity and cholesterol content of broilers. Tian *et al.*[37] found that nano zinc oxide played an important role in improving the activity of glutathione peroxidase (GSH-Px) in serum, increasing the total antioxidant capacity (T-AOC), reducing the production of nitric oxide (NO) in serum and improving the activity of catalase (CAT) in liver tissue of broilers, thus significantly improving the antioxidant performance of the body, enhancing the activity of antioxidant enzyme and reducing the production of free radicals.

4 Nano-chromium

It has been reported that the effects of nano-chromium on the body are mainly manifested in improving production performance and feed utilization rate, improving carcass composition, reducing the impact of slaughter, transportation and

other stress on meat quality, improving the levels of growth hormone, insulin-like growth factor and other hormones, and improving body immunity[38]. Gu *et al*.[39] found that nano-chromium treatment increased the daily gain of SD rats by 12.68%, the feed utilization rate by 32.92% and the lean meat weight by 15.11%, and decreased the fat percentage by 24.42%; the levels of insulin, glucose, urea nitrogen and triglyceride in serum were reduced by 45.38%, 31.84%, 48.75% and 38.46%, respectively, compared with the control group; these results suggested that nano-chromium could promote the growth of rats and improve the carcass composition. Shen *et al*.[40] proved that compared with the group with the same dose of chromium chloride, feeding fattening pigs with nano-chromium significantly improved the carcass quality by improving the carcass lean meat percentage by 7.10%, decreasing the fat percentage by 26.57%, increasing the longissimus dorsi muscle area by 20.22%, and decreasing the 24 h drip loss by 21.48%.

5 Prospects

Currently, nanotechnology is on the eve of a major breakthrough. It has made a series of achievements that have shocked the world, and scientists predict that nanotechnology will lead to another industrial revolution in the 21st century. Nano feed additives can improve and solve the common problems of high dose of feed additives, high dose intake, low absorption efficiency, nitrogen source pollution and poor stability in animal breeding, and further increase the nutrient absorption rate, which is of great significance for promoting the growth and development of animals, improving the quality of animal products, increasing the comprehensive economic benefits of feed and breeding production, and protecting the environment.

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