Review Article

Organic Minerals in Poultry

ABSTRACT

Poultry is one of the most important source of animal protein for humans and now a days poultry production system is highly advanced and in context of nutritional advances a number of feed additives are now used to improve the efficiency of birds e.g. prebiotics, probiotics, organic acids etc. But in addition to these, chelated minerals/organic minerals has gained very much popularity. The word chelate derives from the Greek "chele", which means tweezers or claw. They are the result of electron sharing between a metal and a ligand. A ligand is usually an anion or a molecule, which has an atom or a pair of electrons with available valences. Common ligands contain oxygen, nitrogen, sulfur, halogens, or a combination of these due to their electronic structure. Chelated minerals have non-metallic ligands, and are therefore organic. Proteins and carbohydrates are the most frequent candidates in organic mineral combinations. After absorption, organic minerals may present physiological effects, which improve specific metabolic responses, such as the immune response.

Key words: Organic minerals, bioavailability, preparation, poultry.

INTRODUCTION

In commercial poultry diets, mostly trace minerals are supplemented as inorganic forms (sulphate or oxide salts). But, inorganic trace minerals can suffer from high rates of loss due to presence of interfering substances in the diet. Usually inorganic trace minerals are supplemented upto two to ten times more than the amounts recommended by National Research Council (NRC) [28] for poultry diets [20], because of the wide safety margins of ITM (inorganic trace minerals) and their low retention rates [27], excess of which sometimes leads to waste and environmental contamination from excessive excretion [23]. So use of organically complexed/ chelated trace minerals can help to prevent these losses, due to increased stability in the upper gastrointestinal tract of the animal and have greater bioavailability of organically complexed trace minerals, which in turn would allow for lower inclusion rates and reduced excretion[5].

Organic minerals include any mineral bound to organic compounds, regardless of the type of existing bond between mineral and organic molecules. Proteins and carbohydrates are the most frequent candidates in organic mineral combinations. Atoms, which are able to donate their electrons, are called donor atoms. Ligands with only one donor atom are called monodented, whereas those with two or more are called polydents. Organic fraction size and bond type are not limitations in organic mineral definition; however, essential metals (Cu, Fe, Zn, and Mn) can form coordinated bonds, which are stable in intestinal lumen. Metals bound to organic ligands by coordinated bonds can dissociate within animal during metabolism whereas real covalent bonds cannot. Chelated minerals are molecules that have a metal bound to an organic ligand through coordinated bonds; but many organic minerals are not chelates or are not even bound through coordinated bonds.

Utilization of organic minerals is largely dependent on the ligand; therefore, amino acids and other small molecules with facilitated access to the enterocyte are supposed to be better utilized by animals. Organic minerals with ligands presenting long chains may require digestion prior to absorption. Mineral utilization by animals primarily depends of their absorption from the ingested feed. After absorption, organic minerals may present physiological effects, which improve specific metabolic responses, such as the immune response. Chelation is very important in the biological systems. Most enzymes require a chelated metal in their structures to become effective. Vitamins, such as vitamin B12 (cyanocobalamin), have a metal (Co) complexed to a tetradent porphyrin group, nitrogen, and a pseudonucleotide. Porphyrin is also important for the chelation of iron on hemoglobin.

The presence of trace minerals (TM) in feed is vital for the birds's metabolic processes [36]. TM, such as zinc (Zn), manganese (Mn), and copper (Cu) are essential to maintain health and productivity in chickens. They are part of hundreds of proteins and organic molecules involved in intermediary metabolism, hormone secretion pathways, and immune defense systems [13]; they act as catalysts in many enzyme and hormone systems as a result, they influence growth, bone development, feathering, egg production, enzyme structure and function, and appetite of chickens [29].

Variable availability and presence of contaminants, are important considerations when we supplement trace minerals in poultry diet. For instance, zinc oxide and copper sulfate are sources commonly utilized in poultry feeding, but as they are often derived from residues of the steel industry, they can potentially carry high levels of contaminants, such as cadmium, fluorine, and lead to the feed. Also mineral absorption can suffer many interferences, such as mutual antagonisms, which potentially reduce absorption and metabolism rates of some minerals. But in case of metal amino acid chelates, these are chemically inert due to the covalent and ionic bonds between the mineral and the ligand, and therefore are not affected by factors that lead to precipitation, as it happens to minerals ionized after salt solubilization [3]. Due to their stability and small size, most chelated minerals are not altered during their passage through the digestive tract, and are completely absorbed with no break down of their amino acids.

Poultry feeds contain a range of different compounds that possess anti-oxidant activities, many of them being minerals or mineral– dependent. The most important step in balancing oxidative damage and anti-oxidant defence in the poultry is enhancing anti-oxidant capacity by optimizing the dietary intake of anti-oxidant compounds. The key minerals in anti-oxidation [29,30] are: Selenium - essential part of glutathione peroxidase (GSH-Px), thioredoxin reductase (TrxR), iodothironine deiodinase (ID), physiological requirement is low, but if not met, anti-oxidant system is compromised with detrimental consequences for bird's health. There are two major sources of Se: a natural source in the form of various selenoamino acids including selenomethionine and selenocysteine or inorganic selenium in the form of selenite or selenate. Organic selenium supplementation has physiological and biochemical benefits for poultry.

Zinc is the second most abundant trace element in birds and is a component of over 300 enzymes participating in their structure or in their catalytic and regulatory actions in most species. It takes part in anti-oxidant defence as an integral part of SOD, hormone secretion and function (somatomedin-c, osteocalcin, testosterone, thyroid hormones, insulin, growth hormone), keratin generation and epithelial tissue integrity, bone metabolism being an essential component of the calcified matrix, nucleic acid synthesis and cell division, protein synthesis, catalytic, structural and regulatory ion for enzymes, proteins and transcription factors and participates in the metabolism of carbohydrates, lipids and proteins, immune function. Organic Zn has higher availability in comparison to inorganic sources and is considered to be more beneficial for bird's health.

Copper is an essential component of metalloenzymes and takes part in anti-oxidant defence as an integral part of SOD, cellular respiration, bone formation, carbohydrate and lipid metabolism, immune function, connective tissue development, tissue keratinization, myelination of the spinal cord. Inorganic copper has a strong pro-oxidant effect and (if not bound to proteins) can stimulate lipid peroxidation in feed or the intestinal tract [43]. Organic copper does not possess pro-oxidant properties and can improve the copper status of birds. Manganese plays an important role in anti-oxidant protection as an integral part of SOD, bone growth and egg shell formation, carbohydrate and lipid metabolism, immune and nervous function, reproduction and Iron also has a vital role in many anti-oxidant defence as an essential component of catalase, energy and protein metabolism, heme respiratory carrier, oxidation/reduction reactions, electron transport system. Iron is a very strong pro-oxidant and if not bound to proteins can stimulate lipid peroxidation. This is especially relevant to the digestive tract where lipid peroxidation can be stimulated, causing enterocyte damages and decreased absorption of nutrients [43]. If iron is included in the premix in inorganic form, it can stimulate vitamin oxidation during storage. Therefore organic iron is a solution to avoid these problems and improve the iron status of animals.

NRC [28] specifies Zn:Cu:Mn requirements for broilers as 40:8:60 mg/kg. Many commercial nutritionists supply the trace minerals at twice this level in the diet for Zn and Mn. Although the physiological requirements of the bird are met by absorption of a fraction of this amount and in practice the majority of the trace mineral supply is excreted into the environment via the faeces and urine. Broiler and layer litter in England and Wales have been calculated to contain 217 mg/kg and 583 mg/kg Zn respectively. Zinc input rates into agricultural soils in England and Wales (2004) from layer litter was calculated as 2.5 g/ha/yr which was about 60% of the input rate from sewage sludge.

Table1. Nutritional requirements of the trace minerals for the poultry (NRC) [28]

	White-Egg-Laying Strains				**Broilers**		
Trace minerals (mg/kg diet)	**0 to 6 Weeks**	**6 to 12 Weeks**	**12 to 18 Weeks**	**18 Weeks to First Egg**	**0 to 3 Weeks**	**3 to 6 weeks**	**6 to 8 weeks**
Manganese(mg)	60	30	30	30	60	60	60
Zinc (mg)	40	35	35	35	40	40	40
Iron (mg)	80	60	60	60	80	80	80
Copper (mg)	5	4	4	4	8	8	8
Iodine (mg)	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Selenium (mg)	0.15	0.10	0.10	0.10	0.15	0.15	0.15

Organic minerals can be classified into two categories: natural and synthetic. Natural mineral complexes are formed during normal digestion, absorption, and metabolism in a living system. During digestion, a variety of natural mineral complexes are formed which either enhance or diminish the usefulness of the ingested minerals. Herrick [17] categorized natural organic minerals into three types based on their function in biological systems. These include complexes which: (1) transport and store metal ions, (2) are essential to physiological activity, and (3) interfere with metal ion utilization. Amino acids, EDTA (ethylene diamine tetra acetate) and other synthetic ligands are important as metal binding and transporting agents in the gastrointestinal tract, which enhance uptake of metal ions from the intestinal lumen into the mucosal cells. For instance, transferrin is essential for gut absorption, transport, and storage of iron. Additionally, metal complexes may form in biological systems to allow physiological activity of certain compounds. Hemoglobin contains iron and vitamin B12 contains a central cobalt atom.

Synthetic mineral complexes (usually by dietary supplementation) conversely, are used to enhance mineral utilization efficiency. Synthetic organic minerals are produced in an attempt to increase the utilization of dietary minerals. By complexing metal ions with a variety of organic ligands, an effort is made to enhance mineral absorption across the intestinal mucosa.

Absorption of organic minerals

After intake of the organic minerals from the feed, mineral absorption can occur in any region of the intestine but metals are usually absorbed in the duodenum part of the digestive tract. After gastric hydrolysis these inert complexes of minerals reaches the intestinal lumen where ligand bounded to the minerals act as their transporter and protect them from interaction with the various antagonists present there from the diet like phytic acid, oxalic acid, gossypol etc. Then these ligand-mineral complexes get absorbed through the enterocytes while the inorganic minerals only get absorbed when there is any inorganic metal transporter otherwise they will be excreted in feaces.

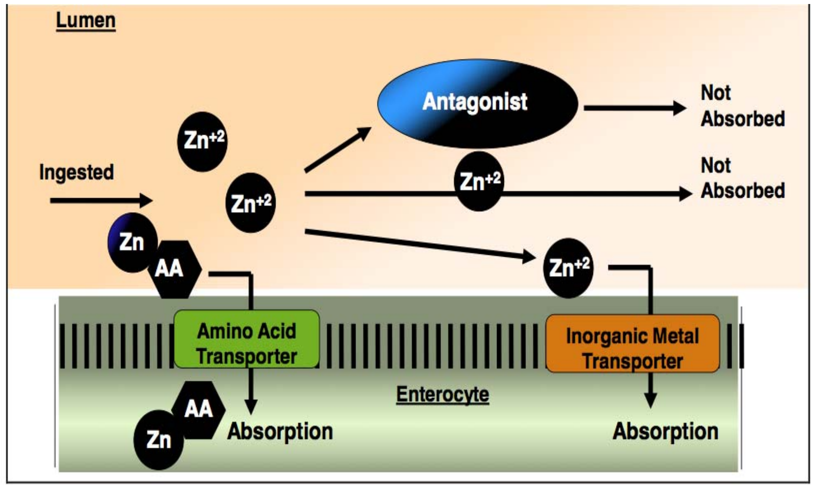


Fig:1 Figure showing the absorption of organic minerals in digestive tract of poultry

Preparation of organic minerals

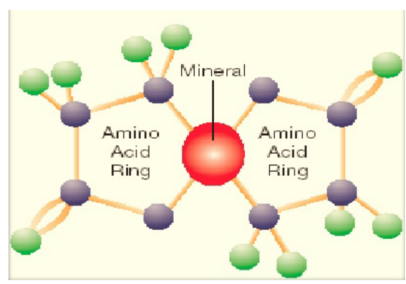
Mineral salt+ enzymatically prepared amino acid/peptide (Controlled conditions) (Hydrolysis of protein and separation by centrifugation and ultrafilteration)

↓

Ligand bind the metal atom at one or more point

↓

Form ring



Mineral proteinates are obtained by means of hydrolysis of a protein source which results into a mixture of amino acids and small peptides with chains of different lengths. In this way stable chelates are formed that protect trace elements against chemical reactions taking place in the course of digestion. This protection maintains the solubility of these substances during their passage through the gastrointestinal tract to the sites of absorption [12]. Such absorption would explain the apparent decrease in interaction between mineral forms shown in various reports as well as allowing inorganic and organic forms to be used together to advantage. Greater stability during digestion, along with absorption and transport via peptide and amino acid routes, results in higher biological availability [39, 30] due to increased absorption of organic trace mineral source. Organic sources include mineral complex with methionine, polysaccharide complexes, lysine, glycine, proteinate, and amino acid complexes.

Bioavailability of Organic Minerals

Bioavailability of organic mineral in poultry are inconsistent. Table2. shows the bioavailability of chelated minerals reported from different studies-

Table2. Bioavailability of different minerals from organic and inorganic sources

Sr.No.	Organic Minerals	Bioavailability	References
1.	Mn-methionine complex	74.4% more available than an inorganic source (MnO) using Mn concentration in bone	Fly *et al.,*1989 [16]
2.	Proteinates and aminoacid chelates of minerals	Had higher bioavailability and lowered excretion.	Wedekind and Baker,1990; Wedekind *et al.,*1992 [46,47].
3.	Copper and zinc (complex with lysine)	Organic minerals were 120% and 106% more available than sulfate (inorganic) form(100%).	Aoyagi and Baker., 1993 [2]
4.	Organic Zinc	Higher bioavailability indicates more zinc was deposited in bone tissue from organic sources compared to inorganic sources.	Cao *et al.*, 2000; Pierce *et al.*,2006 [11,31]
5.	Organic Zinc	Relative bioavailability (RB) of Zn from organic Zn was calculated at 121, 116 and 139% (versus ZnSO4/inorganic source at 100%)	Swiatkiewicz *et al.*, 2001 [44]
6.	Organic Manganese	Higher expression of the gene encoding manganese-containing superoxide dismutase in broiler heart tissue than inorganic source.	Luo *et al.*,2007 [24]
7.	Organic Zinc	Higher expression of m-RNA for metallothionein in tissue from the small intestine exposed to organic Zn sources.	Richards *et al.*, 2007 [34]
8.	Organic Zinc	Organic zinc had RB of 164% than zinc-sulfate (RB=100%) on the basis of tibia zinc content.	Star *et al.*,2012 [40]

9.	Mn proteinate	Higher relative bioavailability of Mn proteinate (139%), as compared to inorganic Mn sulphate (100%) in bone.	Brooks *et al.*, 2012 [7]
10.	Organic Zn (80 ppm, Bio-Plex®	Addition of organic Zn and prebiotic (Mono Oligosaccharides) increased serum Cu and Fe levels.	Yalcinkaya *et al.*, 2012 [48]
11.	Zn proteinate	Higher relative bioavailability of Zn on the basis of tibia zinc content.	Brooks *et al.*, 2013 [8]
12.	Zinc amino acids and peptides chelates (Bio-Plex®)	High RB (147-200%) than inorganic Zn sulphate calculated from the regression of BWG by slope ratio methods.	Sahraei *et al.*, 2013 [36]
13.	Chelated Zinc	Higher expression of the metallothionine (indicator of zinc status) in intestinal tissue than the inorganic salt.	Varun *et al.,* 2017 [45]

Effect of organic minerals on bird's performance

Organic minerals can be utilized at a much lower concentration in the diet than inorganic minerals, without a negative impact on production performance. Inclusion of the metal specific amino acid complex had a significant effect on FCR (feed conversion ratio) over the 45 day growth period when compared to inorganic mineral but not on growth performance [10]. Incremental additions of a number of different organomineral sources of Zn were compared to the sulphate showed a significant improvement in weight gain with the organic versus the inorganic treatments and no impact on FCR [21]. Chicks fed diets containing 100% organic minerals (Zn, Cu, Mn and Fe) had significantly higher body weight and better feed conversion on comparision with those of inorganic minerals [1]. The trace elements Zn, Mn, and Cu influence the organic matrix of eggshells and therefore can influence the mechanical properties of the eggshell. Rodriguez-Navarro *et al.* [35] stated that membranes that compose the organic matrix may provide a network of fibrous reinforcement within the shell that can contribute to the resistance to breaking of the egg.

Table3. Effect of different organic minerals on bird's performance

Sr.No.	Organic Minerals	Results	Reference
1.	Zinc/Manganese methionine	Reported that enhanced humoral and cell mediated immune function in turkeys, and improved feed efficiency.	Ferket and Qureshi.,1992 [15]
2.	Mineral specific amino acid complex	Had a significant effect on FCR over the 45 day growth period when compared to inorganic mineral but not on growth performance.	Burrell *et al.*,2004 [10]
3.	Organic Zn or organic Cu	Reported that birds exhibited a significantly improvement in antibody immune response against coccidiosis.	Richards *et al.*, 2006 [33]

4.	100% organic minerals (Zn, Cu, Mn and Fe)	Significantly higher body weight and better feed conversion than those with inorganic minerals.	Abdallah *et al*., 2009 [1]
5.	Zn glycine (90-120 ppm)	Had a beneficial effect on growth performance and immunological characteristics (Immunoglobulin A, Immunoglobulin G and Immunoglobulin M blood concentrations).	Feng *et al*., 2010 [14]
6.	Organic Zn	Reduced oxidative stress and improved immune responses indices.	Bun *et al*., 2011 [9]
7.	Zn-proteinate	The serum glucose and serum cholesterol levels were significantly ($p<0.05$) lower in organic Zn fed group than inorganic.	Idowu *et al*., 2011 [19]
8.	Zn glycine	Improvement in of Cu/Zn superoxide dismutase and glutathione peroxidase activity, a decrease in liver malondialdehyde content.	Ma *et al*., 2011 [25]
9.	Zn glycine	Increase in the height of intestinal villi, decrease in crypt depth and thickness of intestinal walls	Ma *et al*., 2011 [25]
10.	Mn proteinate	Better results (weight gain, egg weight, % undamaged eggs and tibia bone quality indices) than inorganic Mn sulphate.	Yildiz *et al*., 2011 [49]
11.	Cu proteinate (50, 100, and 150 ppm)	Decreased plasma cholesterol, low-density lipoprotein (LDL) and triglyceride in comparison to Cu sulphate.	Jegede *et al*., 2012 [22]
13.	Organic Zn	Significantly ($P<0.05$) lowered serum cholesterol and higher Serum Glutamate Pyruvate Transferase and Alkaline Phosphatase levels in broilers.	Mishra *et al*., 2013 [26]
14.	Cu proteinate	Alleviated the detrimental effect of aflatoxicosis, improved the growth performance of birds as compared to inorganic Cu sulphate.	Shamsudeen and Shrivastava,2013 [37]
15.	Organic minerals (Zn, Cu, Fe, Mn and Se)	During 2nd, 3rd and 4th weeks organic mineral supplementation showed better growth performance than inorganic.	Baloch *et al*., 2017 [4]

Conclusion

Thus the advent of organic sources of trace minerals with improved absorption characteristics provide an opportunity to meet bird's requirements and reduce trace mineral build up in the environment.

References

1. Abdallah AG, El-Husseiny OM and Abdel-Latit KO. Influence of some dietary organic mineral supplementations on broiler performance. Int. J. Poult. Sci. 2009; 8 (3): 291–98.
2. Aoyagi S, Baker D. Nutritional evaluation of copper-lysine and zinc-Iysine complexes for chicks. Poult. Sci. 1993; 72. 165-171.
3. Ashmead HD. Comparative intestinal absorption and subsequent metabolism of metal aminoacid quelates and inorganic metal salts. Westood: Noyes Publications. 1993.
4. Baloch Z, Yasmeen N, Pasha T.N, Ahmad A, Taj M.K, Khosa A.N, Marghazani I.B, Bangulzai N, Ahmad I and Hua Y.S. Effect of replacing inorganic with organic trace minerals on growth performance, carcass characteristics and chemical composition of broiler thigh meat.African J. Agri. Research. 2017; 12(18); 1570-1575.
5. Bao YM, Choct M, Iji PA. and Bruerton K. Effect of organically complexed copper, iron, manganese and zinc on broiler performance, mineral excretion and accumulation in tissues. J. Applied Poult. Res. 2007; 16: 448-455.
6. Bao YM and Choct M. Trace mineral nutrition for broiler chickens and prospects of application of organically complexed trace minerals: a review. Anim. Prod. Sci. 2009; 49:269-282.
7. Brooks MA, Grimes JL, Lloyd KE, Valdez F. and Spears JW.Relative bioavailability in chicks of manganese from manganese proteinate. The J. of Appl. Poult. Res. 2012; 21: 126-130.
8. Brooks MA, Grimes JL, Lloyd KE, Verissimo S. and Spears JW. Bioavailability in chicks of zinc from zinc proteinate. The J.of Appl. Poult. Res. 2013; 22: 153-159.
9. Bun SD, Guo YM, Guo FC, Ji FJ. and Cao H. Influence of organic zinc supplementation
on the antioxidant status and immune responses of broilers challenged with Eimeria tenella. Poult. Sci. 2011; 90: 1220-1226.
10. Burrell AL, Dozier WA, Davis AJ, Compton MM, Freeman ME, Vendrell PF. and Ward TL. Responses of broilers to dietary zinc concentrations and sources in relation to environmental implications. Bri. Poult. Sci. 2004; 45: 225-263.
11. Cao J, Henry PR, Guo R, Holwerda RA, Toth JP, Littell RC, Miles RD and Ammerman CB. Chemical characteristics and relative bioavailability of supplemental organic zinc sources for poultry and ruminants. J.of Anim. Sci. 2000; 78: 2039–54.

12. Close WH. New developments in the use of trace mineral proteinates to improve pig performance and reduce environmental impact, European Lecture Tour. Alltech Inc., Nicholasville, KYTechnical Publications. 1998; 51-68.
13. Dieck, HT, Doring F, Roth HP, and Daniel H. Changes in rat hepatic gene expression in response to zinc deficiency as assessed by DNA arrays. J. Nutr. 2003; 133:1004–1010.
14. Feng J, Ma WQ, Niu HH, Wu XM, Wang Y, and Feng J. Effects of zinc glycine chelate on growth, hematological and immunological characteristics in broilers. Biol. Trace Elem. Res., 2010; 133: 203-211.
15. Ferket PR, Qureshi MA. Effect of level of inorganic and organic zinc and manganese on the immune function of turkey toms. Poult. Sci. 1992; 71 (Suppl. 1),60 (Abstr.).
16. Fly AD, Izquierdo OA, Lowry K.R. and Baker D.H. Manganese bioavailability in a Mn-methionine chelate. Nutr. Res. 1989; 9:901-910.
17. Herrick JB. Minerals in animal health. The Roles of Amino Acid Chelates in Animal Nutrition. H.D. Ashmead, ed. Noyes Publications, Park. 1993.; 3-20.
18. Herzig I, Navratilova M, Totusek J, Suchy P, Vecerek V, Blahova J, Zraly Z. The effect of humic acid on zinc accumulation in chicken broiler tissues. Czech J. of Anim. Sci. 2009; 54:121–27.
19. Idowu OMO, Ajuwon, RO, Oso AO and Akinloye OA. Effects of zinc supplementation on laying performance, serum chemistry and Zn residue in tibia bone, liver, excreta and egg shell of laying hens. Int. J. Poult. Sci. 2011; 10: 225-230.
20. Inal F, Coskun B, Gulsen N. and Kurtoglu V. The effects of withdrawal of vitamin and trace mineral supplements from layer diets on egg yield and trace mineral composition. Br. Poult. Sci. 2001; 42:77-80.
21. Jahanian R, Moghaddam HN. And Rezaei A. Improved broiler chick performance by dietary supplementation of organic zinc sources. Asian-Austr. J. of Anim. Sci. 2008; 21: 1348-1354.
22. Jegede AV, Oduguwa OO, Oso AO, Fafiolu AO, Idowu OMO. and Nollet L.Growth performance, blood characteristics and plasma lipids of growing pullet fed dietary concentrations of organic and inorganic copper sources. Livestock Sci. 2012; 145: 298-302.
23. Leeson S. A new look at trace mineral nutrition of poultry: Can we reduce the environmental burden of poultry manure? In: Nutritional Biotechnology in the Feed

and Food Industries (Ed. T. P Lyson and K. A. Jaques). Nottingham University Pres,Nottingham. 2003; 125-129.

24. Luo XG, Li S.F, Lu L, Kuang X, Shao GZ. And Yu SX. Gene Expression of Manganese-Containing Superoxide Dismutase As A Biomarker Of Manganese Bioavailability For Manganese Sources In Broilers. Poult. Sci. 2007; 86: 888-894.
25. Ma W, Niu H, Feng J, Wang Y. and Feng J. () Effects of zinc glycine chelate on oxidative stress, contents of trace elements, and intestinal morphology in broilers. Biological Trace Element Research. 2011; 142: 546-556.
26. Mishra SK, Swain R K, Behura N C, Das A, Mishra A, Sahoo G And Dash A K. Effect of Supplementation of Organic Minerals on The Performance of Broilers**.** Indian J.of Anim. Sci. 2013; 83 (12): 1335–1339.
27. Mohanna C. and Y. Nys. Influence of age, sex and cross on body concentrations of trace elements (zinc, iron, copper and manganese) in chickens. Br. Poult. Sci. 1998; 39: 536-543.
28. National Research Council. Nutrient requirements of chickens. 9th Ed. National Academy Press, Washington, DC. 1994.
29. Nollet L, Van der Klis JD, Lensing M, and Spring P. The effect of replacing inorganic with organic trace minerals in broiler diets on productive performance and mineral excretion. J. Appl. Poult. Res. 2007; 16:592–597.
30. Nys Y, Gautron J, Garcia-Ruiz JM and Hincke MT. Avian eggshell mineralization: Biochemical and functional characterization of matrix proteins. C. R. Palevol. 2004, 3: 549-562.
31. Pierce Ao T, Power JL, Dawson R, Pescatore KA, Cantor AJAH and Ford MJ. Evaluation of Bioplex Zn as an organic Zn source for chicks. Int. J.of Poult. Sci. 2006; 5: 808–11.
32. Protection and implications for the well-being of companion animals. In: Nutritional Biotechnology in the Feed and Food Industries. Proceedings of Alltech's 18th Annual Symposium, pp.521-534 (T.P.Lyons and K.A. Jacques, editors).
33. Richards JT, Hampton C, Wuelling M, Wehmeyer M. and Dibner JJ. 2006. Mintrex Zn and mintrex Cu organic trace minerals improve intestinal strength and immune responses to coccidiosis infection and/or vaccination in broilers. Proceedings of the International Poultry Scientific Forum, January 23-24, 2006, Atlanta, GA., pp: 257-259.

34. Richards JD, Shirley R, Winkelbauer P, Atwell C, Wuelling M, Wehmeyer M.and Buttin P. Bioavailability of Zinc Sources in Chickens Determined in Real Time Polymerase Chain Reaction (Rt-Pcr) Assay For Metallothionein. Wpsa France Xvith European Symposium On Poultry Nutrition, Strasbourg, France, August 26-30, 2007.
35. Rodriguez-Navarro A, Kalin O, Nys Y, Garcia-Ruiz JM. Influence of the microstructure on the shell strength of eggs laid by hens of different ages. Br. Poult. Sci. 2002; 43:395-403.
36. Sahraei M, Janmmohamdi H, Taghizadeh A, Ali Moghadam G. and Abbas Rafat S. Estimation of the relative bioavailability of several zinc sources for broilers fed a conventional corn-soybean meal diet. J. of Poult. Sci. 2013; 50: 53-59.
37. Shamsudeen P. and Shrivastava HP. () Biointeraction of chelated and inorganic copper with aflatoxin on growth performance of broiler chicken. Int. J. of Vet. Sci. 2013; 2: 106-110.
38. Soetan KO, Olaiya CO. and Oyewole OE. The importance of mineral elements for humans, domestic animals, and plants: a review. Afr. J. Food Sci. 2010; 4:200–222.
39. Solomon SE. Egg and Eggshell Quality , 1991 Wolfe, London, UK.
40. Star L, Van der Klis JD, Rapp C. and Ward TL. Bioavailability of organic and inorganic zinc sources in male broilers. Poult. Sci. 2012; 91:3115–3120.
41. Surai PF. and Dvorska, JE. Dietary organic selenium and eggs: from improvements in egg quality to production of functional food. Proceedings of the IX European Symposium on the Qualiry of Eggs and Egg Products, Kusadasi, Turkey. 2001; 163-169.
42. Surai PF. Natural Anti-oxidants in Avian Nutrition and Reproduction. Nottingham University Press, Nottingham. 2002.
43. Surai KP, Surai PF, Speake BK. and Sparks NHC. Anti-oxidant-pro-oxidant balance in the intestine: Food for thought. 1. Pro-oxidants. Nutritional Genomics and Functional Foods. 2003; 1: 51-70.
44. Swiatkiewicz S, Koreleski J. and Zhong DQ. The bioavailability of zinc from inorganic and organic sources in broiler chickens as affected by addition of phytase. J. Anim. Feed Sci. 2001; 10: 317-328.
45. Varun A, Karthikeyan N, Muthusamy P, Raja A. and Wilfred Ruban S. Real Time PCR Based Expression of Metallothionein and Evaluation of Zn Bioavailability in Chickens Fed Zinc Oxide and Zinc Methionine. Int.J.Curr.Microbiol.App.Sci. 2017; 6(7): 845-849.

46. Wedekind K J and Baker D H. Zinc bioavailability in feedgrade sources of zinc. J. of Anim. Sci. 1990; 68: 684–89.
47. Wedekind KJ, Hortin AE and Baker DH. Methodology for assessing zinc bioavailability: Efficacy estimates for zincmethionine, zinc sulphate and zinc oxide. J. of Anim.Sci. 1992; 70:178–87.
48. Yalcinkaya I, Cinar M, Yildirim E, Erat S, Basalan M. and Gungor T. The effect of prebiotic and organic zinc alone and in combination in broiler diets on the performance and some blood parameters. Italian J. Anim. Sci. 2012; 11: 298-302.
49. Yildiz AO, Cufadar Y. and Olgun O. Effects of dietary organic and inorganic manganese supplementation on performance, egg quality and bone mineralisation in laying hens. Revue de Medecine Veterinaire. 2011; 162: 482-488.