International Journal of Agriculture Sciences
ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 12, Issue 3, 2020, pp.-9497-9500.
Available online at https://www.bioinfopublication.org/jouarchive.php?opt=&jouid=BPJ0000217

Review Article

APPLICATION OF NANOPARTICLES AND NANOTECHNOLOGIES IN POULTRY PRODUCTION

ROKADE J.J.*, GOPI M., MONIKA M., HABLE A.A. AND MADHUPRIYA
Scientist, ICAR-Central Avian Research Institute, Izatnagar, Bareilly, 243122, Uttar Pradesh, India
*Corresponding Author: Email - jaydeepvet@gmail.com

Received: February 01, 2020; Revised: February 12, 2020; Accepted: February 13, 2020; Published: February 15, 2020

Abstract: Nanoscience has arisen as one of the foremost fascinating branches of contemporary science. Globally the investments are increasing in nanotechnology-based studies and development. In addition to high bioavailability, high biodegradability properties and ability to penetrate directly into the animal body, it offers a scientific gain with its rapid and unique moves, thus rendering the particle utilization rate higher. Trace minerals more effectively used in poultry diets in the form of nanoparticles to satisfy the mineral requirements. The nanoparticles are likely to be different when compared to their conventional forms due to their extremely small size and unique physical properties. Nano form of supplementation increases the surface area which increases the absorption and thus the use of minerals leading to a decrease in the number of supplements and ultimately a decrease in feed costs. Nanoparticles are prepared using different methods. But, before choosing the particles, it is important to take into account the physicochemical stability of the active substance and its toxic effects, its liberation profile. The most widely nanoparticles used in poultry are Nano Zn, Nano-Ag, Nano Se, Nano DCP, Nano Cr. For intensive poultry processing, nano-feed additives and novel detoxifying nano-materials are expected to provide added value for feeding practices as a result of their positive effect on performance. In this review paper, we have our overview of nanoparticles, their preparation and their applications in the poultry industry. This chapter lists possible areas of poultry nutrition where the benefits of these technologies can be used to assist researchers and policy makers.

Keywords: *Nanotechnology, Nano Particles, Synthesis, Application, Poultry*

Citation: Rokade J.J., *et al*., (2020) Application of Nanoparticles and Nanotechnologies in Poultry Production. International Journal of Agriculture Sciences, ISSN: 0975-3710 & E-ISSN: 0975-9107, Volume 12, Issue 3, pp.- 9497-9500.

Academic Editor / Reviewer: Sri Anees K, H. M. Ribeiro

Introduction

Food inflation combined with insufficient productivity gains are obvious indicators that without swift action our ability to feed a rapidly growing population is at serious risk. Nanotechnology could be an exciting emerging technology with a great capacity to revolutionize India's agriculture and livestock market, and throughout the world. Nanotechnology is a novel technology which creates materials and changes structure, enhances quality and texture of foodstuffs at the molecular level and includes a major effect on production, processing, transportation, storage, safety and security of food along with meeting up the demand for ever-increasing demand for feed to some extent due successful interventions in feed technology. As we realize that the utilization rate of minerals from their inorganic sources is absolutely low so these minerals are added 20-30 times higher than the regular animal requirement resulting in extra excretion of these minerals in the stool, which ends up in pollutants for the environment. It can also affect the balance of the various minerals. Therefore, a replacement for organic mineral sources is being studied which have a much higher utilization rate than inorganic mineral sources but organic mineral sources are more expensive than conventional inorganic sources. Recently, it has been shown that material at nanometre magnitude exhibits novel properties other than its normal-sized particles, such as enhanced specific surface area, higher surface activity, greater catalytic efficiency and a stronger adsorption ability which, due to the advantage of the size effect and high surface reactivity, nanoparticles are already used in pharmaceutical applications to boost the bioavailability of drugs and targeting therapeutic agents to specific organs. With vast potential application fields, nanotechnology remains in its infancy on the suitability and effectiveness of mineral nanoparticles in animal feed and nutritional studies, especially in poultry. Furthermore, application of nanotechnology in poultry has shown improvement in immunity, resistance to oxidation and growth, and reduced use of antibiotics and manure odour, ultimately improving the environment. Due to the application of agents with multimode antibacterial action, bacteria's resistance to traditional antibiotics can be reduced by using nanotechnologies.

Trace minerals in the forms of nanoparticles can successfully achieve the mineral requirements in the poultry diets. Micro-minerals are involved in several biochemical pathways and are components of a large number of enzymes necessary for normal biochemical reactions. Because of their incredibly small size and unique physical properties the nanoparticles are considerably different from their standard forms. Nanoparticles can bypass the physiological modes of nutrient distribution and transmission across tissue and cell membranes. Nanotechnology is increasingly being applied in the field of veterinary medicine and poultry production, and various compounds are being used as supplementary sources of trace minerals (Na_2O, MgO, Al_2O_3, SiO_2, K_2O, CaO, TiO_2, and Fe_2O_3) in diets.

Nutrition is a significant portion (around 60–65 percent) of poultry inputs. Nano-feed additives can help improve feed performance, reduce feed costs and raise the yield and quality of poultry-based products. Nano form of supplementation increases the surface area which increases the absorption and therefore the use of minerals which leads to a reduction in the number of supplements and eventually to a reduction in feed costs and increase the yield and quality of products made from poultry. There are many encouraging and promising examples of the present-day use of various nano-materials in poultry. Nano-feed additives and novel detoxifying nano-materials are expected to bring value in feeding strategies as a result of their positive influence on efficiency in intensive poultry production. This chapter discusses the potential areas of nano particles in poultry nutrition where it is possible to use the advantages of such technologies to assist researchers and policy makers.

Nanotechnology

Some have described nanotechnology (which includes both nano-sciences and nano-technologies) as a cornerstone of various converging technology visions. Since the rise of nanoscience in the 21st century it has emerged as one of the most important branches of modern science. Nanotechnology's potential has been recognized globally, and investment in nanotechnology-centered work and development is increasing [1]. Over the years, nanotechnology has become a modern enabling technology, with enormous potential for revolutionizing both the Indian and global agriculture and livestock sectors. Nano is a Latin word meaning little old man or Dwarf and in 1952 Nobel laureate of physics Richard Feynman gave the idea of nanotechnology a first in southern California. In 1980 Eric Drexler made nanotechnology popular in the true sense of the term. Particles measuring between 1 and 100 nano meters in diameter are known as nano particles. Nanotechnology is the use of scientific knowledge to produce certain particles and systems which use them. This deals with the physiochemical properties of structures of molecular scale, and they can be combined to form larger structures for livestock and human use. Nanoparticles and structures acquire certain peculiar and novel characteristics because of this dimensional range, and nanotechnology also deals with the study and analysis of these properties.

The term "nano" refers to a milliard of a meter (10-9 m), or one millionth of a millimetre. In recent years, nanotechnologies have been increasingly being applied in the animal production market. This can not only enhance animal immunity, resistance to oxidation, and growth, as well as reduced antibiotic use and manure odour, which is conducive to improving the environment. "Nanotechnology can also be used to improve the nutritional value of a food by increasing the bioavailability of certain nutrients." In addition to high bioavailability and biodegradability properties it offers a scientific advantage with its rapid and specific moves. Nano trace element can enter the animal body by direct penetration; its consumption rate is therefore much higher than that of ordinary inorganic trace elements. Research has shown that the inorganic trace element utilization coefficient was about 30 percent, while the nano trace element utilization coefficient was close to 100 percent. All of these benefits have significant effects on farm animal production and also economic losses, as well as healthier food and feed production. Nanotechnology is still in its infancy for animal feed and nutrition research, with vast potential areas of use. The ability to produce and manipulate nanoscale matter has created opportunities for new directions and with unprecedented accuracy to interact with biology. Recently trace minerals are used successfully in the diets of poultry in the form of nanoparticles to satisfy the mineral requirements. The nanoparticles are considerably different as compared to their standard forms due to their extremely tiny size and distinct physical properties. These are supposed to have the advantage of better absorption rate, lower dose rate and safe contact with other components as a feed additive. Perhaps the potential of nanotechnology in broiler production is not yet fully appreciated, due to insufficient knowledge. From a different perspective, feeding such antibiotics at low levels in poultry for an extended period of time is normal practice in the poultry industry to increase feed efficiency for birds. Yet, recently, due to the potential growth of antibiotic-resistant bacteria and their residues in poultry processing, an in-feed antibiotic has been banned.

Nano type of supplementation improves the surface area which could potentially increase the uptake and thus the use of minerals leading to a reduction in the number of nutrients and eventually a decrease in feed costs. The growing concern about the possible contribution of phosphorus in poultry excreta to surface water eutrophication has led to increased pressure to limit the amount of excess phosphorus in poultry ration, thereby reducing the phosphorous faecal production Mineral nanoparticles, especially in large-scale poultry farming, will be helpful in reducing the excretion of unused minerals which reduce the environment. Mineral nanoparticles will be helpful in reducing the excretion of unutilized minerals minimizing the environmental pollution, especially in large scale poultry farming.

Differences between nanomaterials and larger materials

The physical, chemical, mechanical, optical, electrical, and magnetic properties on an atomic scale are quite different from those on a larger scale, even when compared with those on a micron scale (10-6) [3]. Because of two effects, the nanomaterials differ from larger ones:

Surface effects

The atoms of nanomaterials lack cohesion relative to those of larger structures, as the energy required to join neighbouring atoms is smaller. The fusion point of a given element changes as a result of this. For instance, the fusion point of a 2.5 nm gold particle is about 930 K (almost 657°C), which is much lower than 1336 K (almost 1.063°C), this metal's usual fusion point at higher volumes. This phenomenon is characteristic in metals, inert gases, semi-conductors and molecular crystals where the particle size is less than 100 nm [4].

Quantum effects

Quantum points are a form of nanostructures, just a few nanometres in size exhibiting a similar behavior to a single atom. Their spatial structure enables them to have properties that are not proper to the material when they are in the form of nanoparticles, such as magnetism in metals like gold or platinum.

Mechanism of action of nanoparticles

The mechanism of action of nanoparticles was described [5]

- The surface area available for interaction was increased in order to establish better biological support.
- The time of residence of the GIT compounds has been expanded.
- Impact of pathways for intestinal clearance has decreased.
- Penetrate deep into tissues through fine capillaries
- Cross epithelial lining fenestration (*e.g.* liver)
- Enable efficient cell use
- Efficient transport of active compounds to target body sites

Various methods of Nano particles preparation are available. The selection of any of these methods depends on the specific goals and conditions for the intended use of where and how they obtained the particles. Therefore, it is necessary to consider, among many other considerations, the physical and chemical stability of the active agent and its toxicity, its liberation profile. Specifies some common methods for the preparation of nanoparticles, such as:

Green synthesis

The word green synthesis means that together the nanotechnology and plant biotechnology are used to prepare a nanomaterial. The extracts from plants play an important role in raising the particle size of metal ions. Extracts containing different compounds are, for example, sugar, alkaloids, polyphenols, proteins etc. Additionally, these compounds give the metal ions stability. The nanoparticles extracted by this process will be of various colours such as gold grey and black, depending on the source of the plant material used.

Role of nano minerals in poultry production

Nano Zinc

Zinc is essential for the normal functioning of many structural proteins, enzymes and hormones, and necessary for development and growth [7&8]. This could be the cause broilers, showing higher weight gains and better FCR when combined with Zn-NP. Dietary Zn can influence the development of eggs by interacting with the endocrine system, and increase the production of eggs in layers. In broiler breeder chicken, an increase in the synthesis and secretion of reproductive hormones found in the blood plasma, especially concentrations of LH and FSH hormones, causes increased deposition of albumen in the magnum, shell membrane secretion in the isthmus and shell formation in the uterus resulted in an increase in egg production and also egg weight.

Proliferation, differentiation, and survival of the bone cells are impaired if Zn is not supplied sufficiently. The resistance to breaking tibia increased in diets supplemented with Zn for chickens due to increased bone mineralization shows that Zn plays a crucial role in bone metabolism [10,11]. Zn also improves osteoblast count and activity, contributes to calcium deposition in bone diaphysis and increased mineralization in the tibia. Zinc is essential to thymulin, a thymic hormone which regulates the maturation of T lymphocytes. Therefore, birds fed with diets supplemented with a more available source of Zn could have more thymulin activity and thus enhance immune response

Nano silver

Chicken embryo is a special biological model because it is independent of the mother body, and no external supply of nutrients is required [12]. Nano-Ag accumulated in the bone of the embryo, but did not impact the bone's structure and mechanical properties. There has been a tendency to increase mineral content, suggesting that nanoparticles may affect bone mineralization [13]. The positive response results in the body weight of birds fed with Nano Ag obtained may be due to the antibacterial properties of nano silver affecting microbial communities without causing resistance and growing anabolic activity, which can promote the development and growth of animals and increase the rate of metabolism. An increased feed intake and an improved feed conversion ratio over the total duration (1-42 days) using nano silver in broiler diet [15]. This action can be due to the effect of ionic silver on harmful intestinal bacteria, resulting in a healthy hindgut and better absorption of nutrients.

When broilers were supplemented with silver nanoparticles, total serum protein increased especially serum globin and albumin. Total serum antioxidant activity also increased significantly relative to control at all levels of the dietary AgNps. In addition, it is found that metallic silver nanoparticles can reduce the viability of potentially harmful species, such as coliforms, whereas lactobacilli, which compete positively against proliferation of pathogens and decrease their virulence, are not affected [16]. In the case of Gram-negative bacteria, the function of the inhibitory effects of AgNPs was greater. This may be due to the thickness of the layer of peptidoglycan in the Gram-positive bacterial cell wall, which can somehow prevent it [17].

A greater effect of silver nanoparticles on *Bacillus subtilis* than on Escherichia coli has been observed, suggesting a selective antimicrobial effect, possibly related to the bacterial membrane structure.

Nano selenium

Dietary Se plays a major role in promoting body weight, feather production, improved FCR, increased levels of blood glucose, improved immunity. Improvement in birds 'live body weight could be due to some of their biological functions, such as their role in enzymatic oxidation-reduction, nucleic acid metabolism and in promoting the activity of easily oxidized substances such as carotenoids and vitamin A. In addition, feather growth improves can be due to improved growth efficiency (BWG) or may be due to increased protein and water in cells [18]. Enhanced FCR of broilers fed organic supplemented diet may be associated with increased concentrations of the active form of thyroid hormone in the serum of chickens supplemented with Se, as well as with the immunomodulating properties of Se [19-22].

The increase in blood glucose may suggest disrupted carbohydrate metabolism due to increased breakdown of liver glycogen, probably mediating the increase in blood glucose. Nano-Se dietary supplementation has also improved both humoral and cellular immunity as assessed against SRBC by an antibody titre, cutaneous basophil hypersensitivity (CBH) responses, and provided better antibody response than untreated control groups. An increased title to an antibody against SRBCs was found when the diet included selenium and vitamin E at higher levels [24-28]. On the contrary, it is observed depression in antibody production against *E. coli* and Newcastle disease virus vaccination in both chicken and turkey when vitamin E supplementation in the diet was increased from 10 to 150 mg kg^{-1} [29]. Selenium supplementation could have affected intracellular signal transmission required for initiation of lymphocytes proliferation [30] leading to increase in the antibody titre.

Compared with other selenium compounds, elemental selenium nanoparticles have higher bioavailability [31, 32]. The Nano-Se had higher retention of Se in the liver, pancreas and muscle of the breast, and was consistent [31]. Higher retention of Nno-Se in the muscle can effectively reduce the Se available to induce the response to selenosis [33]. That may be partly the reason for Nano-Se's lower toxicity relative to selenite. Nanoparticles have been reported to exhibit new transport and take up characteristics, and exhibit higher absorption efficiencies [34-37]. Nanoparticles superior performance may be due to their smaller particle size and larger surface area, increased mucosal permeability and improved intestinal absorption due to the formation of nano emulsion droplets.

Nano DCP

Birds fed Nano DCP diets gained ($p<0.001$) 12.6% more body weight and ate ($p<0.01$) 1.6% more feed than CDCP groups [38]. FCR values increased by 10 per cent ($p<0.001$) for birds fed NDCP diets compared to conventional DCP diets. Nano-sized calcium phosphate materials have a greater specific surface area and surface roughness than conventional calcium phosphate materials [39, 40]. Nano-sized calcium phosphate materials are expected to have better bioactivity compared to conventional materials, because nano-shaped mineral supplementation (Se, Cr and Zn) increases bioavailability and utilization efficiency by increasing the surface area. When the actual production of calcium phosphate nano-particles is upscaled to an industrial level, the usefulness of nanoform in reducing the mineral quantity to half or more in the diet will reduce feeding costs. It was also observed that the cumulative intake of feed tends to increase with an increase in calcium phosphorus nanoparticles supplementation level from 50% to 100%. Greater intake of feed is a result of palatability. Food safety authority of Ireland has registered sensory enhancement due to nanoparticles. Increased palatability due to supplementation of calcium phosphorus nanoparticles could be related to sensory improvement in flavour / texture and also an excessive number of fine particles would generally cause small and irregular intakes, digestive upsets and poor performance. Thus, supplementation with calcium phosphate nanoparticles could be related to the inversely proportional gain in body weight due to incremental increase in fine particles in the feed. Addition of nano-formed dicalcium phosphate increases the absorption and subsequent decrease in their excretion. It has been stated that nano-minerals have greater potential even at very low doses than traditional organic and inorganic sources [41]. Nano type of mineral supplementation improves the surface area which could potentially increase the absorption and consumption leading to reduced supplement amounts and eventually reduced mineral excretion. The growing concern about the possible contribution of phosphorus in poultry excreta to surface water eutrophication has led to increased pressure to reduce the excess phosphorus in poultry rations and thus reduce the output of phosphorous.

Nano-Chromium

Chromium picolinate (CrPic) supplementation did not affect broiler body weight, feed consumption, or feed conversion ratio during 1-21 days, mortality rate decreased, and breast meat yield improved at 300 or 400 ppb levels with supplemental Cr [42]. On the other hand, increased supplemental chromium (200, 400, 800, or 1200 ppb CrPic) resulted in increased body weight, feed intake and feed efficiency in broilers reared under heat stress [43]. Dietary chromium and vitamin C supplementation alleviated the decrease in live weight gain and feed efficiency in broilers reared under heat stress [44]. Increased carcass yield for diets supplemented with CrPic has been reported in broilers [43-45]. It is well known that Cr engages in the metabolism of proteins [46]. In addition, Cr plays an important role as an integral component of the glucose tolerance factor (GTF) which potentiates the insulin action and regulates the metabolism of glucose [47-51].

Conclusion

Nanoparticle research and potential applications in poultry and animal production systems are growing in scale and scope. Data available confirms that various applications of nano-particles have improved the animal's efficiency, livability and biological activity. Production, manufacturing, packaging, and marketing of poultry and animal products could also be enhanced through the use of various nano-materials. While nanotechnology can be used in creating nanoparticles that can be used as novel food additives to enhance digestion and absorption. Nanotechnology applications are increasingly varied and regional, with a high potential for enhancing poultry production.

Application of review: The incorporation of nanoparticles into animal nutrition studies, particularly in the poultry industry, will greatly enhance the growth and production efficiency. Nevertheless, there is still a great deal of research to support the usefulness, and mostly the health of nanotechnology, preventing any damage to the birds.

Review Category: Nanoparticles and Nanotechnologies

Acknowledgement / Funding: Authors are thankful to ICAR-Central Avian Research Institute, Izatnagar, Bareilly, 243122, Uttar Pradesh, India

****Principal Investigator or Chairperson of research: Dr R J Jaywant**
Institute: ICAR-Central Avian Research Institute, Izatnagar, Bareilly, 243122, Uttar Pradesh, India
Research project name or number: Review study

Author Contributions: All authors equally contributed

Author statement: All authors read, reviewed, agreed and approved the final manuscript. Note-All authors agreed that- Written informed consent was obtained from all participants prior to publish / enrolment

Study area / Sample Collection: ICAR-Central Avian Research Institute, Izatnagar, Bareilly, 243122

Cultivar / Variety / Breed name: Nil

Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.
Ethical Committee Approval Number: Nil

References

[1] Dunphy Guzman K.A., Taylor M.R. and Banfield J.F. (2006) *National nanotechnology initiative funding.* 2000-2004.
[2] Food Safety Authority of Ireland, https,//www.fsai.ie/nanotechology andfood.html.
[3] Buzea C., Pacheco II., Robbie K. (2007) *Biointerphases*, 2, MR17-MR71.
[4] Cao G. and Wang Y. (2004) *Properties and Applications*, 2.
[5] Chen H., Weiss J., and Shahidi F. (2006) *Food Technology*, 30-36.
[6] Agnihotri S.A., Mallikarjuna N.N. and Aminabhavi T.M. (2004) *Journal of Controlled Release*, 100(1), 5-28.
[7] Zhao C.Y., Tan S.X., Xiao X.Y., Qiu X.S., Pan J.Q. and Tang Z.X. (2014) *Biological Trace Element Research*, 160(3), 361-367.
[8] Bao Y., Choct M., Iji P., Bruerton K. (2010) *British Poultry Science*, 51, 109-117.
[9] Nys Y., Gautron J., Garcia-Ruiz J.M. and Hincke M.T. (2004). *Comptes Rendus Palevol*, 3(6-7), 549-562.
[10] Scrimgeour A.G., Stahl C.H., McClung J.P., Marchitelli L.J., Young A.J. (2007) *Journal of Nutritional Biochemistry*, 18, 813-819.
[11] Bao Y., Choct M., Iji P., Bruerton K. (2010) British Poultry Science, 51, 109-117.
[12] Sawosz E., Marta G., Marlena Z., Niemiec T., Boena O., Chwalibog A. (2009) *Archiv fur Geflugelkunde*, 73, 208-213.
[13] Sikorska J., Szmidt, M., Sawosz E., Niemiec T., Grodzik M., Chwalibog A. (2010) *Journal Animal and Feed Sciences*, 19, 286-291.
[14] Usama T.M. (2012) *Journal of Advanced Veterinary Research*, 2, 303-306.
[15] Andi M.A., Mohsen H., Farhad A. (2011) *Global Veterinaria,* 7, 605-609.
[16] Blomberg L., Henrikson A. and Conway P.L. (1993) *Applied and Environmental Microbiology*, 59, 34-39.
[17] Yoon K.Y., Byeon J.H., Park J.H. and Hwang J. (2007) *Science of the Total Environment*, 373, 572-575.
[18] Tayeb I. and Qader G. (2012) *KSÜ Doğa Bilimleri Dergisi*, 15(3), pp.46-56.
[19] Zelenka J. and Fajmonova E. (2005) *Poultry Science*, 84,543-546.
[20] Surai P.F. (2006) *1st Edn. Nottingham University Press, Nottingham, UK*
[21] Hoffmann P.R. (2007) *Archivum Immunologiae et Therapiae Experimentalis*, 55, 289-297.
[22] Ozkan S., Malayoglu H.B., Yalcin S., Karadas F. and Kocturk S., *et al.* (2007) *British Poultry Science*, 48, 580-593.
[23] Raja M., Al-Fatah A., Ali M., Afzal M., Hassan R.A., Menon M. and Dhami M.S. (1992) *Drug Metabolism Drug Interact*, 10, 279-291.
[24] Marsh J.A., Dietert R.R. and Combs G.F. (1981) *Proceedings of the Society for Experimental Biology and Medicine*, 166, 228-236.
[25] Gore A.B. and Qureshi M.A. (1997) Poultry Science, 76, 984-991.
[26] Larsen C.T., Pierson F.W. and Gross W.B. (1997) *Biological Trace Element Research*, 58, 169-176.
[27] Leshchinsky T.V. and Klasing K.C. (2001) *Poultry Science,* 80, 1590-1599.
[28] Nageswara A.R., Nageswara R.V. and Nageswara R.M. (2003) *Indian Journal Poultry Science*, 38, 115-120.
[29] Friedman A., Bartov I. and Sklan D. (1998) *Poultry Science*, 77, 956-962.
[30] Schumacher L.K., Roy M., Wishe M.I., Cohenand M.W. and Stotzky G. (1990) *Proceedings of the Society for Experimental Biology and Medicine*, 193, 136-141.
[31] Shi L., Xun W., Yue W., Zhang C. and Ren Y.,*et al.* (2011*) Small Ruminants Research*, 96, 49-52.
[32] Zhou X. and Wang Y. (2011) *Poultry Science,* 90, 680-686.
[33] Kim Y.Y. and Mahan D.C. (2001) *Journal of Animal Science*, 79, 942-948.
[34] Davda J. and Labhasetwar V. (2002) *International Journal of Pharmaceutics*, 233, 51-59.
[35] Chithrani B.D. and Chan W.C. (2007) Nano Letters, 7, 1542-1550.
[36] Zha L.Y., Zeng J.W., Chu X.W., Mao L.M. and Luo H.J. (2009) *Journal of the Science of Food and Agriculture*, 89(10), 1782-1786.
[37] Liao C.D., Hung W.L., Jan K.C., Yeh A.I., Ho C.T. and Hwang L.S. (2010) *Food chemistry*, 119(3), 896-902.
[38] Hassan H.M.A., Samy A., El-Sherbiny A.E., Mohamed M.A. and Abd-Elsamee M.O. (2016) *Asian Journal of Animal and Veterinary Advances*, 11, 477-483.
[39] Chan C.K., Kumar T.S.S., Liao S., Murugan R., Ngiam M. and Ramakrishna S. (2006) *Nanomedicine*, 1, 177-188.
[40] Gross K.A., Andersons J., Misevicius M. and Svirksts J. (2014) *Key Engineering Materials*, 587, 97-100.
[41] Hossain S. M., Barreto S. L. and Silva C. G. (1998) *Anim. Feed Sci. Technol*., 71, 217-228.
[42] Swain P.S., Rajendran D., Rao S.B. and Dominic G. (2015) *Veterinary World*, 8, 888-891.
[43] Sahin K., Sahin N. and Kucuk O. (2002) *The Journal of Trace Elements in Experimental Medicine*, 15, 163-169.
[44] Sahin K., Sahin N. and Kucuk O. (2003) *Nutrition Research*, 23, 225-238.
[45] Saikat S., Haldar S., Bahadur V. and Ghosh T.K. (2008) *The Journal of the Science of Food and Agriculture*, 88, 787-796.
[46] Anderson R.A. (1987) *Chromium, Trace Elements in Human and Animal nutrition* (pp. 225-244). New York, Academic Press.
[47] Mertz W. (1969) *Physiological Reviews*, 49, 163-239.
[48] Samak D.H., El-Sayed Y.S., Shaheen H.M., El-Far A.H. and Abd El-Hack M.E. (2018) *Environmental Science and Pollution Research*, 1-15.
[49] Patra A. and Lalhriatpuli M. (2019) *Biological Trace Element Research*, 1-21.
[50] Hassan S., Hassan F. and Rehman M.S. (2019) *Biological Trace Elements Research*, 1-22.
[51] Hussain I., Singh N.B., Singh A., Singh H., and Singh S.C. (2016) *Biotechnology Letters*, 38, 545.