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Chelated minerals and its effect on animal production: A review

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ABSTRACT

The upcoming Livestock economy demands more effective production in every aspects for which feeding plays a major role. High yielding livestock requires quality feed and hence the bioavailability of minerals forms an essential component in the production system. In this context, chelated minerals can be a better solution compared to other feeding inventions. The purpose of using organic chelates is to increase the bioavailability of minerals by increasing their absorption and avoiding any interference with other minerals. Chelates remain stable in the rumen and get absorbed intact post-ruminally in the intestine by the process different from that of inorganic minerals. The chelated minerals accomplishing plasma are intact while the detachment takes place at the site of utilization. Not only among the ruminants but also in non – ruminants such as poultry and swine, chelated minerals has got similar effects. Thus, in this review, the effect of chelated minerals in the different production, reproduction as well as health status of animals is discussed.

Key words: Chelated minerals, Poultry, Production, Ruminants, Swine.

The term chelate originates from the Greek word "chel" meaning "claw", representing the element is held or clawed tightly by the ligand. Morgan and Drew (1920) coined the term "chelate" and defined it as, "A chemical compound in the form of a heterocyclic ring, containing a metal ion attached by coordinate bonds to at least two non-metal ions" and the phenomenon is known as 'Chelation'. Generally, a mineral complex is a mixture of a mineral and an organic compound, such as a protein or polysaccharide and thus, a chelate is a type of mineral complex. In other words, Chelation or "bringing together," refers to a bond formed between a metal ion (mineral) and a ligand (protein or amino acid chelating agent).Chelates are generated by reacting a mineral salt with, an enzymatically prepared mixture of amino acids and small peptides, under controlled conditions. The ligand binds the metal at several points such that the metal atom becomes part of a ring. Some amino acids and protein digestion products such as small peptides are best ligands as they have at least two functional groups (amino and hydroxyl) that can form a ring structure with the mineral. The resulting mineral organic complex is a "chelate." In animal feed, the primary chelated minerals used are the trace elements such as iron, manganese, cobalt, copper, and zinc (Hilal *et al.*, 2016) These are the "Transitional Elements" on the Periodic Table having chemical characteristics intermediate between metal and non-metal elements. Transitional elements forms coordinate covalent bonds, a hybrid form of association that gives them their distinctive capacity to form stable complexes i.e. coordination complexes or chelates. The definitive goal in the formation of chelates is to enhance the bioavailability of minerals to the animals to support metabolic functions (Ammerman *et al.*, 1995). Chelated minerals are administered mainly during the times of high nutritional demand, such as pregnancy, lactation, weaning, reproductive stress, rapid growth, environmental stress (such as temperature and humidity), or disease challenged conditions (Rabiee *et al.*, 2010). Chelates have been studied with regard to their effect on improved immunity (less disease or sickness), reproductive performance and herd health. In order to maximize the absorption of these trace minerals from the chelated compounds, they should be highly stable in the rumen (Paik, 2001).

Chelates are stable, electrically neutral complexes, which protect trace minerals from chemical reactions during digestion that would render the mineral unavailable to the animal. Added minerals precomplexed with organic ligands thus are used to increase bioavailability and uptake. The chelated mineral reaches to the plasma intact and separates at the site of action. Chelated trace minerals are suitable for use in all species. They can replace 25-40% of the supplementary inorganic minerals as a means of providing highly available trace minerals. Soluble Chelated trace minerals are specially formulated for drinking water supplies (Brown and Zeringue, 1994).

DIFFERENT CATEGORIES OF ORGANIC TRACE MINERALS

The different categories of organic trace minerals as defined by Association of American Feed Control Officials (AAFCO, 1998) include:

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1. Metal (specific amino acid) complexes: Obtained by complexing a soluble metal salt with a specific amino acid. These are most effective and efficiently absorbed in gut among all the organic minerals. Examples: zinc methionine, copper lysine and manganese methionine etc.

2. Metal amino acid complexes: Formed by a metal atom (zinc for example) complexed with several single amino acids. Each individual molecule is still one metal ion and one amino acid but has a variety of amino acids in the blend. Examples: zinc lysine, zinc leucine, zinc cystine, etc.

3. Metal amino acid chelates: Attained by the reaction of a metal ion from a soluble metal salt with amino acids having a mole ratio of one mole of metal to one to three (preferably two) moles of amino acids to form coordinate-covalent bonds. The molecular size of such chelates should not exceed 800 Dalton.

4. Metal proteinates: Resulted by chelation of a soluble mineral salt with amino acids and/or hydrolyzed protein. The final product may contain single amino acids, dipeptides, tripeptides or other protein derivatives.

5. Metal polysaccharide complexes: Prepared by coating the metal with polysaccharide molecules. These are larger molecules based on chains of simple sugars that are known to be highly soluble in the digestive tract.

6. Metal propionates: Obtained by combining soluble metals and soluble organic acids such as propionic acid. The resultant products are highly soluble and generally disassociate in solution.

7. Yeast derivative complexes: Other sources of organic trace elements that show promise are mineral enriched yeast. The most commonly used is the selenium yeast with selenium complexed with a methionine molecule (selenomethionine). Chromium enriched yeast gained acceptance for improving animal production (Rao *et al.*, 2012).

PREPRATION OF CHELATES OF TRACE MINERALS

Amino acid chelates of trace minerals are prepared by chemical reaction using 2:1 molar ratio of amino acid preferably methionine and inorganic trace mineral ions. Metal-amino acid chelate result from the reaction of a metal ion with amino acids at a mole ratio of one mole of metal to three (preferably two) moles of amino acids. In an amino acid chelate, the mineral is transformed into an organic form by the surrounding two or three molecules of amino acids. For example simplest amino acids glycine holds mineral by the carbon end of carboxylic group and the nitrogen end of amine group of the zwitterions, forming a five-membered ring, which is most stable of all chelate rings. Metal cations most often chelated are calcium, copper, iron, magnesium, manganese, potassium, and zinc. When a single chelating agent ligand binds to a cation, that cation is considered 'complexed'. If a metal cation is joined with an organic compound at two or more exchange sites to form a heterocyclic ring structure, then that structure is considered a metal chelate. Amino acids commonly used to chelate cation micronutrients include lysine,methionine, glutamic acid, cysteine, and histidine. Chelating reactions work fastest when both chelating agent and metal to be chelated are present in solution (Brown and Zeringue, 1994). Different preparation are available and are patented by the companies.

BENEFITS OF USING ORGANIC TRACE MINERALS FOR LIVESTOCK PRODUCTION

The progressive effects of organic minerals on animal performance seems mainly due to higher bioavailability as compared to inorganic sources. Several research activities conducted in different livestock species using the vibrant sources of different mineral elements revealed significant difference for bioavailability of organic and inorganic minerals (Nocek *et al.*, 2006, Wang *et al.*, 2010, Feng *et al.*, 2010, Yatoo *et al.*, 2013). There studies recommend that binding Cu, Zn, Fe and Mn with amino acids and peptides can boost the bioavailability of these trace minerals, thereby improved milk production, growth, reproduction and overall health status of livestock (Hackbart *et al.*, 2010, Somkuwar *et al.*, 2011). Supplementation of organic zinc produced better results than inorganic forms in terms of average daily gain and feed intake in steers, growing kids, calves and pigs as well as milk production in goats, ewes, and cattle (Ashmead and Samford, 2004). Trace mineral glycinate using glycine as a ligand can also be used as glycine is readily absorbed in gut and gets transported right into the cells. Supplementation of zinc with glycine chelate improves the growth performance of pigs (Wang *et al.*, 2010) and broiler birds (Feng *et al.*, 2010).

Effect on ruminants: Organic minerals have several beneficial effects such as production enhancer, increases quality of milk yield and also improves reproductive efficiency in ruminants (Griffiths *et al*., 2007, Hackbart *et al.*, 2010). Trace mineral absorption and tissue deposition from some organic source appear to be higher than from inorganic sources. Pal *et al.* (2010) revealed that the relative bioavailability values of Cu and Zn from Cu-methionine and Zn-methionine was found to be 33% and 52% higher than from inorganic copper and zinc sulphate, respectively in ewes. Effect on milk Supplementing cows with organic trace minerals in place of inorganic minerals increased the milk yield and milk fat level as reported by Nocek *et al.* (2006); Griffiths *et al.* (2007) and Hackbart *et al.* (2010). With the same level of supplementation to cows: Zn (15 mg/kg), Mn (20 mg/kg) and Cu (10 mg/kg) from chelated sources resulted higher milk yield (11%), milk fat and protein percentages (both approx.7%) when compared with inorganic sources (El Ashry *et al.*, 2012). Hassan *et al.*, (2011) reported that supplementation with 40% less Zn from chelated sources in ewes increased milk yield by 12% , also 26% and 31% increase in protein and fat production in

comparison with inorganic zinc sulphate source. In cows at late lactation less mineral supplementation to a tone of 40% from chelated sources resulted in 4% increase in milk yield as compared with 100% inorganic minerals (Somkuwar *et al.*, 2011).

Supplementation of inorganic chromium is very difficult because of its poor bioavailability in the feeds (Mowat *et al*., 1993 and Kegley *et al.* 2000). Owing to the situation, several organic chromium products such as chelated-Cr, Cr-enriched yeast, Cr-picolinate, Cr-nicotinate have been developed, claiming an improvement in biological availability of chromium (Yang *et al*., 1996). In the ruminant nutrition, Cr plays a vital role, especially during stress conditions such as transit stress or early lactation stress (Hong *et al.*, 2002). Supplementation of organic Cr has improved resistance to, or recovery from, stress and increased immune function (Hayirli *et al.*, 2001). Improved health and growth performance are invariably associated with reduction in stresses for example stress of late pregnancy, calving and early lactation in dairy cow. Several researchers have reported higher performance of calves with supplemental Cr as Cr-yeast, chelated-Cr during stress period (Rao *et al.*, 2012).

Supplementation to ruminants with zinc proteinate, zinc polysaccharide, zinc methionine or zinc glycine have a higher ruminal soluble zinc concentrations than those receiving inorganic zinc (Cao *et al.*, 2000). Nagalaxmi *et al.* (2018) have reported that growth performance and immunity status of buffalo calves were increased and comparable when organic zinc was replaced with inorganic zinc to an extent 75%. Zinc sulphate when fed in extremely high concentration has got a positive effect on rumen protozoa which affect the degradation of feed protein indirectly (Neathery *et al.*, 1973). The molar proportion of propionate tends to increase with higher dietary concentration of organic zinc such as Zinc methionine and tends to decrease the molar proportions of butyrate and valerate. Also, molar proportion of propionate tends to be higher with organic zinc (Zinc methionine) supplementation than inorganic zinc supplementation (Zinc Sulphate) (Wang *et al.*, 2013 and Kellogg *et al*., 2003). The increased propionate and decreased butyrate concentrations observed in organic zinc supplemented ruminants indicates an improvement in microbial efficiency of energy utilization (Arelovich *et al.*, 2014).

Studies revealed that the in-vitro addition of zinc chloride to rumen liquor significantly decreases the TVFAs and total protozoa count in sheep, while in case of goats a significant increase in ammonia along with a drastic decrease of total protozoal count (Tariq *et al.*, 2017). Also, significant enhancement in the activities of ALT, AST and GDH with inhibition of GGT activity was noticed in both sheep and goat (Mousa *et al.*, 2014). Inorganic zinc ions tend to have an inhibitory effect on the cellulolytic enzymes produced by the bacteria. Henceforth, it decreases the utilization of cellulose by rumen bacteria at higher concentrations. In *in-vitro* cellulolytic bacteria counts decreases with the increase in the ionic zinc levels (Arelovich *et al.*, 2014). In a remarkable study conducted by Černík *et al.* (2013), goats fed different organic and inorganic forms of zinc reported significant differences in the length, width and intensity of keratinisation of ruminal papillae. Well-developed papillae was found in kids supplemented with zinc in the form of zinc oxide (Kawashim *et al*., 1997). The utilization of Co by sheep fed dietary levels of 40 to 60 mg/kg was equal from cobalt-sulphate and cobalt-glucoheptonate (Henry *et al*., 1997, Kawashim *et al*., 1997). Similarly, the utilization of Fe from Fe-citrate, Fe-fumarate and Fe-gluconate is essentially equal to that of ferrous sulphate (Ammerman *et al*., 1995). Supplementing organic zinc @ 20 and 40 mg/kg of diet improved the immunity status of Ganjam sheep in comparison to non supplemented groups. (Sethy *et al*., 2018).

Effect on reproduction: Several studies have recommended that the organic trace minerals improve various manifestations of reproduction in cows, including an increase in pregnancy percentage (Nocek *et al.*, 2006; Defrain *et al.*, 2009), a reduction in open days and services per conception (Kellogg *et al*., 2003), and a decrease in days to first postpartum oestrus (Campbell *et al.*, 1999). Thus, leading to the economic production of the livestock. Supplementation of Amino acid chelated trace minerals could decrease the open days by 42 days and services per conception by 42% when compared with supplementation of inorganic mineral sources because amino acid chelated sources of minerals increase the concentration of specific minerals in their uterine tissue (Nocek *et al.*, 2006, Campbell *et al.*, 1999). Therefore, supplementation of minerals through organic sources is effective in ameliorating the reproductive problems in ruminants. Organic zinc is beneficial in enhancing resistance to mastitis because of postulated role of Zn in maintaining skin integrity and the keratin lining of streak canal (Hassan *et al.*, 2011). The udder health can be improved through reduction in somatic cell count in the herd by supplementing the organic mineral sources (Cao *et al.*, 2000). Supplementation of Zn-methionine has resulted in 22% decrease in somatic cell count on feeding a lower level and 50% decrease in somatic cell count on feeding higher level of Zn-methionine (Wang *et al.*, 2013 and Kellogg *et al.*, 2003).

Pig and poultry: In pig and poultry industry, it is a common practice to supplement the inorganic sources of minerals in the diet to prevent the trace mineral deficiency. Pig diets are often supplemented with excess trace minerals, often exceeding their physiological requirements. But, this over supplementation of inorganic trace minerals often results in poor bioavailability due to trace mineral interactions with other components in the diet and can result in large dietary trace minerals being excreted in the faeces which can lead to soil and surface water contamination. Thus, one of the

effective way to reduce the trace mineral concentrations in diets without affecting the animal's performance is the inclusion of organic sources of mineral that have higher bioavailability and greater body retention than the inorganic form. Studies revealed that the effective supplementation of the organic sources of minerals in the feeds of pigs and poultry enhances their performances (Abdallah *et al.*, 2009, Ao *et al*., 2011).

Organic trace minerals used in broiler feeds enhances the live performance, bird health and meat quality characteristics. Organically-complexed minerals such as zinc, manganese, selenium, copper and iron are the most commonly used (Deyhim and Teeter, 1997). Performance of laying hen and egg shell quality were found to be better in layers fed with Cu-methionine than those fed copper sulphate (Paik, 2001), whereas, significantly higher body weight gain, higher tissue deposition of minerals, better feed conversion efficiency and higher immunity have been observed in chicks fed diets containing same levels of inorganic and organic trace minerals (Abdallah *et al.*, 2009). Broiler birds fed with ration supplemented with 0.5 ppm Cr, organic source showed higher body weight gain than from inorganic source (Mohammed *et al.*, 2014). The Feed Conversion Efficiency of chicks fed on rations containing inorganic minerals is significantly inferior (1.74) than chick fed rations containing 100% organic minerals, which recorded the best feed conversion ratio (1.63) (Paik, 2001). Mineral proteinate fed chicken, displaying ascites was reduced from 5% to 2% when chelates were fed (Deyhim and Teeter, 1997). Ferket and Qureshi (1992) reported that in turkeys, zinc/manganese methionine enhanced humoral and cell mediated immune function. Ferket *et al*. (1992) found that the same chelate combination improved feed efficiency and reduced mortality and leg abnormalities in toms when supplemented on nutritionally adequate inorganic basal diets. Hence chelated form is advantageous than the inorganic form.

Researchers found that levels of organically complexed minerals can be reduced in broiler chicken rations without any negative effects on their performance (Bao *et al*., 2007; Nollet *et al*., 2008; Petrovic *et al*., 2009; Aksu *et al*., 2011a), antioxidant defense systems (SaripinarAksu *et al*., 2010), hematological and biochemical parameters (Aksu *et al*., 2011_b) and meat quality parameters (Aksu *et al.*, 2011_b). Supplementation of broiler birds with organic minerals at 25% of NRC requirement of trace minerals have no negative effect on body weight gain and feed intake (Pierce *et al.*, 2005). Leeson, (2003) reported that the use of organic trace minerals with greater bioavailability does not affect body weight gain and has little effect on feed efficiency of broilers even when fed at 20% of the inorganic trace mineral level, and reduces the environmental contamination due to lower excretion of minerals. The immunity as well as performance of chicks was enhanced with the replacement of inorganic trace minerals with organic trace minerals. (Ao *et al*., 2011).

In the nursery phase, when pigs are fed with mineral proteinates showed higher weight gain than pigs fed with the trace minerals exclusively from inorganic sulphates (Creech *et al.*, 2004). Also studies revealed higher mineral retention of organic minerals, such as Cu-lys in weanling pigs (Apgar *et al.*, 1995), Zn amino acid chelate in growing pigs (Susaki *et al*., 1999) and Cu and Zn proteinates in weanling pigs (Schiavon *et al*., 2000) than from their inorganic forms. Also, researchers showed light on similar performance (growth) in pigs at lower levels of inclusion of organic minerals than inorganic forms commonly used (Veum *et al*., 1995 and Fremaut, 2003).Weaning and growing pigs performed same or even better in the terms of growth rate and/or feed efficiency when fed with organic Cu source than pigs fed $CuSO_4$ and the levels of inclusion of inorganic Cu can be reduced by including Cu in an organic form without affecting pig performance (Schiavon *et al.*, 2000). Piglets in the post-weaning period fed with ration containing Cu-proteinate (50-100 mg Cu) is able to maintain growth performance when compared with the pigs fed with the level of 250 mg of Cu from $CuSO_4$ per kg diet (Apgar *et al.*, 1995). Growing and finishing pigs fed 40 mg of Cu from Cu-proteinate, with similar performance to those fed 150 mg Cu from $CuSO_4$ per kg diet. Also, 250 mg zinc-methionine (Zn-met)/kg diet or 300 mg Zn-polysacharide/kg ration supplementation (Huntington *et al.*, 2002) resulted in weanling pig performance equal to that obtained using 2000 mg ZnO/kg. Replacement of 15-36% of the inorganic minerals of Fe, Zn, Mn, Cu, Se and I in the mineral premix with proteinate forms increased average daily gain and gain: feed in weanling pigs (Veum *et al.*, 1995). Fremaut, (2003) observed that the growing and finishing pigs, fed with a ration containing all minerals (Zn, Fe, Mn and Cu) in the organic form (proteinate) at 30% of normal levels (36 mg Zn/kg, 39 mg Fe/kg, 18 mg Mn/kg and 7 mg Cu/kg), showed faster growth rate compared with that on feeding the normal levels (120 mg/kg Zn, 130 mg/kg Fe, 60 mg/kg Mn and 20 mg/kg Cu).Case and Carlson (2002) and Buff *et al.* (2005) shared similar growth performance in pigs on using reduced level (500 mg/kg) of Zn-polysaccharide complex (Zn-PS) as compared with pharmacological level (300 mg/kg) of ZnO.

CONCLUSION

It is concluded that minerals from organic sources have higher bioavailability than inorganic sources. Organic minerals can be included at much lower levels in the diet than the current recommendations for inorganic minerals, without any negative effect on broilers and pigs. It is suggested that minerals can be supplemented in combination of inorganic and organic sources at two-third and one-third levels of requirements, respectively to obtain the maximum performance in animals and poultry in a cost effective manner to enhance their economic production.

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