Nano Plus: Sci. Technol. Nanomat. 8 (2024) 61-71
10.36108/stnanomat/4202.80.0110

Nano Plus: Science and Technology of Nanomaterials
Journal home page: https://www.stnanojournal.org/
ISSN: 2782-8166 (print) 2782-8174 (electronic)

Applications of Nanotechnology in Animal nutrition: A Review

[1*]Idowu, A. O., [1]Ojebiyi, O. O., [2]Lateef, A., [1]Odunsi, A. A., [1]Ola, A.K. and [1]Akinola, A. O.

[1]Department of Animal Nutrition and Biotechnology, Ladoke Akintola University of Technology, PMB 4000, Ogbomoso, Nigeria
[2]Department of Pure and Applied Biology, Ladoke Akintola University of Technology, PMB 4000, Ogbomoso, Nigeria.

Article info

Received: Sep 28, 2023
Revised: May 2, 2024
Accepted: May 10, 2024

Keywords:
Nanotechnology, Nanoparticles, animal nutrition, synthetic antibiotics, additives

Abstract

Nanoparticles are commonly used in human medicine but their applications in agriculture, animal nutrition and veterinary medicine are quite new. To meet the increasing demands on the livestock industry, synthetic antibiotics are the major substances that are used as growth promoters. However, the use of antibiotics as feed additives is risky due to cross-resistance among bacterial strains and residues in tissues of the animals which could be deposited in man after consumption of animal tissues. Thus, the use of most synthetic antibiotics has been banned in many countries in the world, leading to a reduction in usage and the search for alternative growth promoters with minimal or no residual effect has been intense in recent times. Many reports have suggested that nanoparticles may be good substances for animal growth promotion and antimicrobials because some nanomaterials can remove toxins and pathogens. They can also be better absorbed by animals thereby improving their performance and the quality of products obtained. Nanotechnology has the potential to transform the livestock sector because of better bioavailability, small dose rate, and stable interaction of the nanomaterials with other components. Therefore, the use of nanoparticles is a good alternate approach that is safe and cost-effective for the control of pathogenic microbes and production improvement in livestock. In view of recent developments, this review was undertaken to discuss issues relating to the use of nanomaterials in animal feeds.

1. Introduction

Nanotechnology is a new scientific approach that studies the control of matter on an atomic and molecular scale [1]. According to Sah *et al.* [2], Nanotechnology involves developing materials or devices on the nanometer scale, and helps to use materials and equipment at molecular levels that are capable of showing both the physical and chemical properties of a substance. Nanotechnology encompasses synthesis, design, characterization, and applications of materials, instruments and systems through the manipulation of shapes and sizes at the nanoscale [3].

Nanomaterials are defined as materials that are smaller than micrometric scales and exhibit specific properties [4]. The size varies from 1 to 100 nm with a large surface area that gives unique features to nanomaterials and this property offers enormous applications in various fields [5]. Nanoparticles are the significant parts of nanotechnology that play outstanding functions in spreading the cutting-edge applications of this budding field [6]. Nanoparticles have been used as diagnostic and therapeutic agents in the human medical field for some

Corresponding author: oyeyemiidowu11@gmail.com

time but their application in agriculture especially animal nutrition is still relatively new.

Agriculture is the backbone of several countries in the world because the majority of the population is dependent on it for survival [7]. Therefore, there is a need to use nanotechnology to improve animal production and crop productivity, processing of foods and thereby reducing food insecurity [8]. Nanotechnology interventions as applied to agriculture, especially animal production fields are very important in developing countries like Nigeria because in a few years to come, the livestock sector will face a lot of challenges with increasing population and reduced land area. However, these issues can be overcome by introducing nanotechnology to improve animal nutrition and productivity.

Nanosensors, nanomaterials, microfluidics, and bioanalytical are nanotechnology devices that are used to improve various conditions related to animal health, production, reproduction, treatment, and prevention of diseases [9,10]. Trace minerals in the form of nanoparticles are effectively used to fulfill the requirements for minerals in poultry diets [11, 12]. Consequent upon better bioavailability, small dose rate, and stable interaction with other components [13], some nanomaterials can serve as antitoxins and antimicrobials.

For instance, silver nanoparticles exhibit a strong antimicrobial effect [14, 15, 16]. Also, nano-selenium, nano-chromium and nano-zinc improve the livestock's performance, their healthiness, and the quality of products obtained from them [17]. However, the use of antibiotics at low levels in animal production is a common practice to improve feed efficiency, improve growth performance, prevent some specific pathogenic microorganisms, and increase some useful microorganisms in intestinal microflora [18, 19].

The use of antibiotics has been banned in some countries because of the potential development of antibiotic-resistant bacteria and their residues in animal products. According to Vinus [20], the routine use of antibiotics in animal production systems can leave a residue in the products that reach the final consumer, although there is a variable withdrawal period before the products of treated animals can be placed into the market, but this period is not always valued. However, with the use of nanotechnology, the amount of antibiotics used can be greatly reduced.

Nutritionists are therefore exploring alternatives such as medicinal plants, probiotics, prebiotics and organic acids as substitutes for antibiotics. Additives from nanotechnology in animal nutrition are potentially enhancing the production [21]. The use of nanoparticles is a good alternate and effective approach that is safe and cost-effective for the control of pathogenic microbes and production improvement in livestock [22].

Nanotechnology can make livestock production cost-effective [23]. Nanoparticle incorporation in animal nutrition studies greatly enhances the efficiency of growth and production [24]. There is increased awareness of the application of nanotechnology with the use of various compounds in diets (such as sodium oxide, magnesium oxide, aluminum oxide, silicon oxide, potassium oxide, calcium oxide, tin oxide and iron oxide) as supplemental sources of trace minerals [25].

Nanoform supplementation increases the surface area leading to increased absorption and utilization of minerals with a reduction in the quantity of supplements and ultimately reduction in feed cost. Nanotechnology application in animal nutrition can be used to achieve several goals which include obtaining information on a nutrient or bioactive component, its liberation in specific sites of action, greater availability, maintenance of adequate levels for longer periods, and avoiding its degradation [26], which will ultimately reduce stress in animal handling.

Minerals are one of the most widely used supplements in animal nutrition but the form in which they are presented usually influences their bioavailability. Ferrous sulphate is one of the most bioavailable sources of iron but can impact a metallic taste in food and accelerate the oxidation process of fats in cereals making them rancid [27]. The alternative is ferric phosphate ($FePO_4$) which is more stable but less available. To solve this problem, Rohner *et al*. [28] developed highly available nanoparticles of ferric phosphate, demonstrating that at a nanoscale this source can increase its nutritional value without impacting any metallic taste in food.

2.1 Poultry

The growing concerns about the potential contribution of phosphorus in poultry excreta on the eutrophication of surface waters have led to increasing pressure to limit the quantity of excess phosphorus in poultry diets and thus reduce the fecal output of phosphorus. Mineral nanoparticles will help to reduce the excretion of unutilized minerals minimizing environmental pollution, especially in large-scale poultry farming [19].

Tatli *et al.,* [30] reported that an in-ovo-injection of nano-silver during incubation had shown improved bone mineral concentration and cell-mediated immunity at the 14th and 21st day of age, respectively. Also, the immune response was higher in nano-silver-treated eggs than in the control. In general, injection of nano-silver, thyme and savory extracts into eggs during embryonic development has great potential to improve the immune activities of broiler chickens without affecting the embryo and its hatchability [46].

Nano-silver increases levels of blood alkaline phosphatase which is associated with bone formation in chicken [30]. Grodzik and Sawosz [50] considered the microbial effect of silver nanoparticles in chicken embryos and reported that the particles did not affect embryo development but reduced the number and size of lymph follicles of the bursa of Fabricius. In broiler chicken, supplementation of 1.20 mg/kg Nano-Se showed a wider range between the optimal and toxic dietary levels of Nano-Se with efficient retention in the body compared to sodium selenite. Also, addition of nano-Se to the broiler diet showed an increase in survival rate, average daily gain and feed-to-gain ratio with 0.15-1.20 mg/kg Se concentration [51].

In layer chicks, nano-Se of 0.3 mg/kg of diet was found to have better physiological effects [52]. Nano zinc supplementation of 0.06 ppm in the basal diet of broiler birds improved immune status and bioavailability compared to inorganic zinc [53]. Moreover, different concentrations of ZnO-nanoparticles inhibited the growth of mycotoxic fungi (*Aspergillus flavus*, *A. ochraceus* and *A. niger*), hence the method can be used for feed treatment to reduce the potential hazards of mycotoxicosis [54]. The feed conversion ratio was improved in broiler birds fed with nano form of calcium phosphate by replacing up to 50% requirement of dicalcium phosphate [55]. Ahmadi *et al*. [39] conducted an experiment in which nano-selenium was added to the feed provided *ad libitum* to 180 Ross chicks that were divided into 6 groups with 10 birds each and 3 replicates of the group. Supplementation has significantly ($P < 0.05$) improved weight gain and feed conversion ratio during the entire experiment.

Mahmoud *et al*. [52] used nanoselenium supplementation in feeding thirty-six 15-day-old broiler chicks. Chickens were kept at temperatures of either 22 ± 1°C or 35 ± 1°C. Chickens' diets were supplemented for 15 days with 0.3 mg/kg of nano-selenium. The authors reported that high ambient temperature significantly depressed body weight gain, feed intake and feed conversion ratio, while feeding nanoselenium significantly ($P < 0.05$) reduced these negative effects of high ambient temperature; in comparison with the control group without nanoselenium supplementation.

Nanosilver as a microbicidal preparation reduced the number of *Escherichia coli*, Streptococcus bacteria, harmful Salmonella and a total number of mesophilic bacteria in the litter [14]. Andi *et al*. [56] reported im-

Fig. 1: The uses of Nanotechnology in Animal Nutrition

provement in feed intake, weight gain and feed efficiency of broilers fed nanosilver nanoparticles due to the influence of ionic silver on intestinal harmful bacteria and improved gut health and consequently better nutrient absorption. However, Loghman *et al*. [57] observed that higher levels of nanosilver (8 and 12 ppm) may induce severe lesions in the broiler's liver.

2.2 Egg

Salah *et al*. [32] reported that egg yolk stored at room temperature for 15 days from hens receiving nano-selenium has higher activity of glutathione peroxidase and lower malondialdehyde content. The addition of nano selenium also improved the fatty acid profile in eggs by reducing the ratio of saturated to unsaturated fatty acids and also it significantly decreased the level of total lipids and total cholesterol, as well as increased the level of its high-density lipoprotein fraction in egg yolk and plasma of laying hens.

In a study conducted by Olgun and Yildiz [33], the effect of different doses of dietary forms of zinc on egg production efficiency, egg quality, and bone characteristics in laying hens was determined. Zinc was given in four forms; zinc sulphate, zinc oxide in inorganic form, zinc-glycine in organic form and powder of nano-zinc oxide in various doses (50, 75, and 100 mg/kg of feed). The addition of zinc-glycine significantly reduced egg mass and feed conversion ratio compared with the zinc sulphate group. Supplementation of nano -zinc oxide in the amount of 100 mg/kg of feed significantly reduced the thickness of the eggshell but had the highest egg mass. This study also showed that the addition of nano-zinc adversely affects bone mechanical properties.

Abedini *et al.* [34] studied the effect of zinc oxide (ZnO-NP) nanoparticles on yield, egg quality, zinc content in tissues, bone parameters, superoxide dismutase activity, and malondialdehyde content in laying hens. All groups receiving zinc oxide nanoparticles were characterized by a better Haugh index, higher egg mass, thicker eggshell and higher content of zinc in the plasma, tibia, liver, pancreas, and egg compared with the control group. Supplementation of zinc oxide also increased the activity of superoxide dismutase in the liver, pancreas and plasma of the birds. However, malondialdehyde content was reduced in the eggs of birds receiving the addition of zinc oxide. Sirirat *et al* [35] reported that the use of chromium picolinate nanoparticles significantly improves egg quality, and increases the accumulation of chromium, calcium, and phosphorus in the liver, yolk and eggshell in laying birds.

In an experiment conducted on Japanese quail by Amiri *et al.* [36], it was revealed that supplementing the feed with nano-chromium increases egg weight, yolk mass, dense protein height, protein mass, shell thickness, and the Haugh index. However, it did not increase the chromium content in the egg and blood of the birds. Sathyabama *et al* [37] studied the effect of different chromium forms and levels on egg quality, it was revealed that eggs from chickens receiving the addition of nano-chromium at 200 μg/kg and organic chromium at 400 μg/kg of feed were characterized with stronger shell strength than eggs of hens from the control group and those receiving chromium in an inorganic form. But other egg qualities parameters were not affected.

2.3 Meat quality and composition

Meat quality is always on constant rise, both in terms of its nutritious and organoleptic properties [58]. Because of this, the livestock industry is searching for new ways to improve the overall quality of the meat. One of the recently developed ways is biofortification with the utilization of nanotechnology which has shown positive effects on the properties of meat. Ahmadi *et al.* [39] reported that breast and drumstick percentages were significantly higher ($P < 0.05$) in chicks with nano-selenium supplementation than in the control group. Also, abdominal fat percentage was significantly ($P < 0.05$) lower in the nano-selenium-supplemented group than in the control. Bakhshalinejad *et al.* [66] investigated the effects of sodium selenite, selenium-enriched yeast, DL-selenomethionine, and nano-selenium addition to the feed from 0.1 to 0.4 mg/kg Se. In the case of breast muscles, significant differences were observed in total superoxide dismutase activity, total antioxidant capacity, and malondialdehyde levels after comparing nano-selenium with sodium selenite. Different sources and levels of selenium had no impact on major thigh muscle composition. Selenium content of thigh muscle was affected by sources of supplemental selenium and levels ($P < 0.001$).

Cai *et al.* [42] investigated the effect of nano-selenium on performance, meat quality, immune function, oxidation resistance and tissue selenium content in broilers. Nano-selenium supplementation was used as follows 0.0, 0.3, 0.5, 1, and 2 mg/kg. No significant difference was observed in the meat colour. After 42 days, a significant effect of supplementation has been observed on peroxidase activity in serum, liver, and muscles; free radical inhibition in serum and liver. It was suggested that the optimal level of supplementation lies between 0.3 and 0.5 mg/kg of nano-selenium, and that supplementation should not exceed 1 mg/kg nano-selenium with the worst parameters received at 2 mg/kg of selenium supplementation.

Li *et al.* [60] conducted an experiment where three hundred and sixty-day-old Chinese Subei male chickens were randomly allocated into four groups. Chickens in each group were fed with feed containing 0.3 mg Se/kg of the following enrichments: sodium selenite, selenium-enriched yeast, selenomethionine, and nano-selenium for 40 days. Dietary selenium-enriched yeast, selenomethionine, and nano-selenium supplementation increased the activity of glutathione peroxidase in serum and breast muscles and decreased the concentration of malondialdehyde in serum and carbonyl in breast muscles compared with the sodium selenite group ($P < 0.05$). Additionally, selenomethionine and nano-selenium supplementation increased pH, total protein solubility, and myofibrillar protein solubility, as well as significantly ($P < 0.05$) decreased the shear force value compared with the group enriched with sodium selenite. Chickens in the selenium-enriched yeast and selenomethionine groups exhibited significantly ($P < 0.05$) lower cooking loss compared with the sodium selenite group. In conclusion, nano-selenium has significantly improved the quality of chicken meat.

Liu *et al* [61] examined the effects of corn -soybean diet supplementation with sodium selenite, nano-elemental selenium, and enriched yeast A and B on 250 chicks that were divided into 5 groups with 5 replicates each. The obtained results have shown that there were no significant ($P > 0.05$) differences between each treatment in terms of growth performance. Selenium-enriched yeast B significantly ($P < 0.05$) increased selenium concentration in the liver and breast muscles in comparison with other diets. No significant ($P > 0.66$) differences were observed in the liver and breast muscle Se concentrations between other utilized enrichments. Selim *et al* [44] have used 400 one-day-old Arbor Acres chickens that were allocated in 10 experimental treatments, with 5 sources of Se, namely, sodium selenite, selenomethionine, zinc-L-selenomethionine, powder form of nano-selenium, and liquid form of nano-selenium; additionally, two levels of supplementation were used, 0.15 and 0.3 ppm. Feeding was in three phases: 1–10, 11–24, and 24–50 days. Results of the experiment showed that selenomethionine, zinc-L-selenomethionine, nano-selenium powder, and liquid form of nano-selenium at level 0.30 ppm significantly ($P < 0.05$) improved the growth performance, oxidation levels, carcass abdominal fat %, giblets % and Se concentrations in both muscles and the liver. The study concluded that further researches on Se-based feed enrichments are still needed.

Zhou and Wang [46] conducted an experiment to investigate the effect of feed supplementation with nano-selenium on growth performance, tissue Se distribution, meat quality, and glutathione peroxidase (GSHPx) activity in 360 Guangxi Yellow chickens. During the experiment, 3 treatment groups with 30 chickens in each were used with 3 replicates. Diets for the control, T1, T2, and T3 groups consisted of unmodified feed without addition (0.00) and enriched feeds (0.10, 0.30, and 0.50 mg/kg) of nano-selenium. Groups receiving nanoselenium supplementation showed higher ($P < 0.05$) hepatic and muscle Se contents, drip loss percentage, inosine 5′-monophosphate content, and GSHPx activities in the serum and liver in comparison with the control group. For the T2 and T3 groups, growth, muscle Se content, breast drip loss, and GSHPx activities in the serum and liver were significantly improved ($P < 0.05$) compared with the T1 group. No significant differences were observed in GSHPx activities in the serum and liver between the T2 and T3 groups. It was concluded that supplementation of diet with 0.30 mg/kg of nano-Se was the most effective in increasing the Se content of tissues and the quality of the meat.

Liu *et al.* [40] performed an 8-week feeding trial to investigate the effects of feed enrichment with sodium selenite, selenium nanoparticle (nano-Se) and selenium yeast (Se-yeast). Sodium selenite and selenium nanoparticles were supplemented at 0.2 mg/kg Se, and selenium yeast (Se-yeast) was supplemented at 0.1, 0.2, 0.4, and 0.8 mg/kg in the basal diet; no Se was added to the control. The following parameters were analyzed: growth, selenium status, antioxidant activities, muscle composition, and meat quality of blunt snout bream. The results have shown that groups of 0.2 and 0.4 mg/kg Se-yeast had significantly ($P < 0.05$) higher weight gain and nano-Se 0.2 and 0.4 mg/kg Se-yeast had significantly lower feed conversation ratio when compared with the control group.

The Se concentrations of the whole body, muscle, and liver linearly increased with increasing dietary Se-yeast levels. The group of 0.4 mg/kg Se-yeast significantly increased activities of catalase and glutathione peroxidase. Muscle colour of nano-Se, 0.2 and 0.4 mg/kg. Se-yeast groups and the water holding capacity of 0.4 and 0.8 mg/kg Se-yeast groups were significantly better ($P < 0.05$) compared with the control group. The authors concluded that supplementing Se-yeast and nano-Se in the diet improved the meat quality of blunt snout bream at 0.2 mg/kg Se.

2.4 Ruminants

Supplementation of nano-selenium at the rate of 3 ppm in sheep basal diet significantly decreased the ruminal pH, and ammonia concentration and increased total VFA concentration. Also, there was an improvement in nutrient utilization and urinary excretion of purine derivatives [45]. Similarly, dietary supplementation of nano-selenium in male goats

Table 1: Application of Nanotechnology in Animal nutrition

Nanoparticle used	Animal	Level of inclusion	Impact/Effect	References
Calcium carbonate	Laying hen	0.5-1.5g/kg	Improved eggshell thickness and shell weight percentage	[29]
Silver	incubated egg	7.09-18.1nm	Reduction in the eggshell microbial count without affecting the hatchability percentage	[30], [31]
Selenium-methionine	Laying hen	0.3mg/kg	Increase egg mass	[32]
Zinc oxide	Laying hen	100mg/kg	Increase egg mass but reduce the thickness of eggshell	[33]
Zinc oxide	Laying hen	40-120mg/kg	Better haugh index but above 80mg reduced the egg mass	[34]
Chromium picolinate	Laying hen		Improve egg quality, increase the accumulation of Cr, Ca and P in the liver, yolk and eggshell	[35]
Chromium	Japanese quail	200-800ppb	Increase egg weight, yolk mass, shell thickness and haugh index	[36]
Chromium	Laying hen	200µg/kg	Thicker shell strength	[37]
Calcium carbonate	Laying hen	0.126-2.015%	No effect on egg weight, feed conversion rate and haugh index but lower egg production in group that received 0.126%	[38]
Selenium	Broiler		Improved weight gain, feed conversion rate, increase breast and drumsticks percentage and lowered abdominal fat percentage	[39]
Selenium	Broiler	0.3mg/kg	Improved growth performance, oxidation level, abdominal fat percentage and the meat quality. It reduced the negative effects of high ambient temperature.	[40],[41],[42], [43]
Zinc	Dairy cow	40-69.6mg/kg	Improved milk production	[44],[17]
Selenium	Sheep	3ppm	Improved nutrient utilization, decrease the ruminal PH and Ammonia concentration	[45],[46]
Selenium	Goat	0.3ppm	Improved weight gain and fertility	[47]
Selenium	Cow	0.3mg/kg	Improved milk production	[47]
Silver	Pig	100mg	Promote growth and improve health status	[14]
Chromium	Pig	200mg	Improved growth performance, Reduced the level of glucose and cholesterol in serum	[48]

at the rate of 0.3 ppm revealed an increase in the final body weight and average daily weight. Whole blood, serum, tissue selenium concentration and serum antioxidant enzyme activity were also improved. With respect to the fertility in male goats, supplementation of 0.3mg/kg of nano-Se (60-80 nm) improved the testicular microstructure, testicular spermatozoa ultramicroscopic structure, testicular glutathione peroxides activity and semen quality [46].

Romero-Perez *et al* [45] assessed the oral use of *in vitro* sodium selenite nanoparticles in ruminants using copolymers of methacrylate, which yielded positive results on their performance. Nanostructures have been used to develop immunosensors that are capable of detecting the concentration of progesterone in cow milk and hence help in the detection of ovulation in cows [62].

2.5 Milk quality and composition

In developing countries, there has been an increase in demand for dairy products. This is because milk is a good source of nutrients, and its consumption affects the health and well-being of people. Korczynski *et al.* [63] stated that on average, about 88.5% of water, 11.5% of dry matter, 4.7% of lactose, 3.7% of fat, and 3.7% of protein can be found in cow's milk, that is why it is so important to use preparations with high bioavailability like nanominerals that will not alter the milk quality and composition.

Several studies have been carried out regarding the use of nanominerals in ruminant nutrition to check how nanominerals affect animal health, digestibility of feed ingredients and reduction of odours [46, 44]. Rajendran *et al.* [17] used nano-zinc in feeding dairy cows. Their research has shown that the use of nanomineral reduces the number of somatic cells in cow's milk with subclinical mastitis and also improves milk production compared with conventional sources of zinc.

2.6 Pigs

Silver NPs and Cu-montmorillonite NPs were used as feed additives to increase the average daily weight gain of pigs [30, 14]. The administration of copper and zinc as growth promoters in pigs were reported to improve animal health status [64, 65]. The use of nanotechnology permits a specific administration of microminerals avoiding their excessive use, which could lead to toxic effects for animals, consumers and the environment [14].

Dietary supplementation of chromium (Cr) as chromium nanocomposite (CrNano) at the rate of 200 mg in finishing pigs reduced serum levels of glucose, urea nitrogen, triglyceride, cholesterol and non-esterified fatty acid. In contrast, serum levels of total protein, high-density lipoprotein and lipase activity were increased. The CrNano also had appreciable effects on carcass characteristics, pork quality, skeletal muscle mass and increased tissue chromium concentration in selected muscles and organs [48].

In piglets, supplementation of nano copper (Cu) at the rate of 50 ppm improved growth performance, reduced feacal copper level and significantly improved copper availability as compared to the conventional copper sulphate ($CuSO_4$). In addition, significant improvements in the digestibility of crude fat and energy were observed in pigs under nano Cu diet. Supplementation of metallic silver nanoparticles of 20 and 40 ppm as antimicrobial and growth promoters during the transition phase (5-20 kg weight) of weaned piglets resulted in Coliform reduction in ileal contents. Besides, the concentration of the pathogen *Clostridium perfringens* or *Clostridium histolyticum* group in the ileum was reduced with 20 ppm silver [30].

3. Conclusion

Nanotechnology is in constant development and its applications are both varied and specific, with a high potential for improving livestock production, and animal health. Although there may be concern about biosafety and toxicity, immense research is still needed to support its efficiency, avoiding any harm to animals, humans and the environment. Further investigations are necessary to reassure the consumer, fill the knowledge gap about nano-toxicity and at the same time improve the risk assessment and evaluate their potential economic advantages, especially in animal husbandry. However, it can be concluded that micro and macroelements in the form of nanoparticles can be better absorbed by animals, which improves the quality of products obtained from them and excess mineral components can be as dangerous as their deficiency.

Therefore, it should be considered whether the enrichment of animal products with the aid of feed supplementation with various levels and forms of minerals will consequently be safe for human health and life, especially since no concrete proposal of the optimal level of nanomaterials used in animal nutrition has emerged. Also, it should be remembered that their use does not always bring the intended effect. Sometimes, it turns out that inorganic and organic forms of minerals are better absorbed and the use of nanoforms sometimes negatively affects the production parameters of farm animals. Therefore, despite many promising results, the study on the use of nanomaterials should be continued.

References

[1] Meena, N.S., Sahni, Y.P., Thakur, D. and Singh, R.P. (2018). Applications of nanotechnology in veterinary therapeutics. *Journal of Entomology and Zoology Studies*, 6(2):167-175. www.entomoljournal.com

[2] Sah, S.K., Kaur, A. and Wani, S. (2014). Nanobiotechnology: changing horizons of science. *Biolife*, 2(3):905-916. www.biolifejournal.com

[3] Elegbede, J.A. and Lateef, A. (2019). Green Nanotechnology in Nigeria: the Research Landscape, challenges and Prospects. *Annals of Science and Technology*, 4(2):6-38. https://doi.org/10.2478/ast-2019-0008

[4] Miller, G. and Senjen, R. (2008). "Out of the laboratory and onto our plates: nanotechnology in food and agriculture," in A report prepared for Friends of the Earth Australia, Friends of the Earth Europe and Friends of the Earth United States and supported by Friends of the Earth Germany, Friends of the Earth Australia Nanotechnology Project, Australia. http://nano.foe.org.au

[5] Khan, M., Tufenkji, N., and White, J.C. (2019). Nano-enabled strategies to enhance crop nutrition and protection. *Nature Nanotechnology*, 14:532–540. https://doi.org/10.1038/s41565-019-0439-5

[6] Lateef, A., Ojo, S.A., Elegbede, J.A., Akinola, P.O. and Akanni, E.O. (2018). Nanomedical applications of nanoparticles for blood coagulation disorders. *Environmental Nanotechnology,* 1: 243-277. https://doi:10.1007/978-3-319-76090-2-8

[7] Kanianska, R. (2016). Agriculture and its impact on land use, environment and ecosystem services. Landscape ecology-The influences of land use and anthropogenic impacts of landscape creation (pp 1-26). Amjad Almusaed, IntechOpen. https://doi.org/10.5772/63719

[8] Marchiol, L. (2018). Nanotechnology in agriculture: new opportunities and perspectives. In book: New Visions in Plant Science, pp.121-141. https://doi.org/10.5772/intechopen.74425

[9] Kroubi, M., Daulouede, S., Karembe, H., Jallouli, Y., Howsam, M. and Mossalayi, D. (2010). Development of a nanoparticulate formulation of diminazene to treat African trypanosomiasis. *Nanotechnology,* 21(50):505102. https://doi:10.1088/0957-4484/21/50/505102

[10] Tarafdar, J., Sharma, S. and Raliya, R. (2013). Nanotechnology: Interdisciplinary science of applications. *African Journal of Biotechnology*, 12 (3):219-226. https://doi.org/10.5897/AJB12.2481

[11] Sekhon, B.S. (2014). Nanotechnology in agri-food production: An overview. *Nanotechnology, Science and Application*, 7:31-53. https://doi.org/10.2147/NSA.S39406

[12] Muktar, Y., Bikila, T. and Keffale, M. (2015). Application of nanotechnology for animal health and production improvement: A review. *World Applied Science Journal*; 33(10):1588-1596. https://doi.org/10.5829/idosi.wasj.2015.33.10.96253

[13] Verma, A.K, Singh V. and Vikas, P. (2012). Application of nanotechnology as a tool in animal products processing and marketing: An overview. *America Journal of Food Technology*, 7(8): 445-451. https://doi.org/10.3923/ajft.2012.445.451

[14] Fondevila, M., Herrer, R., Casallas, M.C., Abecia, L. and Ducha, J.J. (2009). Silver nanoparticles as a potential antimicrobial additive for weaned pigs. *Animal Feed Science and Technology*, 150(3):259-269. https://doi:10.1016/j.anifeedsci.2008.09.003

[15] Fondevila, M. (2010). Potential Use of Silver Nanoparticles as an Additive in Animal Feeding: *Silver Nanoparticles*, InTech, Mountain View, CA, USA. https://doi:10.5772/8509

[16] Pineda, L., Sawosz, E. and Lauridsen, C. (2012). Influence of in ovo injection and subsequent provision of silver nanoparticles on growth performance, microbial profile, and immune status of broiler chickens," *Open Access Animal Physiology*, 4:1-8. https://doi.org/10.2147/OAAP.S35100

[17] Rajendran, D. Kumar, G., Ramakrishnan, ` S. and Omas, K. S. (2013). Enhancing the milk production and immunity in Holstein Fresian crossbred cow by supplementing novel nano zinc oxide, *Research Journal of Biotechnology*, 8(5):11-17.

[18] El Saby, M.I., McMillin, K.W. and Sabliov, C.M. (2018). Nanotechnology considerations for poultry and livestock production systems–a review. *Annals of Animal Science Journal*, 18(2): 319-334. https://doi:org/10.1515/aoas-2017-0047

[19] Vinus, S.N. (2017). Role of nanotechnology in poultry nutrition. *International Journal of Pure and Applied Bioscience*, 5:1237-1245. https://doi.org/10.18782/2320-7051.5948

[20] Monica, R.M. and Omar, H.M. (2010). Nanotechnology on Animal Production. *Tropical and Subtropical Agroecosystem*, 12:423-429. http://www.redalyc.org/articulo.oa?id=93915170002

[21] Mohapatra, P., Swain, R.K., Mishra, S.K., Behera, T., Swain, P., Behura, N., Sahoo, G.R., Sethy, K., Bhol, B.P. and Dhama, K. (2014). Effects of dietary nano-selenium supplementation on the performance of layer grower birds. *Asian Journal of Animal and Veterinary Advances*, 9(10):641-652. https://doi.org/10.3923/ajava.2014.641.652

[22] Kumar, V. and Yadav, S.K. (2009). Plant-mediated synthesis of silver and gold nanoparticles and their applications. *Journal of Chemical Technology and Biotechnology*, 84(2):151-157. https://doi.org/10.1002/jctb.2023

[23] Liao, C.D., Hung, W.L., Jan, K.C., Yeh, A.I., Ho, C.T. and Hwang, L.S. (2009). Nano/sub-microsized lignan glycosides from sesame meal exhibit higher transport and absorption efficiency in Caco-2 cell monolayer. *Food Chemistry*, 119(3): 896-902. https://doi:10.1016/j.foodchem.2009.07.056

[24] Weiss, J., Gibis, M., Schuh, V. and Salminen, H. (2010) Advances in ingredients and processing systems for meat and meat products. *Meat Sc*ience, 86(1):196-213. https://doi.org/10.1016/j.meatsci.2010.05.008

[25] Sekhon, B.S. (2014). Nanotechnology in agri-food production: An overview. *Nanotechnology, Science and Application*, 7:31-53. https://doi.org/10.2147/NSA.S39406

[26] Ross, S.A., Srinivas, P.R., Clifford, A.J., Lee, S.C., Philbert, M.A. and Hettich, R.L. (2004). New technologies for nutrition research. *Journal of Nutrition*. 134:681-685. https://doi.org/10.1093/jn/134.3.681

[27] Hurrell, R. (2002). Fortification: Overcoming Technical and practical barriers. *Journal of Nutrition,* 132(4):806-812. https://doi:10.1093/

jn/132.4.806S

[28] Rohner, F., Ernst, F., Arnold, M., Hilbe, M., Biebinger, R., Ehrensperger, F., Pratsinis, S., Langhans, W., Hurrell, R., Zimmermann, M. (2007). Synthesis, characterization, and biodisponibility in rats of ferric phosphate nanoparticles. *Journal of Nutrition*, 137(3):614-619. https://doi.org/10.1093/jn/137.3.614

[29] El-Maaty, H.A., El-Khateeb, A.Y., Al-Khalaifah, H., El-Hameed E.A., Hamed, S., El-Said, E.A., Mahrose, K.M. Metwally, K. and Mansour, A.M. (2021). Effects of ecofriendly synthesized calcium nanoparticles with biocompatible *Sargassum latifolium* algae extract supplementation on egg quality and scanning electron microscopy images of the eggshell of aged laying hens. *Poultry Science Journal*, 100(2):675-684. https://doi:10.1016/j.psj.2020.10.043

[30] Tatli, S.P., Seven, I., Gul, B.B., Iflazoglu M.S., and Salem, A.Z. (2018). Nanotechnology and nanopropolis in animal production and health: an overview. *Italian Journal of Animal Science*, 17(4): 921 -930. https://doi.org/10.1080/1828051X.2018.1448726

[31] Hamouda, N.H., Saleh, N.F. and Sabry, M.I. (2023). Benefits and risks of using bacterial and plant produced nano-silver for Japanese quail hatching egg sanitation. *Archives of Microbiology*, 205(6):228. https://doi:10.1007/s00203-023-03547-3

[32] Salah, E.T.A., Hamady, G.A.A., Abdel-Moneim, M.A., Farroh, K.Y. and El-Raffaei, W.H.M. (2015). Nutritional evaluation of selenium-methionine nanocomposite as a novel dietary supplement for laying hens, *Journal of Animal Health and Production*, 3(3):64-72. https://doi.org/10.14737/journal.jahp/2015/3.3.64.72

[33] Olgun, O. and Yildiz, A.O. (2017). Effects of dietary supplementation of inorganic, organic or nano zinc forms on performance, eggshell quality, and bone characteristics in laying hens," *Annals of Animal Science*, 17(2):463-476. https://doi.org/10.1515/aoas-2016-0055

[34] Abedini, M., Shariatmadari, F., Torshizi, M.A.K. and Ahmadi, H. (2018). Effects of zinc oxide nanoparticles on egg quality, immune response, zinc retention and blood parameters of laying hens in the late phase of production. *Journal of animal physiology and animal nutrition*, 102(3):736-745. https://doi.org/10.1111/jpn.12871

[35] Sirirat, N., Lu, J.J., Hung, A.T.Y. and Lien, T.F. (2013). Effect of different levels of nanoparticles chromium picolinate supplementation on performance, egg quality, mineral retention and tissues minerals accumulation in layer chickens. *Journal of Agricultural Science*, 5:(2):150-159. https://doi.org/10.5539/jas.v5n2p150

[36] Amiri, A.M. and Shahamat, A. (2015). Effects of deferent levels of nano chromium chloride in diet on egg quality on blood chromium content of laying Japanese quail. *Journal of Advanced Biological and Biomedical Research*, 3(4):378-383. https://doi.org/10.18869/IJABBR.2015.378

[37] Sathyabama, T., Nanjappan, K., Jagadeeswaran, A. and Kirubakaran, A. (2017). Effect of chromium supplementation on external egg quality characteristic of layer chickens. *Indian Veterinary Journal*, 94(10):9-10.

[38] Ganjigohari, S., Ziaei, N., Ramzani G.A. and Tasharoffi, S. (2018). Nano-calcium carbonate: effect on performance traits and egg quality in laying hens. *Journal of Livestock Science and Technologies*, 6(1):49-56. https://doi:10.22103/jlst.2018.9756.1180

[39] Ahmadi, M., Ahmadian, A. and Seidavi, A.R. (2018). Effect of different levels of nano-selenium on performance, blood parameters, immunity and carcass characteristics of broiler chickens. *Poultry Science Journal*, 6(1):99:108. https://doi:10.22069/psj.2018.13815.1276

[40] Liu, G.X., Jiang, G.Z., Lu, K.L. (2017). Effects of dietary selenium on the growth, selenium status, antioxidant activities, muscle composition and meat quality of blunt snout bream, *Megalobrama amblycephala*. *Aquaculture Nutrition*, 23(4):777–787. https://doi.org/10.1111/anu.12444

[41] Selim, N., Radwan, N., Youssef, S., Eldin, T.S. and Elwafa, S.A. (2015). Effect of inclusion inorganic, organic or nano selenium forms in broiler diets on growth performance, carcass and meat characteristics. *International Journal of Poultry Science*, 14 (3):135-143. https://doi.org/10.3923/IJPS.2015.135.143

[42] Cai, S. J., Wu, C. X., Gong, L.M., Song, T., Wu, H. and Zhang, L.Y. (2012). Effects of nano-selenium on performance, meat quality, immune function, oxidation resistance and tissue selenium content in broilers. *Poultry Science Journal*, 91 (10):2532-2539. https://doi:10.3382/ps.2012-02160

[43] Zhou, X. and Wang, Y. (2011). Influence of dietary nano elemental selenium on growth performance, tissue selenium distribution, meat quality and glutathione peroxidase activity in Guangxi yellow chicken. *Poultry Science Journal*, 90(3):680 -686. https://doi.org/10.3382/ps.2010-00977

[44] Xun, W., Shi, L., Yue, W. Zhang, C., Re, Y. and Liu, Q. (2012). Effect of high-dose nano-selenium and selenium-yeast on feed digestibility, rumen fermentation, and purine deriverates in Sheep. *Biological Trace Elements Research*, 150(1-3):130-136. https://doi.org/10.1007/s12011-012-8452-3

[45] Romero-Pérez, A., García-García, E., Zavaleta-Mancera, A., Ramírez-Bribiesca, J.E., Revilla-Vázquez, A., Hernández-Calva, L.M., López-Arellano R. and Cruz-Monterrosa, R.G. (2010). Designing and evaluation of sodium selenite nanoparticles *in vitro* to improve selenium absorption in ruminants. *Veterinary Research Communication*. 34(1):71-79. https://doi.org/10.1007/s11259-009-9335-z

[46] Shi, L., Xun, W. and Yue, W. (2011). Effect of elemental nanoselenium on feed digestibility, rumen fermentation, and purine derivatives in sheep. *Animal Feed Science and Technology*, 163(2):136-142. https://doi.org/10.1016/j.anifeedsci.2010.10.016

[47] Han, L., Pang, K., Fu, T., Philiphs, J.C. and Gao, T. (2020). Nano-selenium supplementation increas-

es selenoprotein gene expression profiles and milk seleniumconcentration in lactating dairy cows. *Biological Trace Element Research*, 199:113-119. https://doi:10.1007/s12011-020-02139-2
[48] Wang, M.Q., Xu, Z.R., Zha, L.Y. and Lindemann, M.D. (2007). Effects of chromium nano composite supplementation on blood metabolities, endocrine parameters and immune traits in finishing pigs. *Animal Feed Science Technology,* 139:69-80. https://doi.org/10.1016/j.anifeedsci.2006.12.004
[49] Saki, A. and Salary, J. (2015). In ovo injection of silver nanoparticles, thyme and savory extract on growth performance and blood parameters in broiler chicks. *Animal Sciences Journal,* 101: 70-78. https://doi.org/10.22069/PSJ.2015.2655
[50] Grodzik, M. and Sawosz, E. (2006). The influence of silver nanoparticles on chicken embryo development and bursa of Fabricius morphology. *Journal of Animal and Feed Sciences*, 15(1):111-114. https://doi:10.22358/jafs/70155/2006
[51] Hu, C.H., Li, Y.L., Xiong, H.M., Zhang, J.S. and Xia, M.S. (2012). Comparative effects of nano elemental selenium and sodium selenite on selenium retention in broiler chickens. *Animal Feed Science and Technology*, 177:204-210. https://doi.org/10.1016/j.anifeedsci.2012.08.010
[52] Mahmoud, H.E., Daichi I. and Akira, O. (2016). Effects of dietary Nano-Selenium supplementation on growth performance, antioxidative status and immunity in broiler chickens under thermoneutal and high ambient temperature conditions. *Journal of Poultry Science*, 53(4):274-283. https://doi.org/10.2141/jpsa.0150133
[53] Sahoo, A, Swain, R.K., Mishra, S.K., Behura, N.C. Beura, S.S., Sahoo. C., Das, A., Mishra, A. and Jena, B. (2016). Growth, feed conversion efficiency and carcass characteristics of broiler chicks fed on inorganic and nano zinc supplemented diets. *Animal Science Reported,* 10(1):10-18.
[54] Hassan, A.A., Howayda, M.E. and Mahmoud, H.H. (2013). Effect of zinc oxide nanoparticles on the growth of mycotoxigenic mould. *Studies in Chemical Process Technology*, 1(4):66-74. www.as-se.org/scpt
[55] Ahmadi, F. (2012). Impact of different levels of silver nanoparticles (Ag-NPs) on performance oxidative enzymes and blood parameters in broiler chicks. *Pakistian Veterinary Journal,* 32:325-328.
[56] Andi, M.A., Hashemi, M. and Ahmadi, F. (2011). Effects of feed type with/without nanosilver on cumulative performance, relative organ weight and some blood parameters of broilers. *Global Veterinaria,* 7:605-609. http://www.idosi.org/gv/GVT(6)11/14.pdf
[57] Loghman, A., Iraj,, S.H., Naghi, D.A. and Pejman, M. (2012). Histopathologic and apoptotic effect of nanosilver in liver of broiler chickens. *African Journal of Biotechnology,* 11:6207-6211. https://doi.org/10.5897/AJB11.1768
[58] Schosler, H. and De Boer, J. (2018). Towards more sustainable diets: insights from the food philosophies of “Gourmets” and their relevance for policy strategies. *Appetite*, 127:59-68. https://doi.org/10.1016/j.appet.2018.04.022
[59] Bakhshalinejad, R., Kakhki, R.A.M. and Zoidis, E. (2018). Effects of different dietary sources and levels of selenium supplements on growth performance, antioxidant status and immune parameters in ross 308 broiler chickens. *British Poultry Science*, 59(1):81-91. https://doi:10.1080/00071668.2017.1380296
[60] Li, J.L., Zhang, L., Yang, Z.Y., Zhang, Z.Y., Jiang, Y;., Gao, F., and Zhou, G.H. (2018). Effects of different selenium sources on growth performance, antioxidant capacity and meat quality of local Chinese subei chickens. *Biological Trace Element Research*, 181(2):340-346. https://doi:10.1007/s12011-017-1049-4
[61] Liu, S.B., Tan, H.Z. and Wei, S. (2015). Effect of selenium sources on growth performance and tissue selenium retention in yellow broiler chicks. *Journal of Applied Animal Research*, 43(4):487-490. https://doi.org/10.1080/09712119.2014,978780
[62] Carralero, V., González-Cortés, A., Yañez-Sedeño, P. and Pingarrón, J.M. (2007). Development of a progesterona immunosensor based on a colloidal gold-graphite-teflon composite electrode. *Electroanalysis*, 19:853-858. https://doi.org/10.1002/elan.200603794
[63] Korczynski, M., Swiniarska, M., Konkol, D. and Opalinski, S. (2017). Fortification of animals foodstuff. *Food Biofortification Technologies*, Saeid, A. Ed., pp. 273-312, CRC Press, Boca Raton, FL, USA. https://doi:10.1201/9781351228350-8
[64] Han, J.D. and Baker, D.H. (1993). Growth and plasma zinc responses of young pigs fed pharmacologic levels of zinc. *Journal of Animal Science,* 71:3020. https://doi:2527/1993,71113020x
[65] Smith, J.W., Tokach M.D., Goodband, R.D., Nelssen J.L. and Richert B.T. (1997). Effects of the interrelationship between zinc oxide and copper sulfate on growth performance of early weaned pigs. *Journal of Animal Science*; 75:1861-1866. https://doi.org/10.2527/1997.7571861x