__Review Article__

A REVIEW: THE EFFECT OF TRACE MINERAL SUPPLEMENTATIONS ON EGG PRODUCTION AND QUALITY

ABSTRACT

This review aimed to study and discuss the effects of organic and inorganic sources of trace minerals; zinc, copper, and manganese in the diet of laying hens on egg production and quality. These trace minerals are required in producing proteins that are involved in various biochemical reactions, hormone secretion pathways, eggshell formation, antioxidative properties, immune system defence, etc. The results of different studies were not always consistent, mainly concerning the egg quality indices; however, most of the findings have shown positive effects of these trace minerals on laying hens. Recent studies have shown organic minerals are a more effective source than inorganic. The benefit of using organic sources is their lower inclusion rates due to their better absorption rate and the low output through excreta.

Keywords: trace minerals, egg production, egg quality, Zinc, Copper, Manganese, Iron, Chromium

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INTRODUCTION

Minerals are important micronutrients which require for various anabolic and catabolic biochemical reactions and different physiological functions. Minerals are needed for the production, growth, and reproduction of animals. Minerals in poultry nutrition are mainly classified into macrominerals and micro/trace minerals depending on the levels needed in the diet. The macro minerals mainly include Calcium (Ca), Phosphorus (P), Chlorine (Cl), Magnesium (Mg), Potassium (K), Sodium (Na) and Sulphur (S). And the micro minerals mainly include Cupper (Cu), Iodine (I), Iron (Fe), Manganese (Mn), Selenium (Se) and Zinc (Zn). Trace minerals are required in producing proteins which are having a role in various biochemical reactions, hormone secretion pathways, eggshell formation, antioxidative properties, immune system defence, etc (Tom Dieck et al., 2003; Yatoo et al., 2013).

The feedstuffs usually added in poultry diets present marginal deficiency of minerals. To avoid such deficiencies, feeds are commonly supplemented with inorganic sources, such as carbonate, sulphate, or chloride salts. But, due to the pH variations that naturally occur in the digestive tract of poultry, there are chances of antagonism and interactions among the trace minerals, as well as with other compounds may occur and prevent their absorption into the body (Saripinar et al., 2012). The organic form of trace elements may protect against the formation of indigestible complexes with some other anti-nutritive dietary compounds in the gastrointestinal tract and mineral antagonisms. The benefit of using organic sources is their lesser inclusion rates due to their better absorption rate and the low output through excreta (Zafar et al., 2018).

Numerous studies have demonstrated that consuming trace minerals enhances the quality of eggs. As cofactors of specific enzymes, microelements like Zn, Mn, and Cu have an impact on the mineralization and microstructure of eggshells, which can have an impact on egg quality. For example, Zn as a cofactor of carbonic anhydrase is closely linked to eggshell formation (Li et al., 2019); Mn is a cofactor of metalloenzymes necessary for the synthesis of carbonate and mucopolysaccharides and is important in the formation of eggshells (Swiatkiewicz et al., 2008); Fe increases egg production while also increases blood haemoglobin (Taschetto et al., 2017); and Cu serves as a component of lysyl oxidase, and a deficiency of Cu led to abnormal eggshell formation (Gheisari et al., 2011). The absorption of inorganic trace minerals is constrained by interactions with dietary components and cross-interactions between various trace minerals (Xie et al., 2019). A pictorial representation of various effects of trace minerals in egg production and egg quality is given in Fig. 1. In this article, we are going to discuss the effects of organic and inorganic sources of various trace minerals on egg production and quality.

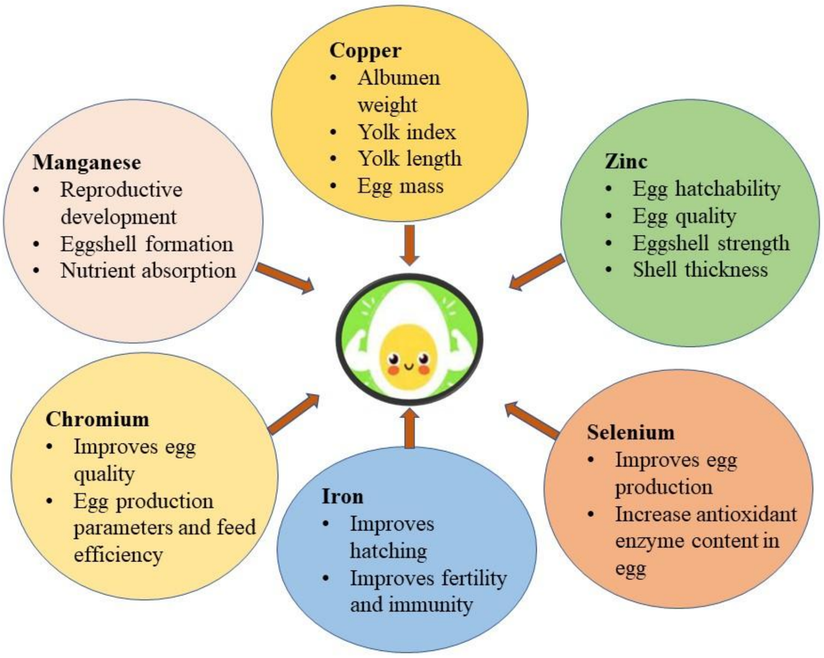

Fig 1. Pictorial representation of various effects of trace minerals in egg production and egg quality

<u>ZINC (Zn)</u>

Zinc is an important egg component. Supplementation of zinc in the diet shows visible effects on egg hatchability and egg quality. Zinc is a cofactor of carbonic anhydrase, which catalyses the conversion of carbon dioxide into bicarbonate ions, and it influences the crystal and texture morphologies of the shell, which is directly related to the formation of eggshell (Li et al., 2019).Supplementing broiler breeder hens with a combination of inorganic and organic zinc sources have improved the quality of eggshell and reduced the chances of laying the cracked egg. The sources used in the study were zinc sulphate (ZnSO4) andzinc amino acid complex (ZnAA). The hens supplemented with the combination of these two showed the highest hen-housed egg production (Hudson et al., 2004). Supplementation of Zinc, Copper & Manganese resulted in greater shell thickening indicating better eggshell formation (Stefanello et al., 2014). The use of organic Zinc supplements as zinc chelate increased both eggshell strength and thickness in older hens (Manangi et al., 2015). Another study on older hens using zinc amino acid complex as the source also showed similar results (Swiatkiewicz et al., 2008). Supplementing a diet with 40 ppm of organic Zinc to laying quails positively affected the fertility, hatchability, and weight of eggs (Abd El-Sameeet al., 2012). Dietary Zn supplementation could improve performance and shell quality in laying ducks at the late phase of production when supplemented at 80ppm (Zhang et al., 2022). These studies show the positive effect of zinc on egg production.

But some other studies indicated the negative effect of zinc supplementation on egg quality and production. When hens were supplemented with zinc methionine (Zn-Met) and zinc manganese methionine (Zn-Mn-Met), they showed decreased egg production and the highest incidence of softshell and broken eggs (Lim et al., 2003). A reason for this may be the antagonistic interaction of zinc and manganese while they compete for absorption sites. Another experiment with organic zinc in post-moult hens resulted in a significant decrease in mortality and an increase in egg production, but a reduction in egg albumen and shell weight also followed (Stanley et al., 2012). A study done by Stahl et al. (1986), showed no benefits of zinc supplementation except for a reduction of feather fraying. In this study, a basal diet containing 28 ppm of zinc was supplemented with zinc at four different levels (0, 10, 20, and 40 ppm). There were no significant differences in egg production, feed intake, fertility, or hatchability noticed, making the researchers conclude that the level of zinc in the basal diet was sufficient for normal production parameters and extra supplementation was not necessary. On critical review, more studies suggest that extra zinc supplementation has positive effects on laying hens.

<u>MANGANESE (Mn)</u>

Manganese is an essential nutrient for poultry. Birds require an adequate amount of manganese in their diet for reproduction, development, eggshell formation, nutrient absorption, and preventing perosis. Research conducted to assess Manganese requirements of broiler breeder hens showed when hens were fed diets having 48.5 to 168.2 ppm Mn the number of defective, cracked and contaminated eggs decreased, and the hatchability and the eggshell thickness increased (Noetzold et al., 2020). An experiment conducted to find the effects of environmental temperature and dietary Manganese on egg production performance and egg quality of broiler breeders found that dietary supplementation of either inorganic or organic Manganese improved eggshell strength and thermo-tolerance and the organic Manganese could alleviate the detrimental effect of heat stress on egg production (Zhu et al., 2015). A work conducted for comparing the effects of supplementation of manganese from its inorganic and organic sources (Manganese sulphate or Manganese chelate of protein hydrolysate or Mn- chelate of glycine hydrate) on performance and some parameters of egg quality of laying hens showed, the weight, thickness and index of eggshell were noticeably increased in all the groups supplemented with Manganese. And also found feed supplementation with organic manganese sources is more effective for preventing yolk lipid peroxidation during the cold storage of eggs than that from an inorganic source (Venglovska et al., 2014).Particularly at the supplement level of 40 mg/kg, inorganic Mn increased egg production and mass while decreasing FCR in laying ducks (Zhang et al., 2022). Along with these positive effects, some studies claimed Manganese does not have much effect on egg production. A study on laying ducks, fed with 15, 30, 45, 60, 75, or 90 mg Mn/kg in the form of Manganese sulphate for different treatment groups showed that dietary Manganese supplementation didn't affect the egg production, egg mass, and egg quality but higher levels increased manganese content in their egg yolk.

COPPER

Copper is related to iron metabolism and absorption, elastin and collagen synthesis, bone formation, feathers development, etc and it is a part of blood protein (Scheideler, 2008; Uauy et al., 1998). In an experiment to compare the effect of organic and inorganic copper sources for poultry, that diet supplementation with organic Copper (yeast enriched) increased copper concentration in the egg content and eggshell, which proved the superior availability of organic copper compared to inorganic copper sulphate (Dobrzanski et al., 2008). Bovan Nera layers of twenty weeks old were used for the twelve-week experiment to find the effects of two sources of dietary inorganic copper supplementation (Copper Oxide and Copper Sulphate) in layer diets. The various levels of inclusion with the two dietary sources of copper had a significant influence on the egg albumen weight, albumen height, yolk index, yolk length and egg mass. The study concluded that the hen could tolerate these two Cu sources up to 300 mg/kg without any detrimental effects on the egg qualities (Adu et al., 2017). These studies showed the advantages of copper supplementation in poultry diets. But in an experiment using Lohmann Brown hens of 16 weeks of age, to compare three different supplemental dietary copper sources on layer performance and egg yolk cholesterol, layers were fed diets containing 0 (control) or 250 ppm of Cu from Copper sulphate, Copper proteinate, or Copper lysine for 24 weeks. No differences were observed between Copper sources for body weight, egg mass, egg specific gravity and egg yolk cholesterol. Supplementation with 250 ppm of Coppersulphate improved egg production but reduced egg weight as compared to the other diets. Supplementation with Copper proteinate resulted in decreased feed intake. The eggshell thickness of layers fed with the Copper sulphate and

Copper lysine diets was lower than the shell thickness of layers fed with the control diet (Pekel et al., 2011).

IRON

One of the most crucial trace elements for poultry is iron (Abbasi et al., 2015). Iron increases egg production along with increasing blood hemoglobin without influencing the eggshell color or egg components(Taschetto et al., 2017). It participates in a variety of crucial processes, such as the movement and storage of oxygen, energy supply, protein metabolism, antioxidant activity, and immunity (von Drygalski and Adamson, 2013; Abbaspour et al.,2014). Dietary iron content affects egg quality and hatchability, hen hematocrit and haemoglobin, and lay performance (Taschetto et al., 2017). Egg iron concentration could be increased by providing a suitable concentration of Fe (Bess et al., 2012). According to research, amino-chelated or proteinated sources of iron are preferable to FeSO4 as a form of iron supplementation (Creech et al., 2004, Mohammadi et al., 2015). Then again, other studies discovered that the inorganic and organic sources (amino acid complexes) were equivalent in terms of mineral retention and eggshell quality (Xie et al., 2019). When Fe-Lys-Glu was given to hens at a dosage of 45 mg/kg, the yolk Fe content was higher ($p < 0.05$) than when FeSO4 was added at the same dosage (Cao et al., 2022). Fe-Gly supplementation increased egg quality and iron enrichment when given at a rate of 60 mg Fe/kg. According to the study, there were no appreciable differences between the control group and the Fe-Gly (40 mg Fe/kg) group in terms of albumen height, Haugh unit, or Fe concentration in the eggshell and yolk. This study showed that a lower concentration of Fe-Gly could replace $FeSO_4$ and that Fe-Gly might even be better for laying hens' eggs than FeSO4 (Xie et al., 2019).

Fe recommendations found in the literature at the moment are based on statistical analyses and estimates derived from a variety of models (Taschetto et al., 2017). It's relevant to note that the majority of recent references for the use of Fe focus on fast-growing broiler breeder lines like Arbor Acres, Cobb, etc. There is a lack of information on feeding slower-growing hens the right amount of Fe supplements (Gou et al., 2020).

SELENIUM (Se)

Selenium, an essential element in birds, is a crucial component of the unusual amino acids selenocysteine and seleno-methionine in laying hens. The physiological status, immune response, and growth performance of chickens were all improved by Se supplementation.

Better growth performance and immune response were seen in chicken-fed organic diets supplemented with Se (Elnaggar et al., 2020). Several enzymes, including glutathione peroxidases and some varieties of thioredoxin reductase, use selenium as a cofactor for their antioxidant activity (Rotruck et al., 2010, Ferguson et al., 2012). Se additives can be added to the diets of hens to produce selenium-enriched eggs.

Sodium selenite (SS), an inorganic source of selenium, is one of the most well-known Se enhancements used, but organic sources showed a better effect than SS (Muhammad et al., 2021). Compared to other sources of Se, organic Se increased Se deposition in the egg and improve egg quality (Asadi et al., 2017). Due to the animal's better utilisation and absorption of Se yeast, some researchers suggested it might be a more advantageous organic source of selenium than other selenite sources (Delezie et al., 2014; Hanet al., 2017). When compared to the Se non-fed group, organic Se-fed hens significantly ($p < 0.05$) increased eggshell-breaking strength and Haugh unit (Muhammad et al., 2021). There was no difference in egg weight, Haugh units, yolk colour, eggshell strength, or eggshell thickness when selenium nanoparticles were added to laying hens' feed (Qu et al. 2017). Urso et al. (2015) showed that increasing the Se in the diet by 0.15 to 0.3 mg/kg caused an increase in the Se content of egg yolks. Laying hens produce eggs at significantly higher rates when selenium levels are increased in their diets, and selenium yeast (0.5 mg/kg) supplementation is more effective than sodium selenite at increasing selenium deposition in the yolk (Liu et al., 2020). Hens-fed nano-selenium at a level of 0.2 mg nano-Se/kg diet might lessen the severe effects of heat stress in hot desert conditions, and it can have a positive impact on productive performance and egg quality (Elfiky et al., 2021). However, when laying hens were given glycine nano-selenium (NS-Gly) at 0.60 mg Se/kg as a feed supplement, there was no difference between the treatment groups in terms of egg quality (Zhou et al., 2022).

IODINE (I)

Iodine-enriched eggs could be a good source of iodine in the human diet because some people in developing nations suffer from iodine deficiency diseases. According to the WHO 2019, 8.5% of the world's population consumes less iodine each day than is necessary. It is a crucial microelement for egg-laying hens as well. It is a part of the thyroxin hormone, which controls body metabolism and has a significant impact on the development and productivity of hens (Lewis, 2004). Iodine can be added to poultry diets in the form of inorganic salts like potassium iodide (KI), potassium iodate (KIO3), and calcium iodate (Ca(IO3)2; CIOD), or it can be added as an organic salt to mineral mixtures like ethylenediamine dihydroiodide (EDDI) (European Commission 2016).

The increased iodine content may also have an antibacterial effect on the egg yolk, adding to the value of eggs as nutritious food items. Iodine helped to improve production performance indices like laying production, egg weight, and FCR when I was added to diets for laying hens (Damaziak et al., 2018). This study found that adding 10 mg/kg of calcium iodate to the diet improved the laying performance of hens in terms of egg production, egg weight, and feed conversion efficiency. However, another study discovered that as iodine supplementation increased to 8 mg/kg, egg production gradually decreased (Sarlak et al., 2020). When hens were fed diets containing 3.13 mg I/kg, they produced eggs with higher eggshell strength than those produced by hens fed diets containing 10.65 mg I/kg (Bakhshalinejad et al., 2018).

<u>CHROMIUM (Cr)</u>

In the poultry industry, heat stress is one of the major environmental stressors that contribute to poor performance, an imbalance in the antioxidant system, and compromised immune and health statuses in egg-laying birds around the world (Sahin et al., 2018, Luo et al., 2018). Cr supplementation in a poultry diet can lessen the effects of heat stress on laying hens' egg production by acting as an allostatic modulator or feed additive (Sahin et al., 2018). Cr's potent antioxidant properties may help to reduce the risk of lipid peroxidation brought on by heat stress (Stpniowska et al., 2020).

When exposed to heat stress, laying ducks' laying rate, egg quality (yolk colour score, albumen height, and Haugh unit linearly), and antioxidant function may all benefit from dietary supplementation with Cr in the form of chromium propionate, especially at 800 g/kg (Chen et al., 2021). Cr functions as a structural element of egg albumin or in protein cross-linking, which is required for the synthesis of albumen proteins and makes it easier for cations to enter egg albumin during the uterine process of uterine enlargement, and it is proposed that Cr is required to preserve albumin's physical state (Khan et al., 2014). When laying hens were under heat stress, adding Cr, Zn, or Vit C (400 g/kg diet, 30 mg/kg diet, or 250 mg/kg diet, respectively) increased some egg quality parameters (Karami et al., 2018). Sahin et al. (2018) reported an improvement in the Haugh unit of eggs when birds were supplemented with chromium histamine. But Siloto et al., (2021) reported, there was no significant impact on the bird's feed intake, egg weight, egg production, egg mass, intact eggs, feed conversion ratio, or egg quality when four levels of Cr supplements (0, 0.2, 0.4, and 0.8 ppm as chromium yeast) were fed to the birds.

Effects of trace minerals on egg quality based on recent studies conducted

Table 1: Effect of organic trace mineral supplementation on egg production and quality

Supplementation	**Bird species/ breed/ variety**	**Results**	**Reference**
80 and 120 mg Zn-methionine/kg	Laying hens	Eggshell thickness significantly improved	Mehrabani et al., 2021
Copper Polysaccharide complex at 8 and 4 mg/kg diet	Isa Brown hens	Reduced egg yolk cholesterol contents Reduction of cracked egg percentage	El-Katcha et al., 2022
25% sulfate Manganese and 75% organic Manganese chelated	Leghorn laying hens	The lowest feed conversion ratio Increased egg production, egg weight, and egg mass	Khoshbin et al., 2022
0.3 mg/kg of Se from Se yeast	Laying hens	Increased the egg yolk color	Wang et al., 2022
2 or 4 mg/kg of iodine as Ethylenediamine dihydroiodide	Shaver white layers	Increased the iodine content of eggs	Sarlak et al., 2020
Organic Cr (400 µg/kg)	Layer chickens	Improved shell-breaking strength, shell weight, and shell thickness	Sathyabama et al., 2017
75 mg Fe/kg as Fe-	Beijing White laying	Decrease in feed	Cao et al., 2022

Lys-Glu	hens	conversion ratio Increased the laying rate and average daily egg weight	

Table 2: Effect of inorganic trace mineral supplementation on egg production and quality

Supplementation	**Bird species/ breed/ variety**	**Results**	**Reference**
ZnSO4 at 80 mg/kg	Longyan laying ducks	Improved egg production (4.3%) Increased egg mass (5.7%) Reduced FCR (2.9%) The shell-breaking strength (15.8%) was higher Improved shell ultrastructure	Zhang et al., 2022
Application of copper waterline	Laying hens	Increased egg weight Increased the Cu level in eggshell	Ma et al., 2022
40 mg/kg $MnSO_4$	Longyan laying ducks	Egg production and mass increased, and FCR decreased Increased egg albumen height and Haugh unit	Zhang et al., 2022
2 or 4 mg/kg of iodine as calcium iodate	Shaver White layers	Increased the iodine content of eggs without adverse effects on hen performance and egg quality traits	Sarlak et al., 2020
800 μg/kg Cr as	Laying ducks	Improved laying rate	Chen et al., 2021

chromium propionate		increase in albumen height and the Haugh unit	
30, 60, and 120 mg/kg of added iron as ferrous sulfate	Shaver White layers	Enhanced laying rate, egg weight, and egg quality	Sarlak et al., 2021

CONCLUSIONS

In reviewing the research data, it can be concluded that most of the works done on poultry about the effect of trace minerals on egg production and quality have shown the efficacy of organic and inorganic sources of zinc, copper and manganese-added feedstuffs are superior to traditionally used ones. Among these two, organic sources are showing better results than inorganic ones. However, some studies perhaps have shown the null effect or negative effect of these minerals when they are added extra to the basic diet. Consequently, adequate levels of dietary organic and inorganic trace minerals can be added with positive influences on egg production indices, egg quality measurements, and the growth performance of birds.

REFERENCES

1. Abbasi, M., Zaghari, M., Ganjkhanlo, M., &Khalaji, S. (2015). Is dietary iron requirement of broiler breeder hens at the late stage of production cycle influenced by phytase supplementation?. Journal of Applied Animal Research, 43(2), 166-176.
2. Abbaspour, N., Hurrell, R., &Kelishadi, R. (2014). Review on iron and its importance for human health. Journal of research in medical sciences: the official journal of Isfahan University of Medical Sciences, 19(2), 164.
3. Abd El-Samee, D. L., El-Wardany, I., Ali, N. G., & Abo-El-Azab, O. M. (2012). Egg Quality, Fertility and Hatchability of laying quails fed diets supplemented with Organic Zinc, Chromium Yeast or mannan-oligosaccharides. *International Journal of Poultry Science*, *11*(3), 221-224.
4. Adu, O. A., Olarotimi, O. J., Olayode, S. O., &Adelowo, A. O. (2017). EffEcts of DiEtarysupplEmEntation of coppErsulphatEanDcoppEroxiDE on somE Egg Quality paramEtErs of laying hEns. *Slovak Journal of Animal Science*, *50*(3), 118-127.
5. Bakhshalinejad, R., Hassanabadi, A., Nassiri-Moghaddam, H., &Zarghi, H. (2018). The effects of dietary calcium iodate on productive performance, egg quality and

iodine accumulation in eggs of laying hens. Journal of animal physiology and animal nutrition, 102(3), 746-754.

6. Bess, F., S. L. Vieira, A. Favero, R. A. Cruz, and P. C. Nascimento. 2012. Dietary iron effects on broiler breeder performance and egg iron contents. Anim. Feed Sci. Technol. 178:67–73.
7. Cao, J., Zhu, J., Zhou, Q., Zhao, L., Zou, C., Guo, Y., ... & Yu, D. (2022). Efficacy evaluation of novel organic iron complexes in laying hens: Effects on laying performance, egg quality, egg iron content and blood biochemical parameters. Animal Bioscience.
8. Chen, X. L., Zeng, Y. B., Liu, L. X., Song, Q. L., Zou, Z. H., Wei, Q. P., & Song, W. J. (2021). Effects of dietary chromium propionate on laying performance, egg quality, serum biochemical parameters and antioxidant status of laying ducks under heat stress. Animal, 15(2), 100081.
9. Creech, B. L., Spears, J. W., Flowers, W. L., Hill, G. M., Lloyd, K. E., Armstrong, T. A., & Engle, T. E. (2004). Effect of dietary trace mineral concentration and source (inorganic vs. chelated) on performance, mineral status, and fecal mineral excretion in pigs from weaning through finishing. Journal of Animal Science, 82(7), 2140-2147.
10. Damaziak K, Marzec A, Riedel J, Szeliga J, Koczywas E, Cisneros F, Michalczuk M, Lukasiewicz M, Gozdowski D, Siennicka A, et al. 2018. Effect of dietary canthaxanthin and iodine on the production performance and egg quality of laying hens. Poult Sci. 97(11):4008–4019.
11. Delezie, E.; Rovers, M.; Van der Aa, A.; Ruttens, A.; Wittocx, S.; Segers, L. Comparing responses to different selenium sources and dosages in laying hens. Poult. Sci. 2014, 93, 3083–3090.
12. Dobrzañski, Z., Korczyñski, M., Chojnacka, K., Górecki, H., &Opaliñski, S. (2008). Influence of organic forms of copper, manganese and iron on bioaccumulation of these metals and zinc in laying hens. *Journal of elementology*, *13*(3).
13. Elfiky, A. A., Enab, A. A., Zanaty, G. A., Morsy, A. S., &Sewalem, H. Z. (2021). Productive performance and egg quality traits of laying hens fed on diets treated with nano-selenium under hot desert conditions. Menoufia Journal of Animal Poultry and Fish Production, 5(6), 71-81.
14. El-Katcha, M. I., Soltan, M. A., El-Kassas, S. M., Arafa, M. M., Kawarei, E. S. R., & El-Naggar, K. M. (2022). The Impact of Alternative Dietary Replacement of Inorganic

Copper Salt with Organic and Nano Form on Productive Performance and Egg Quality Characteristics of Laying Hens.

15. Elnaggar, A. S., Ghazalah, A., Elsayed, A. H., &Abdelalem, A. (2020). Impact of selenium sources on productive and physiological performance of broilers. Egyptian Poultry Science Journal, 40(3), 577-597.
16. European Commission 2016. Summary report of the standing committee on plants, animals, food and feed held in Brussels, on 12 November 2015–13 November 2015 (Section Animal Nutrition). Brussels (Belgium): Directorate-General for Health and Food Safety.
17. Ferguson, L.R.; Karunasinghe, N.; Zhu, S.; Wang, A.H. Selenium and its' role in the maintenance of genomic stability. Mutat. Res. 2012, 733, 100–110.
18. Gheisari AA, Sanei A, Samie A, Gheisari MM, Toghyani M. Effect of diets supplemented with different levels of manganese, zinc, and copper from their organic or inorganic sources on egg production and quality characteristics in laying hens. Biol Trace Elem Res. (2011)
19. Gou, Z., Fan, Q., Li, L., Jiang, Z., Lin, X., Cui, X., ... & Jiang, S. (2020). Effects of dietary iron on reproductive performance of Chinese Yellow broiler breeder hens during the egg-laying period. Poultry science, 99(8), 3921-3929.
20. Han, X.J.; Qin, P.; Li, W.X.; Ma, Q.G.; Ji, C.; Zhang, J.Y.; Zhao, L.H. Effect of sodium selenite and selenium yeast on performance, egg quality, antioxidant capacity, and selenium deposition of laying hens. Poult. Sci. 2017, 96, 3973–3980.
21. Hudson, B. P., Dozier Iii, W. A., Wilson, J. L., Sander, J. E., & Ward, T. L. (2004). Reproductive performance and immune status of caged broiler breeder hens provided diets supplemented with either inorganic or organic sources of zinc from hatching to 65 wk of age. *Journal of Applied Poultry Research*, *13*(2), 349-359.
22. Karami, M. ,Torki, M. , & Mohammadi, H. (2018). Effects of dietary supplemental chromium methionine, zinc oxide, and ascorbic acid on performance, egg quality traits, and blood parameters of laying hens subjected to heat stress. J ApplAnim Res, 46(1), 1174–1184. 10.1080/09712119.2018.1481411
23. KhanR.U., S. Naz, K. Dhama, M. Saminathan, R. Tiwari, G.J. Jeon, V. Laudadio, V. Tufarelli Modes of action and beneficial applications of chromium in poultry nutrition, production and health: a review International Journal of Pharmacology, 10 (2014), pp. 357-367

24. Khoshbin, M., Vakili, R., &Tahmasbi, A. (2022) Effect of different sources of organic and inorganic manganese on productive performance, antioxidant status, immune system and bone strength in aged laying hens (82 to 94 weeks). Iranian Journal of Animal Science Research, 14(1), 97-107.
25. Lewis, P. D. (2004). Responses of domestic fowl to excess iodine: A review. British Journal of Nutrition, 91, 29–39. https://doi.org/10.1079/ BJN20031017
26. Li L, Miao L, Zhu M, Wang L, Zou X. Dietary addition of zinc-methionine influenced eggshell quality by affecting calcium deposition in eggshell formation of laying hens. Brit J Nutr. (2019) 122:961–73. 10.1017/S000711451900206X
27. Lim, H. S., & Paik, I. K. (2003). Effects of supplementary mineral methionine chelates (Zn, Cu, Mn) on the performance and eggshell quality of laying hens. *Asian-Australasian Journal of Animal Sciences*, *16*(12), 1804-1808.
28. Liu, H., Yu, Q., Fang, C., Chen, S., Tang, X., Ajuwon, K. M., & Fang, R. (2020). Effect of selenium source and level on performance, egg quality, egg selenium content, and serum biochemical parameters in laying hens. Foods, 9(1), 68.
29. Ma, N., Liu, M., Song, M., Li, S., Lin, X., Jiao, H., ... & Lin, H. (2022). The Application of Copper Waterline on Laying Performance and Gut Health of Aged Laying Hens. The Journal of Poultry Science, 0210124.
30. Manangi, M. K., Vazques-Anon, M., Richards, J. D., Carter, S., & Knight, C. D. (2015). The impact of feeding supplemental chelated trace minerals on shell quality, tibia breaking strength, and immune response in laying hens. *Journal of Applied Poultry Research*, *24*(3), 316-326.
31. MehrabaniMamduh, A., MirzaieGoudarzi, S., Saki, A. A., &Aliarabi, H. (2021). Various zinc sources and levels supplementation on performance, egg quality and blood parameters in laying hens. Journal of Livestock Science and Technologies, 9(2), 1-9.
32. Mohammadi, V., S. Ghazanfari, A. Mohammadi-Sangcheshmeh, and M. H. Nazaran. 2015. Comparative effects of zinc-nano complexes, zinc-sulphate and zinc-methionine on performance in broiler chickens. Br. Poult. Sci. 56:486–493.
33. Muhammad, A. I., Mohamed, D. A., Chwen, L. T., Akit, H., &Samsudin, A. A. (2021). Effect of selenium sources on laying performance, egg quality characteristics, intestinal morphology, microbial population and digesta volatile fatty acids in laying hens. Animals, 11(6), 1681.

34. N. Sahin, A. Hayirli, C. Orhan Effects of the supplemental chromium form on performance and metabolic profile in laying hens exposed to heat stress Poultry Science, 97 (2018), pp. 1298-1305
35. Noetzold, T. L., Vieira, S. L., Favero, A., Horn, R. M., Silva, C. M., & Martins, G. B. (2020). Manganese requirements of broiler breeder hens. *Poultry Science*.
36. Pekel, A. Y., & Alp, M. (2011). Effects of different dietary copper sources on laying hen performance and egg yolk cholesterol. *Journal of Applied Poultry Research*, *20*(4), 506-513.
37. Qu, W.; Yang, J.; Sun, Z.Z.; Zhang, R.H.; Zhou, F.; Zhang, K.C.; Xia, Y.; Huang, K.H.; Mao, D.N. Effect of Selenium Nanoparticles on Anti-Oxidative Level, Egg Production and Quality and Blood Parameter of Laying Hens Exposed to Deoxynivalenol. J. Anim. Res. Nutr. 2017, 2.
38. Rotruck, J.T.; Pope, A.L.; Ganther, H.E.; Swanson, A.B.; Hafeman, D.G.; Hoekstra, W.G. Selenium: Biochemical role as a component of glutathione peroxidase. Science 2010, 179, 588–590.
39. Saripinar-Aksu, D., Aksu, T., &Önel, S. E. (2012). Does inclusion at low levels of organically complexed minerals versus inorganic forms create a weakness in performance or antioxidant defense system in broiler diets?. *International Journal of Poultry Science*, *11*(10), 666.
40. Sarlak, S., Tabeidian, S. A., Toghyani, M., ForoozandehShahraki, A. D., Goli, M., &Habibian, M. (2020a). Supplementation of two sources and three levels of iodine in the diet of laying hens: effects on performance, egg quality, serum and egg yolk lipids, antioxidant status, and iodine accumulation in eggs. Italian Journal of Animal Science, 19(1), 974-988.
41. Sarlak, S., Tabeidian, S. A., Toghyani, M., Shahraki, A. D. F., Goli, M., &Habibian, M. (2021). Effects of replacing inorganic with organic iron on performance, egg quality, serum and egg yolk lipids, antioxidant status, and iron accumulation in eggs of laying hens. Biological Trace Element Research, 199(5), 1986-1999.
42. Sathyabama, T., Nanjappan, K., Jagadeeswaran, A., &Kirubakaran, A. (2017). Effect of chromium supplementation on external egg quality characteristics of layer chickens. Indian Veterinary Journal, 94(10), 9-10.
43. Scheideler, S. E. (2008). Trace mineral balance in poultry. In *Midwest Poultry Federation Convention (in Zootecnica International–World Poultry Journal).*

44. Siloto, E. V., Sartori, J. R., Santos, T. S. D., Fascina, V. B., Centenaro, L. P., Miranda, C. C. D., ... & Sartori, D. R. D. S. (2021). Effects of chromium yeast supplementation on productive and metabolic responses of laying hens fed diets containing different energy levels. RevistaBrasileira de Zootecnia, 50.
45. STAHL, J. L., Cook, M. E., &Sunde, M. L. (1986). Zinc supplementation: Its effect on egg production, feed conversion, fertility, and hatchability. *Poultry Science*, *65*(11), 2104-2109.
46. Stanley, V. G., Shanklyn, P., Daley, M., Gray, C., Vaughn, V., Hinton, A., & Hume, M. (2012). Effects of organic selenium and zinc on the aging process of laying hens.
47. Stefanello, C., Santos, T. C., Murakami, A. E., Martins, E. N., & Carneiro, T. C. (2014). Productive performance, eggshell quality, and eggshell ultrastructure of laying hens fed diets supplemented with organic trace minerals. *Poultry Science*, *93*(1), 104-113.
48. Stępniowska, A. Drażbo, K. Kozłowski, K. Ognik, J. Jankowski. The effect of chromium nanoparticles and chromium picolinate in the diet of chickens on levels of selected hormones and tissue antioxidant status Animals, 10 (2020), p. 45
49. Swiatkiewicz, S., &Koreleski, J. (2008). The effect of zinc and manganese source in the diet for laying hens on eggshell and bones quality. *VeterinarniMedicina*, *53*(10), 555-563.
50. Taschetto, Diogo, Sergio Luiz Vieira, Clara Roselina Angel, Catarina Stefanello, LirisKindlein, Marco Antonio Ebbing, and Cristina TonialSimões. "Iron requirements of broiler breeder hens." Poultry Science 96, no. 11 (2017): 3920-3927.
51. Tom Dieck, H., Döring, F., Roth, H. P., & Daniel, H. (2003). Changes in rat hepatic gene expression in response to zinc deficiency as assessed by DNA arrays. *The Journal of nutrition*, *133*(4), 1004-1010.
52. Uauy, R., Olivares, M., & Gonzalez, M. (1998). Essentiality of copper in humans. *The American journal of clinical nutrition*, *67*(5), 952S-959S.
53. Urso, U.R.A.; Dahlke, F.; Maiorka, A.; Bueno, I.J.M.; Schneider, A.F.; Surek, D.; Rocha, C. Vitamin E and selenium in broiler breeder diets: Effect on live performance, hatching process, and chick quality. Poult. Sci. 2015, 94, 976.
54. Venglovska, K., Grešáková, Ľ., Placha, I., Ryzner, M., &Čobanová, K. (2014). Effects of feed supplementation with manganese from its different sources on performance and egg parameters of laying hens. *Czech Journal of Animal Science*, *59*(4), 147-155.

55. von Drygalski, A., & Adamson, J. W. (2013). Iron metabolism in man. Journal of Parenteral and Enteral Nutrition, 37(5), 599-606.
56. Wang, W., Kang, R., Liu, M., Wang, Z., Zhao, L., Zhang, J., ... & Ma, Q. (2022). Effects of Different Selenium Sources on the Laying Performance, Egg Quality, Antioxidant, and Immune Responses of Laying Hens under Normal and Cyclic High Temperatures. Animals, 12(8), 1006.
57. WHO. 2019. Global Scorecard: 30 years of iodine status monitoring. IDD Newsletter. 48:5–8.
58. X. Luo, C. Zheng, W. Xia, D. Ruan, S. Wang, Y. Cui, D. Yu, Q. Wu, D. Huang, Y. Zhang, W. Chen Effects of constant or intermittent high temperature on egg production, feed intake, and hypothalamic expression of antioxidant and pro-oxidant enzymes genes in laying ducks Journal of Animal Science, 96 (2018), pp. 5064-5074
59. Xie, C., Elwan, H. A. M., Elnesr, S. S., Dong, X. Y., & Zou, X. T. (2019). Effect of iron glycine chelate supplementation on egg quality and egg iron enrichment in laying hens. Poultry Science, 98(12), 7101-7109.
60. Xie, C., H. A. M. Elwan, S. S. Elnesr, X. Dong, J. Feng, and X. T. Zou. 2019. Effects of iron glycine chelate on laying performance, antioxidant activities, serum biochemical indices, iron concentrations and transferrin mRNA expression in laying hens. J. Anim. Physiol. Anim. Nutr. 103:547–554.
61. Yatoo, M. I., Saxena, A., Deepa, P. M., Habeab, B. P., Devi, S., Jatav, R. S., &Dimri, U. (2013). Role of trace elements in animals: a review. *Veterinary world*, *6*(12), 963.
62. Zafar, M. H., & Fatima, M. (2018). Efficiency Comparison of Organic and Inorganic Minerals in Poultry Nutrition: A Review. *PSM Veterinary Research*, *3*(2), 53-59.
63. Zhang, Y. N., Wang, S., Huang, X. B., Li, K. C., Ruan, D., Xia, W. G., ... & Zheng, C. T. (2022). Comparative effects of inorganic and organic manganese supplementation on productive performance, egg quality, tibial characteristics, serum biochemical indices, and fecal Mn excretion of laying ducks. Animal Feed Science and Technology, 283, 115159.
64. Zhang, Y., Deng, Y., Jin, Y., Zhuang, Z., Huang, X., Li, K., ... & Chen, W. (2022). Dietary zinc supplementation affects eggshell quality and ultrastructure in commercial laying ducks by influencing calcium metabolism. Poultry science, 101(1), 101539.
65. Zhou, W., Miao, S., Zhu, M., Dong, X., & Zou, X. (2021). Effect of glycine nano-selenium supplementation on production performance, egg quality, serum

biochemistry, oxidative status, and the intestinal morphology and absorption of laying hens. Biological Trace Element Research, 199(11), 4273-4283.

66. Zhu, Y. W., Xie, J. J., Li, W. X., Lu, L., Zhang, L. Y., Ji, C., ... & Luo, X. G. (2015). Effects of environmental temperature and dietary manganese on egg production performance, egg quality, and some plasma biochemical traits of broiler breeders. *Journal of Animal Science*, *93*(7), 3431-3440.