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RESEARCH ARTICLE

Selenium as an essential micronutrient in poultry nutrition: A review.

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Abstract

Selenium is one of the most important trace elements in animal nutrition, as it helps animals stay healthy and productive. Selenium is a vital component of poultry nutrition, and its bioefficacy is determined by the chemical form in which it is consumed. Inorganic Se, such as sodium selenite, and organic Se, such as Se-enriched yeast, DL-selenomethionine, and nano-selenium are available as Se supplements in the poultry diet. Because chickens are unable to synthesize Se, dietary supplementation is an important technique for combating commercially significant stressors. Indeed, in stressful situations, when increased selenoprotein expression necessitates additional Se, and Se provision via feed is typically reduced due to reduced feed consumption, Se reserves primarily in the muscles could help maintain an effective antioxidant and prevent stress-related harm. For commercial application, the poultry industry is looking for the most effective sources of environmentally friendly Se. The benefits and drawbacks of Se sources for poultry (inorganic, organic, and nanoparticles) are discussed in this review, as well as future directions for the development of new Se sources and the recommended levels as well as mode of actions.

Keywords: Nutrition; Poultry; Selenium; Sustainability.

1. Introduction

The maintenance of poultry's optimum health and meat quality depends on selenium (Se), which is a crucial component of many selenoproteins, the majority of which are engaged in the body's antioxidant system (Choct *et al.*, 2004). Selenium can be added to chicken diets in a variety of forms, including inorganic-Se, organic-Se, and most recently, nano-Se. Se selenite, an inorganic form that is utilised as a dietary supplement, has a very thin line separating its dietary requirement from its toxicity (Wolffram *et al.*, 1986). Organic selenium is preferred for broilers' diets because it has a higher rate of tissue retention, bioavailability, and lower toxicity than inorganic selenium (Briens *et al.*, 2013). According to Choct *et al.* (2004), organic-Se is deposited in breast muscle more effectively than inorganic forms. Due to its superior catalytic performance, increased adsorption capacity, robust absorption efficiencies, and decreased toxicity as compared to inorganic-Se, nano-Se has recently been presented (Zhang *et al.*, 2008). Additionally, nano-Se has shown to be more effective than selenium-selenite at regulating seleno enzymes and lowering toxicity (Zhang *et al.*, 2005). Selenium deficiency in poultry causes a variety of diseases and injuries, including skeletal myodegeneration, exudative diathesis, muscular haemorrhages, pancreatic atrophy, decreased egg production, liver injury, reduced hatchability, and inhibited growth of the bursa and thymus (Gao *et al.*, 2012). It also makes people more susceptible to certain degenerative diseases, like cancer (Gromadzinska *et al.*, 2008). According to Arthur *et al.* (2003), selenium is crucial for the health of

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the cells that participate in the immune response and is necessary for several immune system functions (Singh *et al.,* 2006; Whitacre and Combs, 1983). According to Arthur *et al.* (2003), selenium deprivation has a negative impact on interleukin production and reduces macrophages' ability to perform phagocytic tasks (Schumacher *et al.*, 1990). A decrease in CD4+ T-helper cells occurs concurrently with the blood selenium level falling. These cells produce cytokines and chemotactic factors that activate infected cells to become resistant to infection. These cells have viral antigen on their surface (Look *et al.*, 1997). Superoxide dismutase (SOD), glutathione peroxidase (GSH-Px), catalase, and other antioxidant enzymes as well as non-enzymatic compounds like glutathione (GSH) are all part of the body's antioxidant systems (Mruk *et al.,* 2002). Malondialdehyde (MDA) is one of the lipid peroxides' metabolic byproducts and is produced in tissues as a result of the lipid oxidation reaction brought on by oxygen-free radicals. It was commonly acknowledged that a healthy Se intake might raise the body's antioxidant state. In general, organic Se demonstrated a greater capacity to enhance the antioxidant state than inorganic Se (Mahan and Parrett, 1996; Mahan *et al.,* 1999). Wang *et al.* (2011) indicated that the antioxidant capability of broilers was greatly improved by dietary Se addition while Selenium methonine (Se-Met) was superior to Sodium selenite (SS) in improving the antioxidant status of broilers.

The Total antioxidant and activity of an antioxidant enzyme SOD and concentration of a non-enzymatic substance GSH was increased, while the metabolic product of lipid peroxides of MDA content was decreased (Skřivan *et al.,* 2008 and 2010). Nanotechnology allows for the use of nanoparticles as an additional source of trace minerals in the diet that have various innovative features not present in bulk materials or commercial salts of these minerals (Abdel-Wareth *et al.,* 2019, 2020, 2022). Due to its superior bioavailability, catalytic effectiveness, potent adsorption capacity, and reduced toxicity as compared to selenite in chickens, nano-elemental Se (Nano-Se) has recently gained more attention. These results revealed that selenium (Se) enhanced the antioxidant capacity of broilers by increasing antioxidant enzyme activities and concentrations, and they also suggested that selenium methonine supplementation may be more advantageous for oxidative stability than sodium selenite. To support the impact of various Se sources on the productive performance of broilers, more research is required. As a result, this review provides an overview of the mode of action, recommended Se dietary levels, and effects of Se sources on broiler growth performance, nutritional digestibility, carcass criteria, antioxidant status, and blood biochemistry.

2. Mode of action of selenium forms in poultry nutrition

Hassan *et al.* (2019) illustrated that trace elements like Se possess wide applicability when supplemented as feed additives to poultry diets. The Se is one of the crucial trace elements needed in poultry, and research has shown that it is critical for the body's antioxidant defence system, antibacterial activities, organ functioning, brain protection, gastrointestinal health, and immune system, as shown in Figure 1.

In relation to selenium metabolism, it is crucial to the majority of bodily physiological activities, according to Mahima *et al.* (2012).

Action of selenium depends on its chemical state and the amount added to the diet.

Plant foods are a simpler source of selenium than other animal products, although some dietary components, such as vitamin C and vitamin E, have an impact on its absorption.

Se is actively or passively transported over the intestinal brush boundary with the majority of the absorption occurring in the duodenum (Wright and Bell, 1966; Whanger *et al.,* 1976), followed by the jejunum, and then the ileum. The kind of absorption depends on the source of se in the diet.

The process begins during digestion in the gastrointestinal tract, where inorganic sources are released and mixed with other feed ingredients to produce insoluble complexes that are expelled. As a result, its absorption across the small intestine is reduced. In contrast, the organic minerals are actively absorbed in the colon by means of peptide and/or amino acid transport pathways (Ashmead, 1993; Schweizer *et al.*, 2004). Se, on the other hand, has an inherent physical and chemical characteristic, such as variations in solubility, absorption, transport mechanisms, and excretion.

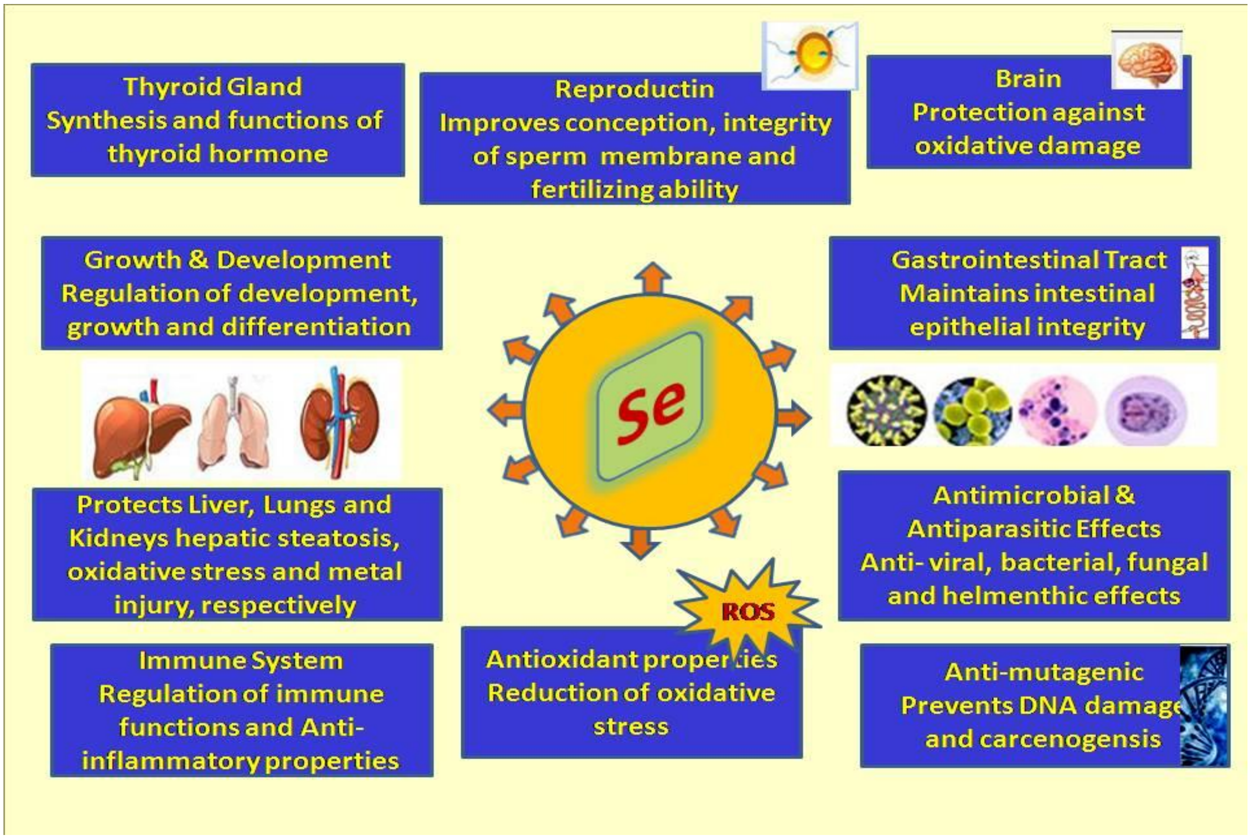

Figure 1. Functions of selenium in poultry.

As a result, using Se in various forms offers numerous advantages. The mechanisms of action of nanoparticles include expanding their surface area to enable wide interaction with biological support, extending the compound's time in the gut, reducing the impact of intestinal clearance mechanisms, penetrating deeply into tissues through fine capillaries, crossing epithelial fenestration, enabling cells for efficient transport, effectively delivering functional compounds to target sites, and improving bioavailability (Chen *et al.*, 2017). The effect of selenium on growth rate may be related to its action in the development of selenoprotein P and selenoenzymes type I iodothyronine deiodinase, which are essential for the manufacture of thyroid hormones and the transport of selenium (Zhan *et al.*, 2014). Additionally, Saleh (2014) said that an increase in thyroid hormone, which controls the body's energy metabolism, and an increase in protein digestibility could be the explanation for Ibrahim *et al.* (2019) results of increased growth performance with Se. Additionally, Wang and Xu (2008) demonstrated that dietary organic Se supplementation, as opposed to inorganic Se, preserved the contents of selenium in the liver and muscles. Additionally, Cai *et al.* (2012) reported that an increase in dietary nano-Se concentration may be the cause of the large increase in Se in liver and muscle tissue. Because of the smaller particle size and greater surface area of nano-Se, intestinal absorption of the substance may have improved, which could account for the rise in nano-Se levels in tissue (Liao *et al.,* 2010).

The process by which antioxidants alter the water-holding capacity and drip loss of meat can be linked to the fact that protein oxidation and proteolysis play a crucial role in regulating the meat's ability to retain moisture (Huff-Lonergan and Lonergan, 2005).

Lambert *et al.* (2001) reported that the buildup of a significant amount of lactic acid in the muscles and the interruption of blood flow that causes cellular hypoxia and lowers pH after slaughter may be related to the loss in water retaining capacity. Ibrahim *et al.* (2019) showed that broilers fed on Met-Se and Nano-Se increased water-holding capacity of breast meat. This may be because organic Se or nano-Se supplementation delayed the metabolic conversion of glucose to lactic acid in post-mortem muscle, which improved the water-holding capacity of meat and reduced drip loss (Oliveira *et al.,* 2014).

Hassan *et al.* (2019) explained the effect of selenium as it has an anabolic role on fat deposition decline total plasma cholesterol and Low density Lipid (LDL-cholesterol) aside from the supplementation of selenium organic forms that could modulate the fatty acids composition in the entire body.

Artur *et al.* (2003) stated that cellular and humoral immunity can be damaged by decreasing of selenium. Because of selenium plays an important role, it can be stimulated immune system, strengthening proliferation of activated T lymphocytes. It has been demonstrated that severe Se deficiency is linked to the rise of a number of illnesses that are no longer present in the modern commercial poultry industry. However, farms continue to show lower reproductive and productive performance as a result of poor antioxidant defences under stress conditions and inadequate dietary Se levels. The most important take away from the studies that were chosen is that more study is required to clarify the appropriate amount of selenium supplementation as well as the best sources of selenium for dietary supplementation.

3. Recommendation of selenium levels in poultry diets

While there has been a lot of effort put into finding the ideal level of Se supplementation in broiler diets, the outcomes have been inconsistent. In this review, we will attempt to analyse the more promising outcomes. On the basis of the literature review, a thorough survey will be presented below. According to the NRC (1994), the suggested addition of 0.3 ppm selenium in broiler feed is enough to sustain normal development and productivity. According to Bakhshalinejad *et al.* (2019), broiler growth performance appeared to be maintained at 0.09 to 0.15 mg Se/kg of feed in the basal diet. El-Deep *et al.* (2017) findings, which took into account the interactions between antioxidants, revealed that dietary 0.3 ppm organic Se or Nano-Se may be beneficial in improving hens raised in hot climates' productivity, egg quality, semen quality, antioxidative characteristics, and immunity. Optimal responses were seen in Cai *et al.* (2012). Investigation's at a nano-Se level of 0.3 mg/kg, while adverse effects started to show at nano-Se levels over 1.0 mg/kg.

These results support the suggestion that broiler diets should contain 0.3 to 0.5 mg/kg of nano-Se supplementation. The optimal supplementation level of nano Se, according to Upton *et al*. (2008), was 0.3 mg/kg diet. According to Peric *et al.* (2009), chickens given 0.3 ppm of organic Se exhibited less evident liver damage and less drip loss from the breast meat. Using Se yeast, Zn-Se-Meth, or Nano Se as organic or nano forms of Se at levels of 0.30 ppm in broiler feeds or its equivalent in drinking water, respectively, is more successful to produce higher growth performance and quality of broiler meat (Selim *et al.*, 2015). The findings of Zhou and Wang (2011) shown that adding 0.30 mg/kg of nano-Se to chicken diets improved the Se content in tissues and meat quality while also enhancing chicken development performance. From the production point of view, it is difficult to guarantee recommended dose of selenium sources, as a range of production-related factors, including yeast strain, medium composition, selenite concentration, and temperature, affect the composition of the end product (Surai *et al.*, 2018).

3.1. Effects of selenium sources on broiler growth performance

Many studies explain the behavior concerning growth parameters where a positive response was recorded. In this concern, mention may be made of many authors such as Ahmadi *et al.* (2018) indicated significant improvement in weight gain and feed conversion ratio in starter, grower, and whole periods of experiment when diet supplemented by nano-Se. When broiler chicks were fed Se yeast as an organic form of Se or when nano Se was used growth performance was improved, These findings were consistent with many previous studies, including those by Selim *et al.* (2015) observed improvements in growth performance parameters such as body weight (BW), body weight gain (BWG), and feed conversion ratio (FCR). Supplementation of Nano-Se improved growth performance (Zhou and Wang, 2011; Dlouha *et al.*, 2008; Upton *et al.*, 2008; Fu-xiang *et al.*, 2008).

Zhou and Wang, (2011) clearly indicate that providing Nano-Se supplemented diet, could improve the final BW, DWG and FCR of Guangxi Yellow chickens. Also, Upton *et al.* (2008) reported that broilers given diets supplemented with 0.2 mg/kg of organic Se showed significant increase in the BW as compared with a diet supplemented with inorganic Se and a control diet.

Srimongkol *et al.* (2004) reported that adding the organic form of Se enhanced performance parameters during growing, finishing and overall periods.

On the contrary, many other studies explain an inverse behavior concerning growth parameters such as Bakhshalinejad *et al.* (2019) who showed that including Se in the diets of broiler chickens indicated no significant difference ($P > 0.05$) in the BWGfeed intake, mortality, and FCR during the experimental period. Peric *et al.* (2009) in that using different Se sources including sodium selenate, selenium yeast, selenium methonine, nano selenium did not influence the growth parameters under the controlled conditions. However, Göçmen *et al.* (2016) stated that the effects of dietary Se supplementation on broiler performance according to Se sources and levels had no significant ($P> 0.05$) effect on the performance parameters (BW, BWG, FI or FCR) and mortality of broilers at the end of trial. They observed no difference in mortality due to Se supplementation, which is in agreement with the results of Edens *et al.* (2001) who also reported that broilers fed diets containing 0.20 ppm Se from either organic or inorganic sources showed no differences in BW or feed efficiency. Spears *et al.* (2003) reported also that broilers fed diets containing 0, 0.05, or 0.15 ppm Se from organic or inorganic sources had no difference in gain or feed efficiency. Deniz *et al.* (2005) reported that Se supplementation using organic or inorganic Se forms were not significantly changed feed intake and mortality. Ryu *et al.* (2005) noticed that feeding Se from an inorganic source at higher concentrations (1 to 8 ppm) of diets did not affect the BW of broilers. Yoon *et al.* (2007) observed that dietary supplemental Se did not affect the growth performance of broilers.

Moreover, Liu *et al.* (2015) reported that growth performance results showed no significant differences ($P > 0.27$) among the five treatments in ADG, ADFI and FCR of chicks during 7–17 days of age, and the mortality of chicks in all groups was zero.

Chen *et al.* (2013) mentioned repeatedly in their study that adding 0.3, 0.5, 1.0, or 2.0 mg/kg organic selenium did not significantly increase broiler performance, which was consistent with prior results (Swain *et al.*, 2000; Yoon *et al.*, 2007). Peric *et al.* (2009) demonstrated that mortality assessments or performance metrics were not significantly different between treatments at this point. They added that there was no difference in FCR ($P > 0.05$) between broilers on organic Se diets and those fed conventional diets. On the other hand, according to a number of other investigations, adding organic Se, inorganic Se, or both to the diet had no impact on the BW and DWG of chickens (Niu *et al.*, 2009; Ozkan *et al.*, 2007; Payne and Southern, 2005; Choct *et al.*, 2004). However, Srimongkol *et al.* (2004) claimed that broiler performance during the first two weeks of age did not differ significantly when either 0.2 mg of inorganic or organic Se/kg of broiler feeds were added.

Finally, despite using organic or nanoforms of selenium in broiler diets, Cai *et al.* (2012), Choct *et al.* (2004), Mei-Sheng (2005), Payne and Southern, (2005), and Niu *et al.* (2009) were unable to document an increase in the growth performance of broiler chicks. These findings could be explained by the high levels of selenium in the control diet, which obscured the impact of supplementary selenium (Zhou and Wang, 2011).

3.2. Effects of selenium sources on apparent digestibility of nutrients

It is important to highlight that there is a dearth of research on the relationship between Se source supplementation and the apparent digestibility of the nutrients in chicken. When Japanese Quil (JQ) was supplemented with several Se sources, including organic and inorganic-Se, in the base diet, Hassan (2020) found that only this had a significant impact on the digestion of ether extract when compared to the control diet. Additionally, Edens (2001) reported that broiler chicken diets supplemented with Selplex had an enhanced DM digestibility.

In discordance with the above-mentioned results, Hassan, (2020) Observed no significant difference was observed on DM, CP and CF digestibility on using various Se sources. Also, Sundu *et al.* (2019) showed that diets supplemented different Se sources exhibited no increase in DM digestibility. On the other hand, Amer *et al.* (2018) showed nearly the same results as insignificant differences on DM, OM, and CP digestion coefficient were found between the Se treated and the untreated groups. The results were also in accordance for organic and inorganic-Se, where there were no significant differences in DM, OM, and CP digestion coefficient.

3.3. Effects of selenium sources on broiler Carcass criteria

Results from Selim *et al.* (2015) demonstrated that organic and nano forms of sodium selenite were more effective at enhancing carcass criteria than inorganic sodium selenite (dressing percentage). The use of Se in nano form, with its novel properties including a large surface area, high surface activity, high catalytic efficiency, strong adsorbing ability, high bioavailability, and low toxicity, was also credited by Zhang *et al.* (2008) and Wang *et al.* (2007) for the improvement. Additionally, birds treated with organic Se in their diets had improved eviscerated weight and breast yield (Payne and Sonthern, 2005; Choct *et al.*, 2004). Nano Se has a size-dependent impact, according to Huang et al. (2003). However, broilers fed diets supplemented with sodium selenite (SS) or organic Se showed no differences in the carcass, breast, and thigh muscles yields (Payne and Southern, 2005; Downs *et al.*, 2000). Also, Bakhshalinejad *et al.* (2019) did not find any significance when diet supplemented with different Se sources and levels on carcass, breast, and thigh muscles yield. Furthermore, Ahmadi *et al.* (2018) showed that there were no differences between the experimental groups in the weights of edible organs (liver, heart, and gizzard), non-edible organs (lungs, kidneys, pancreas, testicles, crop, proventriculus, right and left cecum), and thymus. They also showed that there were no differences in the percentages of breast and drumsticks, abdominal fat percentage, and non-edible organs

However, there were noticeable variations in testicular relative weight between the regimens. In keeping with the findings of Deniz *et al.* (2005) and Jamnongtoi, *et al.* (2018) found that employing various sources of Se had no impact on the carcass criterion for broiler chickens). They are also in agreement with Chen *et al.* (2014) and Cai *et al.* (2012) who found no effect of Se addition (nano-Se or sodium selenite/selenium enriched yeast, respectively) on the weights of bursa of Fabricius, thymus and spleen. Reaptily, Chen *et al.* (2013) showed that carcass yield, drip loss and flesh colour had no significant difference among different groups till day 42, which indicated that the redundant Se yeast did not improve the slaughter performance and meat quality. According to Cai et al. (2012), Nano-Se had no appreciable impact on the weights of the carcass portions of broilers. Additionally, Payne et al. (2005) provided evidence to the contrary, showing that the Se level had no effect on carcass production, breast weight, or moisture loss from the breast (Payne and Southern, 2005; Payne et al., 2005). Last but not least, studies by Downs et al. (2000) and Payne and Southern (2005) demonstrated that adding Se to the diets in the form of sodium selenite or Se-enriched yeast had no effect on the carcass criteria of broilers.

3.4. Effects of selenium sources on meat quality

The organic sources of selenium have a superior effect on preserving the integrity of muscle cells and encouraging less drip and cooking loss (Bakhshalinejad *et al.,* 2019; Peric *et al.,* 2009; Boiago *et al.,* 2014). However, Bakhshalinejad *et al.* (2019) discovered that supplementing Se with SY and NS could enhance the meat's physicochemical properties. Moreover, the use of organic sources of Se promotes an increase in pH of chicken (Calvo *et al.,* 2017; Boiago *et al.,* 2014). Göçmen *et al.* (2016*)* recorded significant effects of dietary Se levels and sources on the water holding capacity (WHC) of breast meat. Furthermore, the Se could significantly improve meat color of broilers (Oliveira *et al.* 2014; Cai *et al.,* 2012). While, broilers fed diets supplemented with Selenium Yeast as an organic source at 0.3 mg/kg had a higher redness in their breast and thigh compared to those fed sodium selenite (SS), and an improvement in cooking loss of the breast muscle, according to (Yang *et al.,* 2012; Naylor and Choct, 2000).

The Se can also greatly enhance animal serum GSH-Px activity, increase oxidation resistance, effectively stop myoglobin from being oxidised to metmyoglobin, deepen muscle chroma, raise flesh colour scores, enhance meat quality, and improve muscle's ability to retain water (Cai *et al.,* 2012; Tsopelas *et al.,* 2011; Vignola *et al.,* 2009). Wang *et al.* (2011) stated that the ability of muscle proteins to attract water and hold it within the cells is of paramount importance for meat quality. It is well understood that Se is vital for the intra- and extra-cellular antioxidant systems of the body (Surai and Dvorsk, 2002).

Also, Zhou and Wang (2011) explained that birds fed diets supplemented with Nano-Se at 0.3 mg/kg had 45.10% lower drip loss due to the improved integrity of cell membranes compared to those fed diets supplemented with organic source.

In this line, Wang *et al.* (2011) showed that Se supplementation of Nano-Se decreased drip loss in 24 and 48 h, while broilers receiving sodium selenite had a greater drip loss than those consuming Selenium –Methonine. Perić *et al.* (2009) revealed that Breast meat of birds fed diets containing 0.3 ppm of Se from organic source (Sel-plex) had significantly ($P < 0.05$) less drip loss. Improvements in drip loss seem to be higher with increasing Se dose from (0.1 to 0.3). Likewise, Jiang *et al*. (2009) reported that chicken supplemented organic Se and inorganic Se in diet caused lower drip loss than unsupplemented Se. The higher pH in chicken fed with organic Se may be the cause of observed lower drip loss (Choct *et al.,* 2004). Finally, King and Whyte, (2006) stated that several factors including pH, myoglobin concentration, nitrites, etc. affect meat color which is an essential quality attribute for consumers.

Whereas, Bakhshalinejad *et al*. (2019) indicated that using different sources (SS, SY, SM and NS) at levels of 0.1 and 0.3% Se did not affect the pH of breast or thigh meats of broiler chickens. This is in match with Peric *et al*. (2009) who reported that no significant differences between treatments in pH of the breast or thigh meat when adding (0.1,0.2, 0.3) ppm of organic selenium from (Sel-plex) and inorganic source from sodium selenite. Jamnongtoi *et al*. (2018) indicated that there was no effect of Se source from (organic Zn-L-selenomethionine (Zn-L-SeMet) and inorganic sodium selenite (Na-Se) on broiler in diet on drip loss. Also, Göçmen *et al*. (2016) recorded no significant effect on pH, color criteria, cook loss (CL) or penetrometer values (PM) for breast and thigh meat in broilers when diet supplemented by various Se sources from organic (Sel –plex 50) and inorganic from (sodium selenite) at different levels (0,0.15,0.30 and 0.60). Boiago *et al*. (2014) observed that there was no effect (P>0.05) of selenium supplementation on the WHC, CL, shear strength and pH when used different levels from Se at (0.3 and 0.5 mg kg) in the form of selenomethionine (Se-Met) and sodium selenite (SS). However, Chen *et al*. (2013) showed no significance on broilers in drip loss and flesh color among the different groups from selenium yeast at levels (0.3 ,0.5, 1.0 and 2.0 mg .kg) all over the entire period. This was in match with Payne *et al*. (2005) who provided that breast meat had no significant drip loss by altering Se level.

3.5. Effects of selenium sources on Selenium retention

When compared to sodium selenate, selenium yeast and nano-se sources increased the amount of selenium in breast and thigh muscles, having a more noticeable positive effect (Bakhshalinejad *et al.,* 2019; Payne and Southern, 2005; Zhou and Wang, 2011; Hu *et al.,* 2012). According to Zeng (2009), supplementing diets with various Se sources can quickly overload seleno enzymes, which increases the retention of Se. According to Liao *et al.* (2010), novel Nano-Se particles transport and uptake characteristics show greater absorption efficiencies which may result in higher Nano-Se retention.

The Se concentrations in the plasma and liver considerably increased P (0.01) as the Se levels in diets increased, and the Se concentrations in the breast and thigh were similarly impacted by the sources and levels interaction (Göçmen *et al.*, 2016; Payne and Southern, 2005; Sevcikova *et al*., 2006; Wang and Xu, 2007; Yoon *et al.*, 2007). Sevcikova *et al.* (2006) reported that birds fed with Se-yeast and Se-chrolle each with 0.3 ppm compared to the control showed an significance increased breast, thigh and liver. Choct *et al.* (2004) also reported that an increasing supplementation of dietary Se from 0.1 to 0.25 mg/kg increased the Se concentration in breast muscle from 0.232 to 0.278 mg/kg.

Boiago *et al.* (2014) reported that supplementation with the organic Se source had a higher concentration of Se in the meat of broilers. Additionally, Downs *et al.* (2000) noted that broilers fed diets supplemented with organic Se had higher breast muscle Se content than those fed diets supplied with inorganic Se. According to Suzuki (2005), the trans-selenation route can change selenocysteine into selenide by converting selenomethionine and selenium yeast to selenocysteine. The higher Se concentration in the liver and blood respectively is dependent on the Se supplemental level (Zhou and Wang, 2011; Cai *et al.,* 2012). According to Chen *et al.* (2013), broiler selenium deposition in the liver and chest muscle increased significantly as selenium levels dose, and selenium content in the liver tissue increased significantly in the 0.5 mg/kg, 1.0 mg/kg, and 2.0 mg/kg groups compared to the 0.0 mg/kg control group. In addition, the concentration of Se in serum and in the studied organs was significantly increased by Se-Met supplementation compared to SS supplementation, according to Wang *et al.* (2011), who also demonstrated that the liver had a higher Se content and that this difference from the Se content in the muscle was significant.

According to Liu *et al.* (2015), selenium sources significantly affected (P .05) the concentrations of selenium in the liver and breast muscle, with chicks fed the diet supplemented with selenium yeast B having higher tissue selenium concentrations (P 0.05) than those fed the diet supplemented with sodium selenite or Nano-elemental selenium.

The broiler fed the meals supplemented with Se yeast had higher Se concentrations in the liver, kidney, pancreas, and breast muscle than those fed diets with sodium selenite, according to the results of Yoon *et al.* (2007). Furthermore, Se retention was higher when Se yeast was supplemented than when sodium selenite was, according to Wang and Xu (2008) research's , which also showed that the Se contents in the liver and muscle were indicative of dietary Se supplementation. Selim *et al.* (2015) reported significant increase of Se concentration in thigh muscles and liver by either increasing supplemental level from 0.15 to 0.30 ppm, or by using organic or Nano-Se. Surai (2006) explained that breast muscles of broilers had an observable significant increase of Se concentration in using Nano-Se compared with control in broiler diets. His results are also comparable to those of Kricova *et al.* (2003) who used organic Se at level of 0.20 ppm of Se yeast in young female chickens of the laying strain Isa Brown. Sevcikova *et al.* (2006) stated that increased content of Se sources from (Se-yeast and Se algae) at level 0.3 mg.kg in broiler diets significantly increased its content in thigh muscle tissue.

The response of Se deposition in tissues was consistent with the concept that organic Se tends to be deposited more than inorganic Se does in slow turnover tissues, such as breast and thigh muscles (Schrauzer, 2003). It is likely that organic sources of Se, such as SY, can be absorbed by active transport and non-specifically incorporated into proteins in place of Met, and is preferentially absorbed and utilized by the body over inorganic Se (Schrauzer, 2003). In addition, the difference of tissue Se retention between Se yeast and sodium selenite or Nano-Se might be explained by the proposed metabolic pathway for Se from different Se sources (Zeng, 2009).

While, Wang (2009) also reported that there was no significant difference between sodium selenite and Nano-Se on tissue Se distribution of broilers, Liu *et al.* (2015) findings supported this finding and demonstrated that there was no difference in tissue Se concentrations between Nano-Se and sodium selenite. Wang *et al.* (2011) showed no significant difference in muscle Se content was found between the treated groups.

3.6. Effects of selenium sources on Antioxidant responses

The feeding of 0.3 mg/kg Nano-Se could improve the glutathione peroxidase activities, and the glutathione peroxidase activities in serum, liver, and muscle (Cai *et al.*, 2012; Yoon *et al.*,2007; Wang and Xu, 2008; Leeson *et al.*, 2008; Wang *et al.*, (2009), and Zhou and Wang (2011). The content of glutathione peroxidase (GSH), malondialdehyde (MDA), the activities of total antioxidant capacity (T-AOC), and the capacities to block OH of liver tissue all significantly rise with an increase in selenium level, according to Chen et al. (2013). The outcomes additionally showed that adding selenium to the mix considerably improved broiler oxidation resistance. Zhou and Wang, (2011) showed that Nano-Se supplementation in the diet significantly increased the GSH-Px activity.

Wang *et al.* (2011) indicated that the antioxidant capability of broilers was greatly improved by dietary Se addition while Se-Met was superior to Se selenite in improving the antioxidant status of broilers. The T-AOC and activity of an antioxidant enzyme (i.e. SOD) and concentration of a non-enzymatic substance (i.e. GSH) were increased, while the metabolic product of lipid peroxides of MDA content was decreased (Skřivan *et al.,* 2008 and 2010). These results revealed that Se enhanced broiler antioxidant capacity by increasing antioxidant enzyme activities and reduced peroxidation product concentrations. They also suggested that Se-Met supplementation may be more advantageous for oxidative stability than SS. According to Göçmen *et al.* (2016), Se supplementation resulted in increased plasma and liver GSH-Px activity, which was substantially correlated with dietary Se organic level. The Se supplemented groups had increased GSH-Px activity compared to the control (Yoon et al., 2007; Wang and Xu, 2007; Spears et al., 2003). These findings conflict with those of Payne and Southern (2005), who claimed that neither the source nor the concentration of Se had an impact on the GSH-Px activity. Dalia *et al.* (2017) found that antioxidant enzymes activity increased in the serum and tissues by bacterial organic Se supplementation. Furthermore, Jiang *et al.* (2009) indicated that Se-enriched yeast enhanced antioxidative status of broilers by increasing antioxidant enzyme levels compared to sodium selenite. Also, Chen *et al.* (2014) showed that chickens fed organic Se had increased activity of serum GSH-Px, SOD and T-AOC more significantly than dietary sodium selenite.

Following Se supplementation, Boostani *et al.* (2015) observed increased GSHPx activity and decreased MDA in comparison to the control group. According to Zadeh *et al.* (2018), adding Se to the meal considerably boosted the GPx activity, with the birds receiving Se having the highest GPx activity. According to Spears *et al.* (2003), Se supplementation increased GPx activity in comparison to those who did not get Se.

Others, including Khajali *et al.* (2010) and Markovic *et al.* (2018), demonstrated that broiler diets supplemented with organic Se markedly increased plasma GPx activity and thus enhanced antioxidant activity.

3.7. Effects of selenium sources on blood parameters

Perić *et al.* (2009) reported significant reductions in both Alanine aminotransfere (ALT) at 21 d of age and Asparate aminotransfere (AST) at 21 and 42 d of age enzyme activities of blood samples taken from chickens fed organic Se. These data suggest less oxidative damage within sensitive tissue liver in birds receiving organic Se in feed. Additionally, Surai (2002) explained that measurement of blood enzymes could be an indicative of oxidative damage in liver tissue because of exposure to certain toxins, such as mycotoxins. Also, Petrovič *et al.* (2006) demonstrated that supplementation of Se-yeast significantly increased the Se contents of the blood and of the liver, kidney, spleen, and muscle tissues of laying hens. Payne and Southern (2005) and Pan *et al.* (2007) also reported similar increase in breast and blood Se contents in chickens fed selenomethionine or Se-yeast. In the same time, Mohapatra *et al.* (2014) stated that supplementation of 0.3 ppm nano-Se in layer chicks significantly increased total protein and serum globulin levels compared to control. According to Mohapatra *et al.* (2014), layer chicks supplemented with 0.3 mg/kg of Nano-Se had significantly higher levels of serum glucose, albumin, globulin, urea nitrogen, and total protein as well as lower levels of cholesterol and triglycerides as compared to the control group. According to Cai *et al.* (2012), groups supplemented with 0.3 to 1.0 mg/kg of nano-Se showed an elevated IgM level, with the highest

IgG and IgM levels (P 0.01) seen in birds fed 0.30 mg/kg of nano-Se. Furthermore, Wang *et al*. (2007) noted that Nano-Se feeding a diet including 0.30 mg/kg produced the greatest improvement in chickens for the humoral immunity, and suggested that the Nano-Se supplementation should not be more than 1.0 mg/kg.

Serum ALT, AST, LDH activity, and serum creatinine level of broilers were all considerably reduced by feeding inorganic Se and bacterial organic Se, according to Dalia *et al.* (2017). Additionally, Biswas *et al.* (2011) found a significant decrease in the activity of the ALT and AST enzymes in chicken given organic Se at diet levels of 0.5 mg and 1 mg/kg. The significant decrease was ascribed to adding 0.3 ppm of Nano-Se to the diet in comparison to the control, and this decrease may be due to Se's important function in the thyroid (T3) hormone's dominant effects on fat metabolism (Masukawa *et al.*, 1983).

Glucose and total protein concentrations in blood plasma were not significantly different among the broiler chickens treatments (Ahmadi *et al.*, 2018). Ibrahim *et al.* (2019) reported no significant effect concerning activity of liver enzymes including ALT and AST by the interaction between different levels and sources of Se as also recorded for serum creatinine values. The addition of Zn-Se-Meth, P-Nano-Se, or L-Nano-Se to broiler diets did not significantly impact the activity of liver enzymes like ALT and AST, and an increase in Se level from 0.3 to 0.45 ppm did not significantly affect plasma creatinine levels, according to Selim *et al.* (2015). Dalia *et al.* (2017) observed that inorganic or bacterial organic forms of selenium supplementation did not affect serum total protein, albumin, globulin, albumin/ globulin ratio, and urea.

According to Yang *et al.* (2012), supplementing broiler chicks for 42 days with 0.3 ppm organic selenium had no effect on the blood globulin level compared to the control group.

According to the findings of Yang *et al.* (2012) and Mohapatra *et al.* (2014), selenium (organic or inorganic) supplementation and Nano-Se had no discernible impact on liver enzymes. Yang *et al.* (2012) indicated insignificant effect on total cholesterol of chickens fed diet containing 0.3 mg/kg organic Se as compared to those fed diet without Se supplementation. Also, Kang *et al.* *(*2000) added that no insignificant effect on serum globulin, glucose, total cholesterol, LDL-c, HDL-c, serum urea nitrogen, and total protein levels of broilers were observed when compared to that of control group.

4. Conclusion

In conclusion, selenium sources improved growth performance, carcass traits, immune function, serum antioxidant capacity and gut integrity in broilers. In order to comprehend the benefits and drawbacks of each form of selenium sources, and levels additional research is required on comparative studies of various forms in poultry nutrition.

Se-homolanthionine is indeed commercially accessible, but additional study is needed to clarify the molecular mechanisms underlying its metabolism and potential benefits over inorganic forms of Se.

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Data presented in this study are available at fair request from the respective author.

Ethics Approval and Consent to Participate

This work carried out at Department of Animal and Poultry Production, Faculty of Agriculture, South Valley University and followed all the department instructions.

Consent for Publication

Not applicable.

Conflicts of Interest

The authors declare no conflict of interest.

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