Effects of Cystine-Based Selenium Sources on Egg Quality, Antioxidant Capacity, and Selenium Content in Eggs of Laying Hens (Postprint)

Authors: Long Shuo, Zhang Haijun, WU Shugeng, Wang Xiaocui, Wang Jing, Qi Guanghai

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Abstract

This experiment was conducted to investigate the effects of dietary supplementation with selenocystine (SeC), L-methylselenocysteine (L-MSC), L-selenocysteine (L-SeCys), and sodium selenite (SS) on production performance, egg quality, antioxidant capacity, and selenium content in eggs of laying hens, in order to provide a basis for the production of selenium-enriched eggs. A total of 450 healthy Hy-Line Gray laying hens at 26 weeks of age with similar laying rates were randomly allocated to 5 groups with 6 replicates per group and 15 hens per replicate. The control group was fed a basal diet (without additional selenium supplementation), while the other 4 groups were fed the basal diet supplemented with 0.30 mg/kg selenium from SeC, L-MSC, L-SeCys, and SS, respectively. The measured selenium contents in the diets of each group were 0.08, 0.36, 0.35, 0.31, and 0.37 mg/kg, respectively. The preliminary period lasted for 1 week, and the formal experimental period lasted for 4 weeks. The results showed: 1) Compared with the SS group and the control group, there were no significant differences in average egg weight, laying rate, and feed-to-egg ratio of laying hens in the cystine-type selenium source groups ($P>0.05$). The average daily feed intake of the L-SeCys group was significantly lower than that of the control group during weeks 1-2 of the experiment ($P<0.05$). 2) Compared with the SS group and the control group, there were no significant differences in albumen height, Haugh unit, eggshell strength, egg shape index, and yolk-to-albumen ratio of laying hens in the cystine-type selenium source groups ($P>0.05$). At the end of week 4 of the experiment, the yolk color of the SS group was significantly higher than that of the other groups ($P<0.05$); the eggshell thickness of the SeC and SS groups was significantly higher than that of the other groups ($P<0.05$), and the eggshell thickness of the L-MSC and L-SeCys groups was significantly higher than that of the control group ($P<0.05$); the eggshell percentage of the control group was

significantly lower than that of all experimental groups (P<0.05). 3) Compared with the SS group and the control group, the plasma glutathione peroxidase (GSH-Px) activity of laying hens in the cystine-type selenium source groups was significantly increased (P<0.05); the plasma total superoxide dismutase (T-SOD) activity of the SeC and SS groups was significantly higher than that of the control group (P<0.05); there was no significant difference in plasma malondialdehyde (MDA) content between the cystine-type selenium source groups and the SS group (P>0.05); the plasma total antioxidant capacity (T-AOC) of the control group was significantly lower than that of the other groups (P<0.05), and the plasma T-AOC of the L-MSC group was the highest, significantly higher than that of the SS group (P<0.05). 4) Compared with the control group, dietary supplementation with cystine-type selenium sources significantly increased the selenium content in eggs (P<0.05), with the L-MSC group being the highest; the selenium content in eggs and selenium conversion rate of the cystine-type selenium source groups were higher than those of the SS group (P>0.05). In conclusion, dietary supplementation with the three cystine-type selenium sources can enhance the body' s antioxidant status and increase selenium content in eggs, with SeC and L-MSC being more effective.

Full Text

Effects of Cystine Selenium Sources on Egg Quality, Antioxidant Capacity and Egg Selenium Content of Laying Hens

LONG Shuo, ZHANG Haijun, *WU Shugeng*, WANG Xiaocui, WANG Jing, QI Guanghui

(Key Laboratory of Feed Biotechnology of Ministry of Agriculture, National Engineering Research Center of Biological Feed, Feed Research Institute, Chinese Academy of Agricultural Sciences, Beijing 100081, China)

Abstract: This experiment was conducted to investigate the effects of dietary selenocystine (SeC), L-Se-methylselenocysteine (L-MSC), L-selenocysteine (L-SeCys) and sodium selenite (SS) on production performance, egg quality, antioxidant capacity and egg selenium content of laying hens, aiming to provide a basis for the production of selenium-enriched eggs. Four hundred and fifty healthy Hy-Line Grey laying hens aged 26 weeks with similar laying rates were randomly allocated into 5 groups with 6 replicates per group and 15 hens per replicate. The control group was fed a basal diet without supplemental selenium, while the other four groups received the basal diet supplemented with 0.30 mg/kg selenium from SeC, L-MSC, L-SeCys and SS, respectively. The measured selenium concentrations in the diets were 0.08, 0.36, 0.35, 0.31 and 0.37 mg/kg. The pre-test period lasted for 1 week and the formal test period lasted for 4 weeks. The results showed: 1) Compared with the SS and control groups, the average egg weight, laying rate and feed-to-egg ratio of laying hens in the cystine selenium source groups showed no significant differences (P>0.05). The

average daily feed intake of the L-SeCys group was significantly lower than that of the control group during weeks 1-2 ($P<0.05$). 2) Compared with the SS and control groups, the albumen height, Haugh unit, eggshell strength, egg shape index, and yolk and albumen percentages of laying hens in the cystine selenium source groups showed no significant differences ($P>0.05$). At the end of week 4, the yolk color of the SS group was significantly higher than that of other groups ($P<0.05$); the eggshell thickness of the SeC and SS groups was significantly higher than that of other groups ($P<0.05$), while the eggshell thickness of the L-MSC and L-SeCys groups was significantly higher than that of the control group ($P<0.05$); the eggshell percentage of the control group was significantly lower than that of all treatment groups ($P<0.05$). 3) Compared with the SS and control groups, the plasma glutathione peroxidase (GSH-Px) activity of laying hens in the cystine selenium source groups was significantly increased ($P<0.05$); the plasma total superoxide dismutase (T-SOD) activity of the SeC and SS groups was significantly higher than that of the control group ($P<0.05$); the plasma malondialdehyde (MDA) content of the cystine selenium source groups showed no significant difference from the SS group ($P>0.05$); the plasma total antioxidant capacity (T-AOC) of the control group was significantly lower than that of other groups ($P<0.05$), with the L-MSC group showing the highest T-AOC, significantly higher than the SS group ($P<0.05$). 4) Compared with the control group, dietary supplementation with cystine selenium sources significantly increased egg selenium content ($P<0.05$), with the highest value observed in the L-MSC group; the egg selenium content and selenium conversion rate in the cystine selenium source groups were higher than those in the SS group ($P>0.05$). In conclusion, dietary supplementation with the three cystine selenium sources can enhance antioxidant status and increase egg selenium content, with SeC and L-MSC showing better effects.

Keywords: laying hens; selenium sources; antioxidant capacity; egg selenium content

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1 Materials and Methods

1.1 Experimental Materials and Animals

The selenium sources used in the experiment are shown in Table 1. The experimental animals were 26-week-old Hy-Line Grey laying hens in good health condition.

Table 1 Selenium sources used in the experiment

Selenium sources	Character	Selenium content	Source
Sodium selenite (SS)	Light yellow powder	45.6%	Huanghua Jinhua Additive Co., Ltd.
Selenocystine (SeC)	Light yellow solid	42.6%	Chongqing Zhang-bang Medical Technol-ogy Co., Ltd.
L-Se-methylselenocysteine (L-MSC)	Yellow to light yellow solid	41.7%	Jiyuan Xijian Biomedi-cal Technol-ogy Develop-ment Co., Ltd.
L-selenocysteine (L-SeCys)	Yellow to light yellow solid	46.2%	Chongqing Zhang-bang Medical Technol-ogy Co., Ltd.

1.2 Experimental Diets and Management

The basal diet was formulated according to the *Feeding Standard of Chicken* (NY/T 33–2004). The composition and nutrient levels of the basal diet are shown in Table 2 . The hens were housed in 4-tier cage systems with 3 hens per cage. Random numbering was used for group arrangement to avoid environmental and positional effects. Hens had free access to feed and water. Lighting consisted of natural light plus artificial supplementation (16 h/d). Relative humidity was maintained at 50%-60% with natural ventilation combined with longitudinal negative pressure ventilation. Manure was removed twice daily, and disinfection was performed weekly with conventional immunization. The pre-test period lasted for 1 week and the formal test period lasted for 4 weeks.

Table 2 Composition and nutrient levels of the basal diet (air-dry basis), %

Note: 1) The premix provided the following per kg of diet: VA 12,500 IU, VD3 4,125 IU, VE 15 IU, VK 2 mg, thiamine 1 mg, riboflavin 8.5 mg, calcium

pantothenate 50 mg, niacin 32.5 mg, pyridoxine 8 mg, biotin 2 mg, folic acid 5 mg, VB12 5 mg, choline 500 mg, Mn 65 mg, I 1 mg, Fe 60 mg, Cu 8 mg, Zn 66 mg. 2) ME and AP were calculated values, while the others were measured values.

1.3 Experimental Design

Four hundred and fifty healthy Hy-Line Grey laying hens aged 26 weeks with similar laying rates were randomly allocated into 5 groups with 6 replicates per group and 15 hens per replicate. The control group was fed the basal diet without supplemental selenium, while the SeC, L-MSC, L-SeCys and SS groups received the basal diet supplemented with 0.30 mg/kg selenium from the respective sources. The measured selenium concentrations in the diets were 0.08, 0.36, 0.35, 0.31 and 0.37 mg/kg.

1.4 Measurements

1.4.1 Production Performance Eggs were collected daily at 09:30. Egg weight, number of eggs, and numbers of soft-shelled, broken and abnormal eggs were recorded per replicate. Average egg weight and laying rate were calculated. Feed was weighed and settled weekly per replicate to calculate average daily feed intake (ADFI) and feed-to-egg ratio.

Average egg weight (g) = Total egg weight / Total number of eggs
Laying rate (%) = 100 × Total number of eggs / (Number of hens × Days)
ADFI [g/(hen · d)] = Total feed intake / (Number of hens × Days)
Feed-to-egg ratio = Total feed consumption / Total egg weight

1.4.2 Egg Quality At the end of weeks 2 and 4, 3 eggs were randomly selected from each replicate for egg quality determination. Egg weight, thick albumen height, Haugh unit and yolk color were measured using a SONOVA Egg Analyzer™ (Orka Technology Ltd.). Eggshell strength was measured using an Egg Force Reader (Orka Technology Ltd.). Eggshell thickness was measured using an Eggshell Thickness Gauge (Orka Technology Ltd.). Egg shape index was measured using an Egg Index Reader (Fujibira Industry Co., Ltd.). For egg component analysis, whole egg, eggshell, yolk and albumen were weighed separately, and the percentages of eggshell, albumen and yolk were calculated.

1.4.3 Plasma Antioxidant Indices At the end of week 4, 2 hens were randomly selected from each replicate. Fasting blood samples were collected from wing veins using anticoagulant tubes. Plasma was prepared by centrifugation at 4,000 r/min for 10 min at 4°C, aliquoted and stored at -20°C. Plasma GSH-Px activity and T-AOC were determined by colorimetric assay. Plasma T-SOD activity was determined by xanthine oxidase method. Plasma MDA content was determined by thiobarbituric acid method. Kits from Nanjing Jiancheng Bioengineering Institute were used according to the manufacturer's instructions.

1.4.4 Egg Selenium Content Egg selenium content was determined by hydride generation-atomic fluorescence spectrometry (GB 5009.93–2010). At the end of week 4, 2 eggs were randomly selected from each replicate, shelled, mixed and freeze-dried. For digestion, 2 g of freeze-dried whole egg powder was placed in a digestion flask with 10.0 mL mixed acid (nitric acid:perchloric acid = 9:1, v/v) and a few glass beads, covered with a watch glass and left overnight. The mixture was heated on an electric hot plate with timely addition of nitric acid solution until the solution became clear and colorless with white smoke, then heated continuously to 2 mL remaining. After cooling, 5.0 mL hydrochloric acid was added and heating continued until the solution became clear and colorless with white smoke, reducing hexavalent selenium to tetravalent selenium. After cooling, the solution was transferred to a 50 mL volumetric flask, diluted to volume and mixed. A 10.0 mL aliquot of the digested solution was placed in a 15 mL centrifuge tube, mixed with 2.0 mL hydrochloric acid (6 mol/L) and 1.0 mL potassium ferricyanide (100 g/L). Selenium content was determined using an atomic fluorescence spectrometer with blank control (ultrapure water) and standard sample control (selenium reference material GBW8551).

1.4.5 Egg Selenium Conversion Rate Based on the feed-to-egg ratio, egg selenium conversion rate was calculated as:
Egg selenium conversion rate (%) = 100 × (Selenium content in 1 kg eggs / Total selenium intake for producing 1 kg eggs)

1.5 Data Processing

Data were analyzed by one-way ANOVA using SPSS 19.0. Duncan' s multiple range test was used for pairwise comparisons. $P<0.05$ was considered statistically significant and $P<0.01$ was considered highly significant. Results were expressed as "mean ± standard deviation" .

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2 Results

2.1 Effects of Cystine Selenium Sources on Production Performance of Laying Hens

As shown in Table 3 , compared with the SS and control groups, the average egg weight, laying rate and feed-to-egg ratio of laying hens in the cystine selenium source groups showed no significant differences ($P>0.05$). The ADFI of the L-SeCys group was significantly lower than that of the control group during weeks 1-2 ($P<0.05$), while no significant differences were observed among other groups ($P>0.05$). Dietary supplementation with different selenium sources at the same level tended to reduce the ADFI of laying hens, but had no significant effects on laying rate, average egg weight or feed-to-egg ratio.

Table 3 Effects of dietary cystine selenium sources on production performance

of laying hens

Note: In the same row, values with different small letter superscripts mean significant difference (P<0.05), while with the same or no letter superscripts mean no significant difference (P>0.05). The same as below.

2.2 Effects of Cystine Selenium Sources on Egg Quality of Laying Hens

As shown in Table 4 , compared with the SS and control groups, the albumen height, Haugh unit, eggshell strength, egg shape index, and yolk and albumen percentages of laying hens in the cystine selenium source groups showed no significant differences (P>0.05). However, the Haugh unit of the cystine selenium source groups at the end of week 4 was higher than that of the SS group, and the albumen height of all treatment groups was higher than that of the control group. At the end of week 4, the yolk color of the SS group was significantly higher than that of other groups (P<0.05). The eggshell thickness of the SeC and SS groups was significantly higher than that of other groups (P<0.05), while the eggshell thickness of the L-MSC and L-SeCys groups was significantly higher than that of the control group (P<0.05). The eggshell percentage of the control group was significantly lower than that of all treatment groups (P<0.05). The results indicated that dietary selenium supplementation could improve yolk color, increase eggshell thickness and eggshell percentage, and tend to improve albumen height and Haugh unit.

Table 4 Effects of dietary cystine selenium sources on egg quality of laying hens

2.3 Effects of Cystine Selenium Sources on Plasma Antioxidant Indices of Laying Hens

As shown in Table 5 , compared with the SS and control groups, the plasma GSH-Px activity of laying hens in the cystine selenium source groups was significantly increased (P<0.05), with increases of 141.42%, 83.59% and 117.33% in the SeC, L-SeCys and L-MSC groups compared with the SS group, respectively. The plasma T-SOD activity of the cystine selenium source groups showed no significant difference from the SS group (P>0.05), while the plasma T-SOD activity of the SeC and SS groups was significantly higher than that of the control group (P<0.05), and the plasma T-SOD activity of the L-SeCys and L-MSC groups was also higher than that of the control group (P>0.05). The plasma MDA content of the cystine selenium source groups showed no significant difference from the SS group (P>0.05). The plasma T-AOC of the control group was significantly lower than that of other groups (P<0.05), with the L-MSC group showing the highest T-AOC, significantly higher than the SS group (P<0.05). The results indicated that dietary selenium supplementation could improve the antioxidant capacity of laying hens.

Table 5 Effects of dietary cystine selenium sources on plasma antioxidant indexes of laying hens

2.4 Effects of Cystine Selenium Sources on Egg Selenium Content and Selenium Conversion Rate of Laying Hens

As shown in Table 6 , compared with the control group, dietary supplementation with cystine selenium sources significantly increased egg selenium content ($P<0.05$), with the highest value observed in the L-MSC group. Compared with the SS group, the egg selenium content in the SeC, L-MSC and L-SeCys groups increased by 12.00%, 27.90% and 4.63%, respectively ($P>0.05$). Selenium sources had certain effects on egg selenium conversion rate, with the order being: L-MSC > L-SeCys > SeC > SS. The egg selenium conversion rate of the cystine selenium source groups was higher than that of the SS group ($P>0.05$).

Table 6 Effects of dietary cystine selenium sources on selenium content and selenium conversion rate in egg of laying hens

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3 Discussion

3.1 Effects of Cystine Selenium Sources on Production Performance of Laying Hens

Selenium is an essential trace element for humans and animals. Selenium deficiency can cause Keshan disease, Kashin-Beck disease and endemic fluorosis, while selenium also has functions such as antioxidant, anti-stress, immunity enhancement and anticancer activities. This experiment showed that compared with the SS group, dietary supplementation with 0.3 mg/kg cystine selenium sources had no significant effect on production performance of laying hens. Previous studies have shown that dietary supplementation with 0.3 mg/kg SeMet, YSe and SS had no significant effect on production performance of laying hens, and 0.1, 0.3 and 0.5 mg/kg SeMet also had no significant effect on production performance. Organic or inorganic selenium had no significant effect on production performance of laying hens. Selenium-enriched probiotics could significantly increase laying rate and average egg weight and reduce feed-to-egg ratio, which was directly related to the probiotics themselves. The production performance of laying hens and their sensitivity to selenium are affected by factors such as diet, breed, age and metabolic status, so the effects of different selenium sources and levels on production performance vary. This experiment used Hy-Line Grey laying hens during the transition from onset to peak laying period, when metabolic and antioxidant capacities were vigorous, and production performance was less affected by dietary factors. During weeks 1-2, the ADFI of the L-SeCys group was significantly lower than that of the control group but showed no significant difference from the SS group, possibly because the hens had not adapted to the selenium sources added to the diet at the initial stage. With prolonged feeding time, no significant differences in ADFI were observed among groups, and both laying rate and average egg weight increased. Compared with SS, 0.3 mg/kg SeC, L-MSC and L-SeCys showed stronger effects on improving production performance of laying hens.

3.2 Effects of Cystine Selenium Sources on Egg Quality of Laying Hens

Egg quality is affected by breed, laying age, nutrition level and diseases. Albumen height and Haugh unit are important indicators for measuring egg white quality and freshness. Studies have shown that dietary supplementation with 0.3 mg/kg selenium resulted in higher Haugh unit in the YSe group than in the SS group, but the difference was not significant. This experiment showed that the Haugh unit of the cystine selenium source groups at the end of week 4 was higher than that of the SS group, and the albumen height of all treatment groups was higher than that of the control group, indicating a trend of cystine selenium sources to improve Haugh unit. Sun et al. reported that dietary supplementation with different selenium sources and levels had no significant effect on conventional egg quality, but slightly increased eggshell thickness and deepened yolk color compared with the control group. This experiment showed that dietary supplementation with 0.3 mg/kg cystine selenium sources and SS had no significant effect on egg shape index and eggshell strength. At week 4, the eggshell thickness of the SeC and SS groups was the same and significantly higher than that of other groups, while the eggshell thickness of the L-MSC and L-SeCys groups was significantly lower than that of the SS group but significantly higher than that of the control group. Studies have shown that YSe could increase eggshell thickness but without significant difference, indicating that selenium could improve eggshell quality possibly by enhancing antioxidant capacity to protect eggshell, and SeC and SS had better effects on eggshell thickness than L-MSC and L-SeCys.

3.3 Effects of Cystine Selenium Sources on Plasma Antioxidant Capacity of Laying Hens

The health status of the body is closely related to its antioxidant capacity. Selenium is an essential component of the GSH-Px active center and can regulate the antioxidant capacity of the body through other selenoenzymes or selenoproteins. It exerts antioxidant damage effects by scavenging free radicals in the body and preventing oxidation stress reactions of macromolecules, playing an important role in the antioxidant defense system. Studies have shown that 0.3 mg/kg SeMet significantly increased blood selenium content and GSH-Px activity, and 0.3 mg/kg SeMet, YSe and SS all significantly increased plasma GSH-Px and T-SOD activities. This experiment showed that compared with the SS and control groups, the plasma GSH-Px activity of laying hens in the cystine selenium source groups was significantly increased. Studies have shown that blood selenium content is closely related to plasma T-SOD activity, which can relatively reflect the degree of selenium clearing free radicals in the body. Increased GSH-Px activity can reduce peroxide damage to T-SOD. GSH-Px and T-SOD are important antioxidant enzymes in the antioxidant system. T-SOD can convert superoxide radicals ($O2^{-}$) produced in immune responses into hydrogen peroxide (H2O2), which is then converted into H2O and O2 through

the action of GSH-Px and catalase (CAT), thereby improving the antioxidant capacity of the body. This experiment showed that the plasma T-SOD activity of the cystine selenium source groups showed no significant difference from the SS group, but the plasma T-SOD activity of the SeC and SS groups was significantly higher than that of the control group. Studies have shown that 0.2, 0.5 and 1.0 mg/kg YSe and SS could significantly increase blood T-SOD activity of laying hens.

T-AOC reflects the total antioxidant capacity of the body. Studies have shown that organic selenium could significantly increase serum T-AOC. This experiment showed that the plasma T-AOC of the cystine selenium source groups was higher than that of the SS group, with the L-MSC group showing the highest T-AOC, significantly higher than the SS group. Compared with the control group, dietary supplementation with different selenium sources significantly increased plasma T-AOC. The improvement of T-AOC by organic selenium is mainly related to the increased GSH-Px activity, as selenium in organic selenium is more easily incorporated into the active center of GSH-Px than SS.

MDA is a product of lipid peroxidation in the body. With enhanced free radical activity and oxidation, MDA content increases and antioxidant capacity decreases. Studies have shown that YSe could extremely significantly decrease serum MDA content and liver MDA content, increase plasma GSH-Px activity of broilers, and extremely significantly increase liver T-AOC. This experiment showed that the plasma MDA content of the cystine selenium source groups showed no significant difference from the SS group. Compared with the control group, dietary supplementation with different selenium sources decreased plasma MDA content. This is because dietary supplementation with certain amounts of selenium can increase GSH-Px and T-SOD activities, which can inhibit MDA production and reduce damage from excessive free radicals. Blood selenium content shows a significant linear relationship with dietary selenium level (R^2=0.968, P<0.001).

3.4 Effects of Cystine Selenium Sources on Egg Selenium Content and Selenium Conversion Rate of Laying Hens

Selenium is an essential trace element for humans, mainly obtained from food. Eggs are an important component of human diet, so selenium supplementation can be achieved by increasing egg selenium content. Studies have shown that egg selenium content has a linear relationship with dietary selenium level. After feeding selenium-containing diets, selenium deposition in eggs began at 2 days and peaked at 7 days. After changing the diet for 4 weeks, egg selenium content decreased to normal levels. Dietary supplementation with 0.3 mg/kg different selenium sources in White Leghorn laying hens could significantly increase egg selenium content. Studies have shown that dietary supplementation with the same level (0.3 mg/kg) of four selenium sources could significantly increase selenium deposition in eggs and increase egg selenium content at weeks 4 and 8. Dietary supplementation with 0-0.5 mg/kg selenium resulted in linear increase in

egg selenium content. This experiment showed that compared with the SS group, dietary supplementation with 0.3 mg/kg SeC, L-MSC and L-SeCys all increased egg selenium content, with the highest value in the L-MSC group. Compared with the control group, dietary supplementation with cystine selenium sources increased egg selenium content. Previous studies have shown that with the same dietary selenium level, the egg selenium content of organic selenium groups was significantly higher than that of inorganic selenium groups.

The selenium content of selenium-enriched eggs is 200-500 g/kg (DB36/T 566−2009, DB6124.01−2010). In this experiment, the egg selenium contents of the SeC, L-MSC, L-SeCys and SS groups were 200.70, 229.20, 187.50 and 179.20 g/kg, respectively, all reaching or approaching the standard for selenium-enriched eggs. The recommended daily selenium intake varies by region. The *Regulations on the Declaration and Evaluation of Nutrient Supplements (Trial)* in China stipulates a minimum selenium intake of 15 g/d. The FAO/WHO/IAEA specifies minimum dietary selenium requirements of 21 and 16 g/d for adult men and women, respectively, with an optimal physiological requirement of 41 g/d. The U.S. National Academy of Sciences Food and Nutrition Board recommends daily dietary selenium allowances of 70 and 55 g/d for adult men and women, respectively. Consuming 2-3 eggs from the L-MSC group daily can meet the body' s selenium requirement.

Studies have indicated that selenium is absorbed in the small intestine, where organic selenium can actively cross the intestinal wall with high bioavailability, while inorganic selenium can only passively diffuse into the intestinal wall. Therefore, the deposition effect of organic selenium is far superior to that of inorganic selenium. This explains why the egg selenium conversion rate of organic selenium groups in this experiment was higher than that of the SS group, consistent with previous research results. This experiment also showed that the egg selenium conversion rate of all treatment groups was significantly lower than that of the control group, consistent with the findings of Hu et al. When selenium supply is insufficient, poultry mobilize stored selenium in the body to maintain health and meet partial requirements. Poultry also better utilize the limited selenium source to maintain egg selenium content, resulting in the highest selenium conversion rate in the control group.

This study demonstrates that L-MSC and SeC as dietary selenium supplements can significantly increase egg selenium content in laying hens and have practical application value. L-MSC has antioxidant, anti-aging, cardiovascular disease treatment and heavy metal detoxification effects. It is also an effective cell growth inhibitor that can effectively inhibit tumor cell proliferation and induce apoptosis, and suppress the expression of various oncogenes. In 2002, L-MSC was recognized by the U.S. Food and Drug Administration (FDA) as the latest generation of selenium dietary supplement, and was approved as a new food nutrition fortifier in China in 2009. Therefore, eggs enriched with L-MSC can not only enhance the body' s antioxidant capacity but also have certain anticancer effects.

Conclusions

1. Compared with SS, dietary supplementation with 0.3 mg/kg SeC, L-MSC and L-SeCys showed no significant effects on production performance or egg quality parameters except eggshell thickness and yolk color in Hy-Line Grey laying hens.
2. Compared with SS, the three cystine selenium sources could increase plasma GSH-Px activity and T-AOC of laying hens, significantly enhancing the antioxidant capacity of the body, with SeC and L-MSC showing better effects.
3. The three cystine selenium sources could increase egg selenium content, with L-MSC showing the best deposition effect.

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Note: Figure translations are in progress. See original paper for figures.