Journal of Experimental Biology and Agricultural Sciences

<http://www.jebas.org>

ISSN No. 2320 – 8694

MANGANESE AND ITS ROLE IN POULTRY NUTRITION: AN OVERVIEW

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Received – October 05, 2017; Revision – October 25, 2017; Accepted – December 17, 2017
Available Online – December 27, 2017

DOI: [http://dx.doi.org/10.18006/2017.5\(6\).749.754](http://dx.doi.org/10.18006/2017.5(6).749.754)

KEYWORDS

Manganese

Nutrition

Poultry

Trace elements

ABSTRACT

Manganese (Mn) is an important trace element in poultry nutrition and feeding due to its function in eggshell and bone development, enzymes function and metabolism of nutrients. The nutritional adequacy of Mn is necessary for the enzyme Mn-superoxide dismutase (SOD), therefore research dealing with this enzyme is of current interest. Manganese was reported to prevent perosis in young broilers and in laying hens dietary Mn deficiency decreases egg production and shell thickness. The present review paper reports an overview on the currently available literature related to the influence of different forms of dietary Mn on productive performance, meat and egg quality, fertility and hatchability indexes in poultry (broiler chickens, laying hens, breeders and ducks). Available studies demonstrated that organic sources of Mn such as aminoacids complexes, proteinates and chelates have higher Mn bioavailability compared to commonly used inorganic Mn forms; nevertheless, existing findings remain still controversial.

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Peer review under responsibility of Journal of Experimental Biology and Agricultural Sciences.

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1 Introduction

Manganese (Mn) is an essential trace element that is present in all tissues and it is fundamental for the normal metabolism of amino acid, lipid, protein, and carbohydrate (Aschner & Aschner, 2005; Zhu & Richards, 2017). The Mn-dependent enzyme family is composed by lyases, oxidoreductases, transferases, isomerases, hydrolases as well ligases. The Mn metalloenzymes include arginase, phosphoenolpyruvate decarboxylase, glutamine synthetase, as well Mn-superoxide dismutase (Mn-SOD). In particular, MnSOD is significantly expressed in organs including an elevated mitochondria number such as heart, liver and kidneys (Li et al., 2011; Bai et al., 2012; Zhu et al., 2016). Among tissues expressing MnSOD in human (Marklund, 1980), mice (Jones et al., 1995) and chicken (Kong et al., 2003; Zhu et al., 2016), heart has the highest steady state mRNA expression level. Previous trials using chickens stated that, even if Mn level is significantly lower in heart when compared to other tissues, the activity of MnSOD is higher and very sensitive to supplemental Mn levels in corn-soybean diets (Luo et al., 1991; Luo et al., 1992). In addition, the MnSOD activity in birds' liver and pancreas is not influenced by dietary supplemental Mn (Luo et al., 1992), and MnSOD mRNA level in heart is constantly susceptible to supplemental Mn concentrations in diets containing corn and soybean meal (Luo et al., 2007; Li et al., 2011; Lu et al., 2016).

The Mn is implicated in the function of many organ systems. It is fundamental for normal immune function, regulation of sugar in blood, cellular energy, digestion, reproduction, growth of bone, and it aids in mechanisms defense against free radicals (Aschner & Aschner, 2005; Dominguez, 2013). The Mn together with the vitamin K helps blood hemostasis and clotting. Insufficient dietary consumption, and then Mn deficiency, determines growth problems, reduced bone development and skeletal imperfections, decreased fertility and birth alterations, atypical glucose tolerance, and defects to carbohydrate and lipid metabolism (Freeland-Graves & Llanes, 1994; Keen et al., 1999; Freeland-Graves et al., 2016). While naturally happening states of deficiency have not been documented, the Mn-induced neurotoxicity from excess respiratory or dietary exposures has been well reported. It has been suggested given its sequestration by mitochondria, Mn interferes with respiration, thus leading to high reactive oxygen species (ROS) production. Moreover, Mn is a key trace element for the blood cells development and function of immune system (Bao et al., 2007; Yildiz et al., 2011; Favero et al., 2013). Furthermore, Mn is necessary for mucopolysaccharides formation that are activated for the glycosyltransferases, the main proteoglycans constituents, and these proteins are essential for the growth of bone plate and for the formation of the poultry bone cartilage (Leach & Gross, 1983; Zamani et al., 2005; Peric et al., 2007; Yildiz et al., 2011; Favero et al., 2013). Likewise, keratin

and dermatan proteoglycans are implicated in the formation of the eggshell matrix (Zamani et al., 2005; Zhang et al., 2017). Therefore, the present review paper reports an overview on the currently available literature related to the influence of different forms of dietary Mn on productive performance, meat and egg quality, fertility and hatchability indexes in poultry species such as broiler chickens, laying hens, breeders and ducks.

2 Manganese bioavailability

Manganese is only scantily absorbed from the intestine; on the other hand, the Mn absorption happens into mucosa cells throughout small intestine (Kies, 1987). The Mn excretion through bile and pancreatic juice seems to be more important than the absorption in maintenance of Mn homeostasis even if young animals appear to be deficient in the capacity to excrete Mn. It was stated that Mn is apparently absorbed in the +2 valence state and participates with I and Co for the same sites of absorption (Fairweather-Tait, 1992; Ochiai, 1995; Galán & Drago, 2014). Three of the many determinants of absorption and retention of Mn are: i) developmental status; ii) dietary constituents; and iii) element translocation of membrane (Kies, 1987). Nevertheless, much of the information about the absorption of Mn has been assessed thanks to animal experiments with the assumption made that these mechanisms also apply to humans. Other nutrients have been reported to affect the Mn absorption (Aschner & Aschner, 2005; Zhu & Richards, 2017). The absorption of Mn has been reported to be related to high consumption of Ca in with diet. The probable relationship of Ca, Mn and health of bone may be of significance in the osteoporosis occurrence. Given that Fe and Mn participate for binding sites in intestine it is not unexpected that the dietary I could inhibit the Mg used (Kies, 1987; Zhu & Richards, 2017).

Manganese is important for the mucopolysaccharides synthesis, and a lack of this trace elements in poultry feeding can determine a state of perosis, a decrease in egg production, as well as poor eggshell development (Brooks et al., 2012; Świątkiewicz et al., 2014). Dietary inclusion of Mn in diets for poultry is commonly supplied using inorganic mineral salts; however, the bioavailability of inorganic mineral salts resulted very low, determining high levels of these minerals in poultry excreta (Bao et al., 2007). In addition, high levels of Ca and P have been assessed to decrease the bioavailability of Mn in poultry (Wedekind & Baker, 1990; Świątkiewicz et al., 2014). Nevertheless, it has been reported that an excess of Ca in diet has poor or no influence on the absorption of Mn and that any effects can be ascribed alone to dietary P (Wedekind & Baker, 1990). The phytic acid along with fiber has also been correlated to a decrease in Mn absorption (Halpin et al, 1986). The organic mineral supplements in diet may provide higher Mn

bioavailability in poultry species due to the occurrence of antagonists in comparison to the inorganic sources. In poultry, the Mn methionine was reported to be more bioavailable compared to the MnO (Fly et al., 1989; Hilal et al., 2016) or MnSO₄ (Henry et al., 1989; Bai et al., 2012). Most organic sources of Mn used are bound to amino acids, which are thought to amplify the bioavailability by reducing complex formations with phytate Ca, P or fiber during the digestion process. Given that poultry have a much higher requirement for Mn compared to other livestock species, it would be helpful to include supplemental Mn in diet with lower levels of organic mineral sources, therefore increasing the efficiency of Mn absorption and reducing the concentrations in animals' excreta (Brooks et al., 2012).

In many experiments, sources of organic Mn resulted more bioavailable compared to inorganic Mn sources (Fly et al., 1989; Henry et al., 1989; Ji et al., 2006; Lu et al., 2007). The Mn bioavailability of three organic Mn commercial products (Mn-Met E, Mn-AA A, and Mn-AA B) were compared (Li et al., 2008; Li et al., 2011). Glycine (Gly) has the smallest molecular weight of all amino acids, consequently it might be supposed that Mn as Mn-Gly chelate would be the most simply absorbed of all Mn-AA chelates if the chelates could be absorbed into the mucosal cell and then transferred across gut wall in an intact form (Ji et al., 2006). Methionine is the first limiting AA for broiler chickens, and Mn-Met might become a commonly utilized metal-AA complex in poultry production. Results from Ji et al. (2006) reported that the ileum is the main site of the absorption of Mn in broiler chicks, and Met is more effective in helping Mn absorption than Gly as ligand. The organic form of Mn results more efficiently absorbed than inorganic Mn form as MnSO₄; the absorption of organic Mn with moderate and strong complex strengths is higher than that of the organic Mn form, which is weak, and the organic Mn absorption with strong complex strength is higher than that of organic Mn with moderate strength.

The Mn-propionate relative bioavailability, compared to Mn-sulfate, was investigated by Brooks et al. (2012) in chickens fed a corn-soybean meal-based diet. In this study, the diets included 0, 20, 100 and 500 mg of Mn/kg and assessed for growth, feed consumption and efficiency. The study reported that Ca and P levels increased in diet in comparison to standard diet to see whether, when chickens were challenged using antagonists, a variation was found between Mn-sulfate and Mn-propionate. From their results, no differences were observed for any growth traits for either mineral level or source in diet. In particular, the relative bioavailability of Mn propionate resulted of 139% compared to Mn sulfate, when using the relative slope assay. Thus, organic Mn propionate improved the relative bioavailability compared to the commonly used inorganic feed-grade Mn sulfate in presence of high levels of Ca and P in diet.

3 Manganese in poultry diet

Manganese is a key trace element on poultry for the normal formation of bone, metabolism of amino acid as well enzyme function (Scott et al., 1976). The Mn utilization has become an increasing matter due to the very high growth rate of commercial broiler chicken strains, putting further stress on the structure of bone (Ji et al., 2006).

It was assessed that Mn is a potent antioxidant agent that can be supply to poultry diet in order to enhance the shelf-life of meat (Li et al., 2011; Fouad & El-Senousey, 2014). Furthermore, the Mn helps to reduce the abdominal fat level in broiler carcasses. Sands & Smith (1999) first reported that supplementing Mn in as Mn proteinate at the rate of 240 mg/kg diet decreased the abdominal fat level as a percentage of the broiler carcass weight. Moreover, Lu et al. (2007) conducted a trial using broiler chickens to study the influence of increasing levels of inorganic Mn (0, 100, 200, 300, 400 and 500 mg/kg diet, respectively) on abdominal fat deposit and to clarify the effects of Mn on the metabolism of lipid. This study assessed that including of 100 mg/kg Mn in broiler diet containing 23 mg Mn/kg reduced considerably carcass fat pad by down-regulating the activity of lipoprotein lipase (LPL). In another experiment, Lu et al. (2007) evaluated the response on broilers fed diets supplemented with Mn-sulphate (as inorganic Mn source) and Mn amino acid (as organic Mn source) on abdominal fat deposition. the authors demonstrated that Mn source (organic or inorganic) did not influence the abdominal fat deposition, conversely the level of Mn in diet significant affected the body fat content, in particular, diets including 100 mg of Mn from organic or inorganic sources decreased the carcass fat deposition by reducing the LPL activity and increasing the hormone-sensitive lipase (HSL; lipolysis) activity in the abdominal fat.

Manganese is an important nutrient also for laying hens, and its deficiency determines a significant reduction of egg production, eggs having thinner shells and translucent areas as well anomalies in the ultrastructure of egg-shell (Leach & Gross, 1983; Mabe et al., 2003; Yildiz et al., 2011; Rubio Zapata, 2016). Moreover, the Mn is fundamental the polysaccharides synthesis, and a deficiency of Mn lead to eggshell content of hexosamine and hexuronic acid (Leeson et al., 2001). Further, a diet resulting deficient in Mn have a negative effect on eggs hatchability. A deficiency of Mn can determine a shortened long bone, parrot beak and wiry down (Favero et al., 2013). In addition, the Mn absorption in the intestinal tract is very low (Leeson et al., 2001). Manganese is absorbed by binding divalent metal ion transporters (Aksu et al., 2010), and the Mn retention in poultry body is around equal to 0.2% (Peric et al., 2007). In poultry feed, organic Mn sources are AA complexes, proteinates and chelates. The chelated and complexed Mn bioavailability is related to the chemical

characteristics that are enhanced by chelation efficiency and the organic ligand percentage (Yildiz et al., 2011). Available literature reported that the organic sources of Mn are more bioavailability compared to the inorganic sources. However, some studies found no differences in Mn bioavailability among organic and inorganic sources (Li et al., 2008; Yildiz et al., 2011). The Mn requirement for laying hens is approximately from 30 to 200 mg/kg, but this is dependent on response criteria, cycle of production, age of the hens, production phase and Mn availability in the raw ingredient (Yildiz et al., 2011). The Mn toxicity by interfering with Mg is related to Na accumulation and excessive K in the tissues (Watts, 1990). As a result, high Mn level can interfere with the aminolevulinic acid synthesis that averts the metabolism of Fe (Aksu et al., 2010). In a study, Zamani et al. (2005) investigated the influences of dietary supplementation in laying hens of a combination of Zn and Mn on their productive performances and egg breakage. The Hy-line W-36 hens at 28 weeks of age were used and were fed with corn-soybean based diets containing 50 mg/kg Zn (as Zn oxide) and 30 mg/kg Mn (Mn oxide). The findings reported that Mn and Zn alone, and in combination, reduced the broken eggs number but did not influence the number of eggs produced, feed intake, and feed efficiency. In another study on laying hens, Yildiz et al. (2011) investigated the effects of dietary Mn organic and inorganic sources at 5 increasing levels (15, 30, 45, 60 and 75 mg/kg) for 12 weeks on hens performance, egg quality traits as well on bone mineralization. Supplementing diet with Mn in aged laying hens enhanced eggshell thickness and breaking strength by improving the deposition of uronic and glycosaminoglycan in eggshell membrane (Xiao et al., 2014; Xiao et al., 2015; Fouad et al., 2016). The Mn level in corn-soybean meal based diet results sufficient to satisfy laying performance and egg quality also in laying ducks, but the addition of 90 mg Mn/kg diet is required to enhance the activity of Mn-superoxide dismutase (SOD) and total superoxide dismutase (T-SOD) and promote the Mn content in egg yolk (Fouad et al., 2016). Xiao et al. (2015) demonstrated that feeding aged laying hen with either organic or inorganic Mn sources enhanced notably the eggshells thickness, elastic modulus and breaking strength in comparison to supplemented-diet. Moreover, the authors reported that the bioefficacy of organic Mn resulted as follows: 357% (shell thickness), 458% (elastic modulus), 406% (breaking strength) and 470% (eggshell Mn), as successful as inorganic Mn source at equimolar level. The same authors concluded that organic form of Mn improves eggshell quality in aged laying hens compared to inorganic form of Mn.

4 Concluding remarks

In overall, the available literature indicated that level of Mn in the diet may influence the poultry performance. The egg production and weight result higher with a dietary Mn level higher than the

estimated requirement reported by National Research Council (1994). Both the Mn inorganic and organic forms as dietary additive are normally supplemented to poultry diet to improve the performance traits, egg production and quality. If compared to inorganic Mn forms, organic Mn sources were found to have various advantages, such as protection from undesired chemical reactions in gastrointestinal tract, easy passage integral through the intestine wall with different absorption level, metabolic pathway and mechanisms. Many available studies demonstrated that organic sources of Mn such as AA complexes, proteinates and chelates have higher Mn bioavailability compared to commonly used inorganic Mn forms; nevertheless, available findings remain still controversial.

Disclosure statement

Authors declare that no conflict of interest could arise.

Conflicts of interest

All authors declare that there exist no commercial or financial relationships that could in any way lead to a potential conflict of interest.

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