Replacing dietary sodium selenite with a lower level of hydroxy-selenomethionine improves the performance of broiler breeders and their progeny

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ABSTRACT

The aim of this study has been to compare the effect of sodium selenite (SS) or hydroxy-selenomethionine (OH-SeMet) on the performance of broiler breeders and their progeny. A total of 216 broiler breeders (AP95 Aviagen; 55-65 weeks old) were assigned to two treatments: a diet supplemented with 0.3 mg Se Se/kg as SS or a diet supplemented with 0.2 mg Se Se/kg as OH-SeMet. A total of 520 mixed progeny chicks were used for a growth trial (41 d), in a completely randomised 2 × 2 factorial design: 2 sources of Se for the breeder diets and two sources of Se for the progeny diets – SS at 0.3 mg Se Se/kg and OH-SeMet at 0.2 mg Se Se/kg. OH-SeMet increased the egg production, the Se content in the egg, eggshell strength and hatchability (p < .05), compared to SS. The high Se deposition in the hatching eggs benefitted the progeny, as reflected by the better feed conversion ratio (p < .05). No significant changes were observed in the feed intake or weight gain, or the interactions between the maternal diets and progeny diets. Overall, supplementation with OH-SeMet at 0.2 mg Se Se/kg has proved to be an effective approach to help maintain the productive and reproductive performances of ageing breeder flocks and to enhance the performance of their progeny.

HIGHLIGHTS

• Replacement of dietary sodium selenite with hydroxy-selenomethionine in the broiler breeder diet increased Se accumulation in the eggs and improved egg production, the Se content in the eggs, eggshell strength and hatchability.
• The increased Se deposition in the hatching eggs benefitted the progeny, as reflected by the better feed conversion ratio.
• Supplementation with OH-SeMet at 0.2 mg Se/kg proved to be an effective approach to help maintain the productive and reproductive performances of ageing breeder flocks and to enhance the performance of their progeny.

Introduction

Two main areas should be considered in relation to the selenium (Se) nutrition of breeders. Firstly, it has been found that Se plays an important role in the maintenance of semen quality, and an optimal Se status of poultry males is considered to be an important factor to ensure the fertility of the breeding stock (Surai 2018). Secondly, the Se status of the eggs from breeding birds is of great importance for the maintenance of the antioxidant system of the developing embryo. It is generally accepted that the hatching process causes oxidative stress, and an improvement in the antioxidant defences of an embryo has the potential to increase hatchability (Rajashree et al. 2014). Li et al. (2020) reported a reduction in mortality of
embryos under oxidative stress, induced by a diquat challenge when maternal diets were supplemented with 0.15 mg Se/kg of selenomethionine. Under stressful conditions, when free radical production exceeds the protective ability of the antioxidant systems, poultry experience oxidative stress, a condition that causes detrimental consequences on their health (immunosuppression, higher inflammation response), on their reproduction (decreased fertility and hatchability in breeders), and their growth and feed efficiency (Surai et al. 2018; Bottje 2019; Pappas et al. 2019).

In addition, when there is a deficit of Se in diets or when the Se requirements are not fully covered, broiler breeders and progenies may show an overall performance drag (Zhao et al. 2019). Since most feed ingredients are known to be low in Se, commercial poultry diets are always supplemented with Se via premixes at 0.2–0.3 mg Se/kg diet, depending on the source, in order to avoid a Se deficiency. Selenium can be added to poultry diets in inorganic form (sodium selenite, SS) or organic form, such as selenized yeasts or in pure chemically synthesised forms like hydroxy-selenomethionine (OH-SeMet) or L-selenomethionine. The advantages of organic Se compounds (e.g. selenomethionine) in breeder nutrition have been reviewed in depth and it has been pointed out that organic Se compounds significantly increase the Se body reserves of birds, via selenomethionine deposition, and provide adult birds with better antioxidant protection (Surai and Fisinin 2014). In addition, compared with traditional SS, organic Se compounds are more efficiently transferred from the feed to the eggs and consequently to the developing embryos (Wang et al. 2021). This represents a good strategy to upregulate the antioxidant defence system of poultry and improve their resistance to various stresses. There are also some indications that organic Se compounds in the maternal diet can have long-lasting effects on the progeny (Zhang et al. 2014).

Several reports have indicated an improvement in breeder reproduction at the end of the laying cycle. For example, at the end of the reproductive period (50 weeks), Aseel chickens fed a diet supplemented with organic Se, had significantly increased settable eggs, fertility, hatchability, and A-grade chicks, and reduced embryonic mortality than those fed SS or no supplemented with Se (Khan et al. 2017). Hezarjaribi et al. (2016) observed an improvement in the reproductive characteristics of post-moul ch roosters when they were injected with a vitamin E-selenium solution.

When the efficiency of dietary forms of Se is considered, in terms of transfer of Se to body tissues, OH-SeMet, a pure chemically synthesised organic form of Se, has been proven to be significantly more efficient in transferring Se from the diet to the eggs than both SS or Se-yeast, and in enhancing poultry performances, particularly during critical periods of the production cycle (Jlali et al. 2013; Brito et al. 2019).

Most research on Se in broiler breeder nutrition has been conducted with 0.3 mg Se/kg Se dietary supplementation (Zhang et al. 2014; Emamverdi et al. 2019). However, the European Union regulations have limited the maximum supplementation with organic Se compounds to 0.2 mg Se/kg feed (Commission Implementing Regulation No. 427/2013 of 8 May 2013). Furthermore, the poultry industry is looking for more effective sources of organic Se compounds to provide the most efficient transfer to the egg and tissues and to meet the Se requirements under challenging conditions.

Since OH-SeMet is much more efficiently transferred to the egg than SS (Jlali et al. 2013; Brito et al. 2019), it has been hypothesised that the replacement of sodium selenite, supplemented at a commercial level of 0.3 mg Se/kg by OH-SeMet supplemented at the maximum dose allowed by the EU, that is, of 0.2 mg Se/kg in a broiler breeder diet and progeny diet could maintain and potentially improve their Se status and performance.

Therefore, the aim of the present study has been to evaluate the efficacy of OH-SeMet, supplemented at 0.2 mg Se/kg, in a broiler breeder and progeny diet compared with traditional SS diet supplemented at a commercial level of 0.3 mg Se/kg.

Material and methods

The study was conducted at the Poultry Science Laboratory of the School of Veterinary Medicine and Animal Science at the University of Sao Paulo, in Pirassununga, SP, Brazil. The experimental procedure of this research met the guidelines approved by the institutional animal care and use committee (University of Sao Paulo’s ethics committee – no. 8381220116).

Broiler breeder trial

The experimental installation consists of a facility (a barn) with negative pressure ventilation, two exhaust fans at one end of the barn and two cool-cells at the opposite end to decrease the temperature of the
entering air, and to promote adequate air renewal inside the barn. Since the facility was environmentally controlled, the temperature (18–22°C) and humidity (55–60% RH) were maintained within the birds comfort range. Each pen was equipped with a nest, a bin feeder and nipple-type water to provide fresh and clean drinking water. Birds were placed on 10 cm deep wood shaving litter. The lighting and feeds were provided according to the genetics manual recommendations, with *ad libitum* drinking water.

A total of 216 AP95 Aviagen broiler breeder hens were distributed in a completely randomised design at 50 weeks of age, and after 5 weeks of adaptation to the experimental conditions, they were fed on the same basal diet with the only difference being the Se source: either SS (sodium Selenite 5% Se) at 0.3 mg Se Se/kg or OH-SeMet at 0.2 mg Se Se/kg (Selisseo® 2% – Adisseo France SAS). Each treatment had 27 replicates with 4 hens per experimental unit. An experimental basal diet was formulated without Se supplementation (Table 1) to meet the nutritional levels recommended by Rostagno et al. (2011). The basal diet served as a base to prepare the two experimental diets in which the two Se sources were included via a mineral premix containing either SS (6.67 g/kg of premix) or OH-SeMet (10 g/kg premix). The hens were fed the same amount of feed per day and the same amount between treatments (on average 156 g).

The following performance, egg quality and reproductive parameters were studied in the broiler breeder trial: egg production, feed conversion ratio (FCR) per dozen eggs and per egg mass, egg mass, albumen height, Haugh unit, eggshell strength and eggshell thickness, fertility, hatchability of fertile eggs and embryonic mortality.

The egg production, egg mass and feed conversion ratio (FCR) per dozen eggs produced, and the FCR per egg mass were evaluated in two consecutive laying cycles (from 56–60 and 61–65 weeks of age). Two eggs per replicate were collected on day 28 of each cycle for internal and external quality measurements (egg weight, albumen height, Haugh unit, eggshell breaking strength and eggshell thickness), using a Digital Egg Tester (DET-6000). One egg from each replicate was collected at 60 weeks, and the yolk and the whites were separated and lyophilised for analysis of the Se content.

At 65 weeks of age, the broiler breeder hens were inseminated with fresh semen, which was collected by means of abdominal massaging, using a dose of 0.5 ml to ensure a concentration of $100 \times 10^6$ spermatozoa/ml. The hatching eggs were collected from day 3 until day 12 after insemination and placed temporarily in a holding room at 18°C. Subsequently, the eggs were grouped and placed in an incubator, and were then transferred to a hatchery on day 18; the hatched chicks were counted and selected on day 21. Any soiled, cracked, and/or deformed eggs were not placed in the incubator. Eggs that failed to hatch were broken to determine fertility (the number of fertile eggs divided by the number of incubated eggs), the blastoderm present in the germinal disc was measured, and embryonic mortality was then classified as initial (1 to 7 d), intermediate (8 to 14 d) or final (15 to 21 d). Additionally, egg hatchability (the number of chicks hatched divided by the number of eggs incubated, multiplied by 100) was also evaluated.

### Table 1. Breeder trial: composition of the basal diet.

| Ingredients, % (as fed basis) | Basal diet (56–65 weeks of age) |
|------------------------------|---------------------------------|
| Corn                         | 63.810                          |
| Soybean meal                 | 22.920                          |
| Wheat bran                   | 3.120                           |
| Soybean oil                  | 1.440                           |
| Dicalcium phosphate          | 1.060                           |
| Vitamin premix5              | 0.100                           |
| Salt                         | 0.410                           |
| L-Lysine HCl, 78.4% 4        | 0.060                           |
| Limestone                    | 6.980                           |
| Calculated composition       |                                 |
| Metabolizable energy, kcal/kg| 2820                            |
| Crude protein, %             | 16.500                          |
| Crude fat, %                 | 4.170                           |
| Digestible Lysine, %         | 0.770                           |
| Calcium, %                   | 3.200                           |
| Available phosphorus, %      | 0.450                           |
| Crude protein, %             | 17.790                          |
| Crude fat, %                 | 3.850                           |
| Calcium, %                   | 3.250                           |
| Total phosphorus, %          | 0.610                           |
| Selenium, mg/kg              | 0.035                           |

1Vitamin premix provided per kg of diet: Vitamin A(min.) 9000 U.I./kg; Vitamin D3(min.)26600 U.I./kg; Vitamin E(min.)14 U.I./kg; Vitamin K3(min.)1.6 U.I./kg; Vitamin B12(min.) 0.6 mg/kg; Vitamin B6(min.)3mg/kg; Vitamin B12(min.)10mcg/kg; Nicotidic acid(min.)0.005 g/kg; Folic acid(min.)0.6 mg/kg; Biotin(min.)0.1 mg/kg;

2Mineral premix provided per kg of diet: Zn (ZnO) 0.126 g; Cu (CuSO4) 0.0126 g; I (Ca(IO3)2) 2.52 mg; Fe (FeSO4) 0.105 g; Mn (MnSO4) 0.126 g.

3The Se in the mineral premix was provided as sodium selenite (4.5% Se) – 0.0067 g or as Hydroxy-selenomethionine (Selisseo 2%) – 0.01 g.

4Hydrochloride.

### Progeny trial

The chicks from the broiler breeder experiment were housed in an experimental pen facility, under a negative pressure ventilation system, with two exhaust fans and two cool-cells at the opposite end to decrease the temperature of the entering air and to promote air renewal inside the grow out experimental house. The temperature, pressure and humidity of the...
The chicks were allocated to 1.2 m surface floor pens, equipped with nipple drinkers and a tubular feeder, with rice husk as the bedding material, on the same day as hatching and after sexing. Feed and water were provided ad libitum for the whole trial. Heating was provided using a gas heater, according to the broilers’ needs. The light program was set according to the recommendations of the genetics manual: 23 h light: 1 h darkness until the chicks were 3 d old and then 18 h light: 6 h darkness until the slaughtering age.

A total of 520 mixed progeny broilers, 260 males and 260 females, from the broiler breeder hens were divided equally into 4 groups (sex ratio 1:1) in a completely randomised 2 × 2 factorial design: 2 sources of Se were administered for the broiler breeder diets and 2 sources of Se for the progeny diets – SS at 0.3 mg Se/kg or OH-SeMet at 0.2 mg Se/kg (Table 2). The 4 treatments were replicated 13 times (10 birds each) and the birds were reared until 41 d of age.

The broiler diets were based on corn and soybean meal and were formulated to meet the nutritional recommendations for Se suggested by Rostagno et al. (2011). The basal diets served as a base to prepare the other experimental diets, in which the 2 Se sources were included via a mineral premix containing either SS (6.67 g/kg of premix) or OH-SeMet (10 g/kg premix). The experimental broiler diets were split into three feeding phases: starter (1 to 21 d), grower (21 to 35 d) and finisher (35 to 41 d) (Table 3).

Bodyweight gain (BWG), feed intake (FI) and FCR were determined on a pen basis for the 1–7 day period, 1–21 d and for the overall experimental 1–41 d period.

**Basal diets analysis**

Feed samples were collected, for both trials, immediately after production for each basal diet. The feed samples were ground to pass through a 0.5-mm sieve and analysed for dry matter, crude protein, crude fat, calcium and total phosphorus (Horwitz and Latimer 2005).

**Selenium analysis**

The total Se content of the basal diets was analysed using inductively coupled plasma MS (ICP-MS; Agilent 7500cx, Agilent Technologies, Tokyo, Japan) (Tables 1 and 3). The Se concentration in the egg yolk and egg albumen samples was analysed using Atomic Absorption Spectrometer in a graphite oven.

**Statistical analysis**

Normality of the data distribution and homogeneity of variances were assessed using the Shapiro–Wilk test and the Levene test, respectively. Each replicate was considered an experimental unit in both the parent...
and the progeny experiments. The data from the breeder trial were analysed, by means of a general linear model (GLM), using the source of Se used in the diet as a fixed effect. The data from the progeny trial were analysed, by means of a general linear model (GLM), in a 2\( \times \)2 completely randomised factorial design, using the breeder diet and the progeny diet as fixed effects. Both trials were analysed at a 5% probability level, and a statistical trend was considered at a 10% probability level (SAS Inst. Inc., Cary, NC, USA). The obtained results are presented as mean values and pooled standard error of the mean.

**Results**

**Broiler breeder trial results**

The breeders’ performances, recorded during the trial, are summarised in Table 4. The dietary administration of OH-SeMet at 0.2 mg Se/kg increased egg production by 10% in both of the evaluated production cycles, compared with SS at 0.3 mg Se/kg (\( p = .038 \) and \( p = .044 \), respectively). The FCR per dozen eggs was significantly improved for the 56 to 60-week cycle (\( p = .024 \)) for the OH-SeMet-fed breeders, compared to the breeders fed SS, while a tendency towards significance (\( p = .051 \)) was found between the two treatments from week 61 to 65, and the OH-SeMet-fed breeders performed the best (SS at 0.3 mg Se/kg showed a 11% higher FCR per dozen eggs than OH-SeMet at 0.2 mg Se/kg). OH-SeMet supplementation at 0.2 mg Se/kg significantly decreased the egg weight for both cycles, compared to SS at 0.3 mg Se/kg (\( p = .024 \) and \( p = .005 \), respectively); the egg mass was not affected by the Se source used in the diet (\( p > .05 \)).

The supplementation of 0.2 mg Se/kg of OH-SeMet in the breeder feed improved the eggshell breaking strength, compared to SS at 0.3 mg Se/kg, showed a tendency towards significance (\( p = .083 \)) for the cycle between 56 and 60 weeks and a significantly higher eggshell breaking strength (\( p = .041 \)) for the cycle between 61 and 65 weeks (+6.0% and +9.2%, respectively; Table 5). The albumen height, Haugh units and eggshell thickness were not affected by the experimental treatments (\( p > .05 \)).

A 3-fold increase (\( p < .001 \)) of the Se content was observed in the albumen when the breeders were fed at supplementation of 0.2 mg Se/kg of OH-SeMet, compared with the breeders fed at 0.3 mg Se/kg of SS supplementation, although the Se concentration in the egg yolk was not affected by the treatments. As a result, the Se concentration in the whole egg was also significantly higher for the OH-SeMet at 0.2 mg Se/kg hens than for the SS at 0.3 mg Se/kg ones (\( p < .001 \); Table 6).

The use of 0.2 mg Se/kg of OH-SeMet significantly improved egg hatchability (by 9.6 points) compared to SS at 0.3 mg Se/kg (\( p = .011 \); Table 7). The fertility rate was not affected by the different Se sources and neither was embryonic mortality (\( p > .05 \)). However, the embryonic mortality at the final stage, that is, between 15 and 21 d of incubation, was numerically lower in the OH-SeMet-fed group than in the SS-fed group (–3.61 points).

**Progeny trial results**

The growth performances (1–41 d) of the progeny trial are summarised in Table 8. No interactions (\( p > .05 \)) were detected between the 2 breeder diets and progeny diets for any of the measured criteria. No statistical difference was found for FI or BWG between the 2 Se sources. However, the Se sources in the breeder diet showed a significant effect on the FCR of the progeny; the chicks from breeders receiving 0.2 mg Se/kg of OH-SeMet showed a significantly better FCR than the birds from breeders receiving 0.3 mg Se/kg of SS when both the 1–21 d and 1–41 d periods were considered (–2.1 and –8.4 FCR points, respectively; \( p = .032 \) and \( p = .017 \), respectively). None of the Se

| Table 4. Effect of SS or OH-SeMet on the performance of the broiler breeders. |
|---|---|---|---|---|---|
| Se source | Egg production, % | Egg weight, g | Egg mass, g | FCR\(^1\) per dozen eggs | FCR per egg mass |
| --- | --- | --- | --- | --- | --- |
| 56–60 weeks weeks | | | | | |
| SS-0.3 mg Se/kg | 57.130 | 73.260 | 41.830 | 3.490 | 3.970 |
| OH-SeMet-0.2 mg Se/kg | 62.830 | 71.210 | 44.760 | 3.060 | 3.588 |
| SEM\(^2\) | 1.390 | 0.459 | 1.029 | 0.096 | 0.106 |
| \( p \)-value | .038 | .024 | .157 | .024 | .071 |
| 61–65 weeks weeks | | | | | |
| SS-0.3 mg Se/kg | 50.430 | 72.000 | 36.350 | 3.883 | 4.510 |
| OH-SeMet-0.2 mg Se/kg | 55.940 | 69.600 | 38.950 | 3.452 | 4.140 |
| SEM | 1.380 | 0.437 | 0.996 | 0.111 | 0.134 |
| \( p \)-value | 0.044 | 0.005 | 0.195 | 0.051 | 0.169 |

SS: Sodium selenite; OH-SeMet: hydroxy-selenomethionine.
\(^1\)Feed conversion ratio.
\(^2\)Standard error of the mean.
Sources affected the broiler growth performance when the effect of the progeny diet was considered ($p > 0.05$).

**Discussion**

It is well known that the egg weight of broiler breeders increases and the shell thickness decreases at the end of the reproductive period, and these changes can negatively affect the eggshell quality and hatchability results (Peebles et al. 2000). In fact, as they age, laying breeder hens gradually decrease productivity and the eggshell quality diminishes (Dunn 2013). A fast decline appears in the egg production of laying hens after 400 to 480 days of age, due to ovarian ageing, which leads to reduced egg production and commercial value of the laying hens.

In the present study, the dietary administration of OH-SeMet, at 0.2 mg Se/kg, to breeder hens of between 56 and 65 weeks of age was more effective in maintaining a higher egg production and a better FCR per dozen eggs than those SS supplemented at 0.3 mg Se/kg. Moreover, this dietary level also showed a better eggshell quality, in particular in terms of eggshell breaking strength (Wang et al. 2021). Another study showed that, in comparison with a basal diet, adding 0.2 mg Se/kg of Se as OH-SeMet to the diets of ISA Brown hens led to a significant improvement in eggshell strength, which in turn led to a decreased percentage of broken and shell-less eggs; the authors also observed an increase in egg thickness as a result of OH-SeMet dietary administration (Tufarelli et al. 2016). When a commercial diet, containing 0.11 mg Se/kg Se, was supplemented with 0.4 mg Se/kg Se in the form of SS or Se-Yeast, it was shown that organic Se compound supplementation led to a significant increase in eggshell breaking strength (Invernizzi et al. 2013). Selenium may participate in the formation of the organic matrix of eggshells. It is likely that including SeMet in poultry feeds helps maintain shell gland integrity, especially at the end of the reproductive period (Takata et al. 2006). The anti-inflammatory effects of Se could also be of great importance in maintaining a healthy shell gland (Zhang et al. 2018).

In the present study, OH-SeMet supplementation in the breeder diet increased the Se concentration in the albumen and yolk. Greater efficacy of Se transfer and accumulation has been observed in table eggs after dietary supplementation with OH-SeMet than for SS and selenized yeast supplementation (Jlali et al. 2013). The Se concentration in an egg depends on its dietary provision and the form of Se supplementation in the diet (Surai and Fisinin 2014). Meng et al. 2019 reported that the Se from selenium yeast was deposited more efficiently in eggs than the Se from SS, probably as a result of an enhancement of the methionine metabolism route. Previously, it had been shown that Se is almost equally distributed between the yolk (58%) and albumin (42%) of an egg (Pappas, Acamovic, et al. 2005). It is known that SeMet is non-specifically incorporated into body proteins (Schrauzer and Surai 2009) and thus increases the rate of Se deposition in the albumin and yolk of eggs (Surai and Fisinin 2014). It has in fact been calculated

### Table 5. Effect of SS or OH-SeMet on the egg quality characteristics.

| Se source          | Albumen height, mm | Haugh unit | Eggshell strength, kgf | Eggshell thickness, mm |
|--------------------|--------------------|------------|------------------------|------------------------|
| SS-0.3 mg Se/kg    | 6.070              | 71.430     | 3.310                  | 0.410                  |
| OH-SeMet-0.2 mg Se/kg | 6.010             | 71.680     | 3.510                  | 0.414                  |
| SEM                | 0.094              | 0.855      | 0.056                  | 0.003                  |
| p-value            | .757               | .886       | .003                   | .539                   |

### Table 6. Effect of SS or OH-SeMet on the Se concentration (mg Se/kg, on a dry matter basis) in the albumen, yolk and whole eggs of 65-week-old broiler breeders.

| Se source          | Egg white | Egg yolk | Whole egg |
|--------------------|-----------|----------|-----------|
| SS-0.3 mg Se/kg    | 0.358     | 0.516    | 0.874     |
| OH-SeMet-0.2 mg Se/kg | 1.182   | 0.438    | 1.620     |
| SEM                | 0.108     | 0.019    | 0.098     |
| p-value            | <.001     | .300     | <.001     |

SS: Sodium selenite; OH-SeMet: hydroxy-selenomethionine.

1 Standard error of the mean.

2 Sum of the Se concentration in the egg albumen and yolk.

SS: Sodium selenite; OH-SeMet: hydroxy-selenomethionine.

1 Standard error of the mean.

SS: Sodium selenite; OH-SeMet: hydroxy-selenomethionine.

1 Standard error of the mean.
that the SeMet/Met ratio is approximately 1:160,000 in the egg yolk and about 1:87,000 in the albumen. The results of the present study show that these ratios can be substantially changed after the enrichment of eggs with Se through supplementation of OH-SeMet in breeder diets. These results are a further confirmation of the fact that dietary supplementation with an organic Se compound, and in particular with a pure form, such as OH-SeMet, is an effective way of increasing the Se concentrations in whole eggs (Scheideler et al. 2010; Tufarelli et al. 2016). It is known that an organic Se compound is more efficiently transferred to the egg than SS (Pan et al. 2007; Bennett and Cheng 2010; Wang et al. 2021). Since the egg content is used by embryos during development, an increased Se supply during this important period of development could be an advantage and help the developing embryo to synthesise higher amounts of antioxidant enzymes.

In the present study, the hatchability rate was significantly improved when 0.3 mg Se/kg of SS was replaced with 0.2 mg Se/kg of OH-SeMet. The beneficial effects of an organic Se compound have been shown to increase settable eggs, fertility and the hatchability of native Aseel chickens, as well as the number of A-grade chicks, and to reduce embryonic mortality (Khan et al. 2017). It has recently been demonstrated, in a trial on aged broiler breeders (49 to 64 weeks of age), that organic Se compound supplementation, at 0.45 mg Se/kg, was associated with higher egg production and a lower embryonic mortality rate than an SS (0.3 mg Se/kg) supplemented group (Emamverdi et al. 2019).

### Table 7. Effect of SS or OH-SeMet on hatchability (Hatch.), fertility (Fert.), embryonic mortality (EM) and pipped and contaminated eggs (Cont.) from 65-week-old broiler breeders.

| Se sources          | Hatch, % | Fert, % | EM, % | Pipped eggs, % | Cont. eggs, % |
|---------------------|----------|---------|-------|----------------|---------------|
| SS-0.3 mg Se/kg     | 69.76    | 91.67   | 6.78  | 0.69           | 2.68          |
| OH-SeMet-0.2 mg Se/kg| 79.39    | 94.10   | 6.71  | 0.91           | 2.48          |
| SEM1                | 2.54     | 6.61    | 1.04  | 0.42           | 1.11          |
| p-value             | .011     | .193    | .99   | .678           | .226          |

SS: Sodium selenite; OH-SeMet: hydroxy-selenomethionine; Hatch: hatchability; Fert: fertility; EM: embryonic mortality; Cont: contaminated  
1Standard error of the mean.

### Table 8. Effects of dietary Se source, SS or OH-SeMet, in the breeder or/and progeny diet on the performance of the broilers.

| Se source          | 1–7 days | 1–21 days | 1–41 days |
|--------------------|----------|-----------|-----------|
|                    | FI, g    | BWG, g    | FCR, g/g  | FI, g    | BWG, g    | FCR, g/g  | FI, g    | BWG, g    | FCR, g/g  |
| Broiler breeder/progeny |         |           |           |         |           |           |         |           |           |
| SS/OH-SeMet        | 160      | 148       | 1.089     | 1085    | 884       | 1.229     | 4830     | 2608      | 1.855     |
| SS/SS              | 157      | 147       | 1.078     | 1063    | 868       | 1.225     | 4593     | 2609      | 1.766     |
| OH-SeMet/SS        | 156      | 146       | 1.073     | 1068    | 890       | 1.201     | 4562     | 2664      | 1.724     |
| OH-SeMet/OH-SeMet  | 158      | 152       | 1.047     | 1085    | 895       | 1.212     | 4561     | 2643      | 1.728     |
| P piping           | 1200     | 1.830     | 0.010     | 6.540   | 4.430     | 0.010     | 41.750   | 20.130    | 0.020     |
| p-value            |          |           |           |          |           |           |          |           |           |
| Broiler Breeder    | .491     | .735      | .442      | .866    | .063      | .032      | .088     | .273      | .017      |
| Progeny            | .754     | .385      | .793      | .145    | .225      | .426      | .183     | .794      | .178      |

SS: Sodium selenite; OH-SeMet: hydroxy-selenomethionine; FI: feed intake; BWG: body weight gain; FCR: feed conversion ratio.  
1Standard error of the mean.
showed a reduction in mortality of breeder hens (Rajashree et al. 2014). The authors also showed that supplementing feeds with 0.5 mg Se/kg organic Se in the first part of reproduction (29–39 weeks weeks) increased egg production, the percentage of settable eggs and hatchability. Therefore, it is recommended to use an effective source of organic Se at an adequate level in broiler breeder diets, not only at the end of the reproductive period, as has been shown in the present study, but also the early egg production stages.

In the present study, the FCR was significantly improved in the progeny broilers from breeders fed OH-SeMet, thus reflecting the long-lasting maternal effects of the organic Se compound. Recent developments in the maternal programming and gene expression areas indicate that maternal effects can also be observed further along with the postnatal development of chicks than previously believed. The underlying molecular mechanisms are still under investigation, and epigenetic mechanisms may provide an explanation for the maternal effect phenomenon (Pinney and Simmons 2012). Indeed, next-generation individuals may show different phenotypic traits, depending on the environmental housing conditions of their mothers (Berghof et al. 2013). Commercial poultry raising conditions are more stressful and quite different from those of their wild ancestors, so various effects on the offspring may be expected (Dixon et al. 2016).

Maternal programming in birds could be mediated by changes in the egg composition, and it seems likely that there is an effect of egg composition on the postnatal development of chicks. It has been suggested that the maternal effect of dietary organic Se can last beyond the hatching stage. In fact, an organic Se compound in the maternal diet has been associated with an increased Se level in the liver and muscles of progeny chicks at day 5 (Surai 2000); day 14 (Pappas et al. 2006); days 21 to 28 (Pappas, Karadas, et al. 2005) or even at 56 d of age (Zhang et al. 2014). These results suggest that the maternal deposition of SeMet in the tissues of hens can affect the Se metabolism of the progeny. An increased Se status of newly hatched chicks, as well as of chickens in their early postnatal development, could lead to changes in gene expression in the gut-associated with improved FCR. When broiler breeder diets were supplemented with a Se-yeast product, the results of a gene expression analysis demonstrated that the number of gene transcripts associated with energy production and protein translation were greater in the oviduct of the experimental birds than in the control broiler breeders (Brennan et al. 2011). A better understanding of the epigenetic mechanisms that govern the embryonic and postnatal responses to changes in the maternal diet could open new avenues for the improvement of poultry production efficiency, including their productive and reproductive performance (Morisson et al. 2017).

In this study, the Se sources of the broiler diets did not affect the performance of the broilers. This result appears to be logical, in that there was no major challenge for the birds during the trial. It is in fact well known that the benefits of organic Se (namely SeMet), deposited in animal tissue, emerge when birds face stressful situations (Surai et al. 2018). When SeMet is supplemented, the greater amount of Se stored in the tissues enables the birds to produce antioxidant enzymes when their feed intake drops and/or their Se requirement rises, as an effective means of ensuring their metabolic needs and thus their growth performance.

**Conclusion**

Overall, dietary supplementation with OH-SeMet at 0.2 mg Se/kg has been found to significantly improve egg production, eggshell strength and hatchability for an aged broiler breeder flock, compared with SS at 0.3 mg Se/kg, and this may therefore be an effective approach to help ageing breeding birds maintain and prolong their productive and reproductive performances. Maternal supplementation with OH-SeMet has shown a positive impact on the progeny, in terms of feed efficiency. However, further research is needed to better elucidate the role of dietary maternal Se on the health and antioxidant status of the progeny.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data that support the findings of this study are available from the corresponding author, [CSSA], upon reasonable request.

References

Bennett DC, Cheng KM. 2010. Selenium enrichment of table eggs. Poult Sci. 89(10):2166–2172.

Berghof TV, Parmentier HK, Lammers A. 2013. Transgenerational epigenetic effects on innate immunity in broilers: an underestimated field to be explored? Poult Sci. 92(11):2904–2913.

Bottje WG. 2019. Oxidative metabolism and efficiency: the delicate balancing act of mitochondria. Poult Sci. 98(10):4223–4230.

Brennan KM, Crowdus CA, Cantor AH, Pescatore AJ, Barger JL, Horgan K, Xiao R, Power RF, Dawson KA. 2011. Effects of organic and inorganic dietary selenium supplementation on gene expression profiles in oviduct tissue from broiler-breeder hens. Anim Reprod Sci. 125(1–4):180–188.

Brito A, Cavalcante D, De Marco M, Liu YG, Goncalves GJ, Perazzo F. 2019. Hydroxy-selenomethionine can improve productive performance and egg quality of laying hens in the late phase of production. In Proceedings of Australian Poultry Science Symposium; Feb 17–20; Sidney, Australian. Sidney, Australian: The World’s Poultry Science Association. p. 248.

Dixon LM, Sparks NH, Rutherford KM. 2016. Early experiences matter: a review of the effects of prenatal environment on offspring characteristics in poultry. Poult Sci. 95(3):489–499.

Dunn IC. 2013. Long Life Layer; genetic and physiological limitations to extend the laying period. In Proceedings of European Symposium on Poultry Nutrition; Aug 26–29; Potsdam, Germany. Beekbergen, Netherland: The World’s Poultry Science Association. p. 321.

Emamverdi M, Zare-Shahneh A, Zhandi M, Minai-Tehrani D, Khodaei-Motlagh M. 2019. An improvement in productive and reproductive performance of aged broiler breeder hens by dietary supplementation of organic selenium. Theriogenology. 126:279–285.

Hezarjaribi A, Rezaeipour V, Abdollahpour R. 2016. Effects of intramuscular injections of vitamin E-selenium and a gonadotropin releasing hormone analogue (GnRHa) on reproductive performance and blood metabolites of post-molt male broiler breeders. Asian Pac J Reprod. 5(2):156–160.

Horwitz W, Latimer GW. 2005. Official methods of analysis. 18th ed. Gaithersburg, MD, USA: AOAC International.

Invernizzi G, Agazzi G, Ferroni M, Reucci R, Fanelli A, Baldi A, Dell’Orto V, Savoini G. 2013. Effects of inclusion of selenium-enriched yeast in the diet of laying hens on performance, eggshell quality, and selenium tissue deposition. Ital J Anim Sci. 12:1.

Jlali M, Briens M, Rouffineau F, Mercerd F, Geraert PA, Mercier Y. 2013. Effect of 2-hydroxy-4-methylselenobutanoic acid as a dietary selenium supplement to improve the selenium concentration of table eggs. J Anim Sci. 91(4):1745–1752.

Khan MT, Mahmud A, Zahoor I, Javed K. 2017. Organic and inorganic selenium in Aseel chicken diets: effect on hatching traits. Poult Sci. 96(5):1466–1472.

Li K, Jiang L, Wang J, Xia L, Zhao R, Cai C, Wang P, Zhan X, Wang Y. 2020. Maternal dietary supplementation with different sources of selenium on antioxidant status and mortality of chicken embryo in a model of diquat-induced acute oxidative stress. Anim Feed Sci Technol. 261:114369.

Meng T, Liu Y-L, Xie C-Y, Zhang B, Huang Y-Q, Zhang Y-W, Yao Y, Huang R, Wu X. 2019. Effects of different selenium sources on laying performance, egg selenium concentration, and antioxidant capacity in laying hens. Biol Trace Elem Res. 189(2):548–555.

Morisson M, Coustham V, FréSard L, Collin A, Zerjal T, Métaire-Courtaud S, Bodin L, Minvielle F, Brun JM, Pitel F. 2017. Nutritional programming and effect of ancestor diet in birds. In: Patel V, Preedy V, editors. Handbook of nutrition, diet, and epigenetics. Switzerland: International Publishing. p. 1–18.

Pan C, Huang K, Zhao Y, Qin S, Chen F, Hu Q. 2007. Effect of selenium source and level in hen’s diet on tissue selenium deposition and egg selenium concentrations. J Agric Food Chem. 55(3):1027–1032.

Pappas AC, Acamovic T, Sparks NH, Surai PF, McDevitt RM. 2005. Effects of supplementing broiler breeder diets with organic selenium and polyunsaturated fatty acids on egg quality during storage. Poult Sci. 84(6):865–874.

Pappas AC, Acamovic T, Sparks NH, Surai PF, McDevitt M. 2006. Effects of supplementing broiler breeder diets with organoselenium compounds and polyunsaturated fatty acids on hatchability. Poult Sci. 85(9):1584–1593.

Pappas AC, Karadas F, Surai PF, Speake BK. 2005. The selenium intake of the female chicken influences the selenium status of her progeny. Comp Biochem Physiol B Biochem Systemat Biol. 142(4):465–474.

Pappas AC, Zoidis E, Chadio SE. 2019. Maternal selenium and developmental programming. Antioxidants. 8:145.

Peebles ED, Gardner CW, Brake J, Benton CE, Bruzual JJ, Gerard PD. 2000. Albumen height and yolk and embryo compositions in broiler hatching eggs during incubation. Poult Sci. 79(10):1373–1377.

Pinney SE, Simmons RA. 2012. Metabolic programming, epigenetics, and gestational diabetes mellitus. Curr Diab Rep. 12(1):67–74.

Rajashree K, Muthukumar T, Karthikeyan N. 2014. Comparative study of the effects of organic selenium on hen performance and productivity of broiler breeders. Br Poult Sci. 55(3):367–374.

Rostagno HS, Albino LFT, Donzele JL, Gomes PC, Oliveira RF, Lopes DC, Ferreira AS, Barreto SLT, Euclides RF. 2011. Tabelas brasileiras para aves e suínos: Composição de alimentos e exigências nutricionais. 3rd ed. Viçosa, MG SE: Editora UFV.

Scheideler SE, Weber P, Monsalve D. 2010. Supplemental vitamin E and selenium effects on egg production, egg quality, and egg deposition of α-tocopherol and selenium. J Appl Poult. 19(4):354–360.

Schrauger GN, Surai PF. 2009. Selenium in human and animal nutrition: resolved and unresolved issues. A partly historical treatise in commemoration of the fiftieth anniversary of the discovery of the biological essentiality of selenium, dedicated to the memory of Klaus Schwarz (1914–1978)
on the occasion of the thirtieth anniversary of his death. Crit Rev Biotechnol. 29(1):2–9.

Surai PF. 2000. Effect of selenium and vitamin E content of the maternal diet on the antioxidant system of the yolk and the developing chick. Br Poult Sci. 41(2):235–243.

Surai PF. 2018. Molecular mechanisms of selenium action: selenoproteins. In: Selenium in Poultry Nutrition and Health. Wageningen, Netherlands: Wageningen Academic Publishers. p. 67–122.

Surai PF, Fisinin VI. 2014. Selenium in poultry breeder nutrition: an update. Anim Feed Sci Technol. 191:1–15.

Surai PF, Kochish II, Fisinin VI, Velichko OA. 2018. Selenium in poultry nutrition: from sodium selenite to organic selenium sources. J Poult Sci. 55(2):79–93.

Takata FN, Evencio Neto J, Evencio LB, Simoes MJ. 2006. Oviduct morphology in commercial layers subjected to forced molting supplemented with Sel-Plex. In: Proceedings of Alltech Annual Symposium. Apr 23–26; Lexington, USA. Stamford, UK: Alltech UK. p. 36.

Tufarelli V, Ceci E, Laudadio V. 2016. 2-Hydroxy-4-methylselenobutanoic acid as new organic selenium dietary supplement to produce selenium-enriched eggs. Biol Trace Elem Res. 171(2):453–458.

Wang Z, Kong L, Zhu L, Hu X, Su P, Song Z. 2021. The mixed application of organic and inorganic shows better effects on incubation and progeny parameters. Poult Sci. 100(2):1132–1141.

Zhang L, Wang YW, Zhou Y, Zheng L, Zhan XA, Pu QH. 2014. Different sources of maternal selenium affect selenium retention, antioxidant status, and meat quality of 56-day-old offspring of broiler breeders. Poult Sci. 93(9):2210–2219.

Zhang R, Liu Y, Xing L, Zhao N, Zheng Q, Li J, Bao J. 2018. The protective role of selenium against cadmium-induced hepatotoxicity in laying hens: expression of Hsps and inflammation-related genes and modulation of elements homeostasis. Ecotoxicol Environ Saf. 159:205–212.

Zhao R, Li K, Wang J, Wang Y, Wu R, Zhan X. 2019. Effects of different forms and levels of selenomethionine on productive performance and antioxidant status of broiler breeders and its offspring. Biol Trace Elem Res. 188(2):478–484.