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Original Paper

Effects of selenomethionine and sodium selenite supplementation on meat quality, selenium distribution and antioxidant status in broilers

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ABSTRACT: This study was conducted to investigate the effects of selenomethionine (Se-Met) and sodium selenite (SS) supplementation on meat quality, selenium (Se) distribution, and antioxidant status in broilers. A total of 360 seven-days-old Ross 308 broilers of an average body weight 162 ± 0.59 g were randomly allotted to three treatments, each of which included three replications of 40 birds. The treatments included a control diet containing 0.04 mg Se/kg and other two diets that contained 0.15 mg Se/kg supplemented by SS or Se-Met. The experiment lasted for 42 days. Selenium supplementation improved ($P < 0.05$) the Hunter a value of breast muscle in 8 and 16 h and decreased ($P < 0.05$) the drip loss of breast muscle in 24 and 48 h. Both Se sources and exposed time significantly influenced ($P < 0.01$) the drip loss of breast muscle. Selenium and glutathione concentrations in serum and in the studied organs were significantly higher ($P < 0.05$) after dietary Se supplementation while the Se-Met group showed the highest value ($P < 0.05$). Glutathione peroxidase activity in serum and in the studied organs was also significantly elevated ($P < 0.05$) by dietary Se supplementation while SS increased the glutathione peroxidase activities in pancreas and breast muscle to a larger extent ($P < 0.05$) than did Se-Met. The addition of Se from either source caused a significant increase ($P < 0.05$) in superoxide dismutase activities in tissues (except for kidney) whereas the Se-Met group was more effective ($P < 0.05$) than the SS group in breast muscle. Selenium supplementation increased ($P < 0.05$) the total antioxidant capability in serum, liver, kidney and breast muscle while the Se-Met group proved to be more effective ($P < 0.05$) than the SS group except for kidney. The Se-supplemented diets had a lower ($P < 0.05$) malondialdehyde concentration in serum and in the studied organs but the effect was more pronounced ($P < 0.05$) when Se-Met was used except for the serum. These results indicated that Se-Met supplementation was more effective than SS supplementation for depositing Se in serum and tissues, enhancing the antioxidant status and reducing the drip loss of breast muscle.

Keywords: broiler; selenomethionine; drip loss; Hunter a value; antioxidant status

Selenium (Se) is an essential trace element that is actively involved in the antioxidant defence systems, thyroid function and reproduction (Rayman, 2000). Selenium can be supplemented to diets as inorganic mineral salts, typically as sodium selenite (SS), or as organic forms such as Se-enriched yeast (SY), selenocysteine (Se-Cys) and selenomethionine known as Se-Met. Usually, the organic forms of Se have higher bioavailability and antioxidant properties than inorganic forms (Mahan et al., 1999; Mahmoud and Edens, 2003). In addition, organic forms are less toxic and more environ-

mentally friendly than inorganic forms (Kim and Mahan, 2001; Kuricová et al., 2003). Thus, there is an increasing interest in the use of organic Se rather than inorganic Se.

Drip loss and meat colour are considered among the most important meat quality characteristics (Surai, 2002). Mahan et al. (1999) indicated that SY was superior to SS in decreasing the drip loss of loin muscle in pigs. It was also reported that the broilers fed SS had a higher 24 h drip loss than those fed SY (Choct and Naylor, 2004; Choct et al., 2004). The antioxidant systems in the body contain numerous antioxidant enzymes including super-oxide dismutase (SOD), glutathione peroxidase (GSH-Px) and catalase as well as non-enzymatic substances such as glutathione (GSH) (Mruk et al., 2002). Malondialdehyde (MDA) is one of the metabolic products of lipid peroxides, which is generated by the reaction of lipid oxidation induced by oxygen-free radicals in tissues. It was reported that SY showed a better potential to improve the antioxidant status of pigs than SS (Mahan and Parrett, 1996; Mahan et al., 1999). Many researches stated that the majority of Se in SY was present as Se-Met, a Se analogue of Met (Beistein and Whanger, 1986; Schrauzer, 2000, 2003). However, up to now sufficient research has not been conducted to directly compare the effects of Se-Met and SS supplementation to diets in broilers.

Therefore, the purpose of this study was to compare the effects of inorganic Se as SS with organic Se as Se-Met on meat quality, Se distribution, and antioxidant status in broilers.

MATERIAL AND METHODS

Diets, animals and feeding protocol

This project was approved and conducted under the supervision of the Zhejiang University Animal Care and Use Committee, which has adopted Animal Care and Use Guidelines governing all animal use in experimental procedures.

One-day-old Ross 308 broilers were obtained from a commercial hatchery. From day 1 to day 7, the birds were fed the same basal diet containing 0.04 mg Se/kg from natural ingredients. On day 8, a total of 360 broilers with an average body weight of 162 ± 0.59 g were randomly allotted to three treatments, each of which was replicated three times with 40 birds per replication. The birds were offered

the same basal diet supplemented with 0 (control) or 0.15 mg Se/kg from SS (Sigma-Aldrich Chemical Co., St. Louis, USA) or from Se-Met (seneno-DL-methylseleno) (Sigma-Aldrich Chemical Co., St. Louis, USA) at the expense of maize. The basal diet was formulated to meet or exceed requirements of broilers according to the National Research Council (NRC) (1994) except for Se (Table 1). The starting phase (8 to 21 days of age) diets were provided as crumbles, and the growing (22 to 42 days of age) and finishing phase (43 to 49 days of age) diets were provided as pellets.

The birds were housed in a tunnel-ventilated barn with 9 concrete floor pens (2.2 × 2.2 m) bedded with 10 cm rice hulls. Water was provided to the broilers by two Bell automatic drinkers per pen, and the feed was provided in a feed tray from 1 to 7 days and by two hanging hopper feeders (40-cm diameter each) per pen from 8 to 49 days of age. Infrared brooding lamps per pen were used for the first week. Mortality, temperature, and feed intake were recorded daily.

At 49 days of age, broilers were deprived of feed for 12 h. Then four male broilers per replication were randomly selected, and blood samples were taken from the main wing vein. A 10-ml sample was extracted per bird and let coagulate at room temperature for 1 h. The serum was separated by centrifugation at 4°C, 1000× g for 20 min and transferred into 1.0-ml microcentrifuge tubes. After blood collection, the birds were killed and dissected by a trained team. The right fresh pectoralis major muscle per bird was collected for meat analyses. Tissues of liver, kidney, pancreas, and left pectoralis major muscle were dissected carefully, blotted free of blood and placed in liquid nitrogen. Frozen tissues and serum samples were stored at –80°C until further analysis.

Feed analyses

Diet samples were ground to pass a 1-mm sieve. Crude protein was determined according to the Association of Official Analytical Chemists (1990) procedures. Quintuple samples of diets were digested by a wet ash procedure (AOAC, 1990). Digests were analysed for the concentration of total phosphorus by the colorimetric molybdovanadate method (T6 New Century, Beijing Purkinje General Instrument Co., Ltd., Beijing, P.R. China) and for the concentration of calcium by atomic absorp-

Table 1. Formulation and proximate analysis of basal diets[1] (g/kg, unless otherwise stated)

Items	Starter (8 to 21 days)	Grower (22 to 42 days)	Finisher (43 to 49 days)
Ingredients (g/kg)			
Maize	591.9	638.6	657.6
Soybean meal	360.0	310.0	290.0
Soy oil	10.0	14.0	20.0
Monocalcium phosphate	15.0	12.0	10.0
Limestone	12.0	15.0	12.0
Salt	3.0	3.0	3.0
L-Lysine HCl	1.3	1.0	1.0
DL-Methionine	1.8	1.4	1.4
Vitamin-mineral premix[2]	5.0	5.0	5.0
Composition (analyzed except for (ME)[3])			
ME (MJ/kg)	11.88	12.18	12.43
Crude protein	205.1	186.6	179.3
Lysine	10.4	9.2	8.4
Methionine	4.8	3.4	3.2
Methionine + cysteine	8.2	6.5	5.6
Calcium	9.3	9.1	7.7
Total phosphorus	6.5	5.8	5.4

[1]sodium selenite (SS) and selenomethionine (Se-Met) were premixed in maize and added to the diets at 0.15 mg selenium (Se)/kg to achieve the appropriate treatment levels. The analysed Se concentration (mg/kg) in the diets was as follows: basal diet (starter) 0.046; SS-supplemented diet (starter), 0.204; Se-Met-supplemented diet (starter) 0.208; basal diet (grower) 0.047; SS-supplemented diet (grower) 0.201; Se-Met-supplemented diet (grower) 0.212; basal diet (finisher) 0.049; SS-supplemented diet (finisher) 0.203; Se-Met-supplemented diet (finisher) 0.209; results are presented as means, *n* = 3

[2]supplied per kg of diet: retinyl acetate 3440 μg; cholecalciferol 100 μg; DL-α-tocopheryl acetate 10 mg; menadione 3 mg; thiamine 1.5 mg; riboflavin 3.5 mg; pyridoxine 3 mg; cobalamin 15 μg; niacin 30 mg; folic acid 0.5 mg; pantothenic acid 10 mg; biotin 150 μg; iron 80 mg; copper 8 mg; manganese 60 mg; zinc 40 mg; iodine 0.33 mg; ethoxyquin 100 mg

[3]ME was calculated from data provided by Feed Database in China (1999)

tion spectrophotometry (AA320CRT, Shanghai Precision Instruments Co., Ltd., Shanghai, P.R. China). Amino acids were measured using the amino acid auto-analyser (L-8800, Hitachi Ltd., Tokyo, Japan).

Drip loss measurement

Pectoralis major muscles of broilers were taken from the carcass. Samples were trimmed to 5 × 2 × 1 cm size, blotted to remove the surface water, and the initial breast muscle weight was determined. Samples were placed in a plastic bag filled with air and fastened to avoid evaporation and vertically hung in the refrigerator at 4°C, the final breast muscle weight was determined after 24 and 48 h *post mortem*. The percentage of drip loss was calculated by 100× (initial breast muscle weight-final muscle fillet weight)/initial weight (James et al., 2002).

Colour measurement

The Hunter a value of the pectoralis major muscle was determined using a Chroma meter (SP60 Series, X-Rite Incorporated, Michigan, USA) after

8-h and 16-h exposure in the 25°C room, respectively (Pi et al., 2005). A reading was done from the surface of the sample, representing the whole surface of the muscle.

Selenium analyses

All reagents were of analytical grade. Hydrochloric acid (HCl), sodium borohydride (NaBH$_4$), nitric acid (HNO$_3$) and hydrogen peroxide (H$_2$O$_2$) were purchased from Huadong Medicine Co. Ltd. (Hangzhou, P.R. China). Selenium stock standard solutions of SS [GBW(E)080215] were provided by the National Research Centre for Standard Materials (Beijing, P.R. China).

The Se assay of the samples was performed by hydride generation atomic fluorescence spectrometry (Gámiz-Gracia and Luque de Castro, 1999). Briefly, the samples (1.0 g wet weight basis) of tissues were weighed accurately and placed in a digestion vessel. 5 ml of HNO$_3$ and 2 ml of H$_2$O$_2$ were added and the mixture was subjected to microwave (MW) irradiation (25% power, 5 min) in order to digest the sample. After this, 10 ml of 6 mol/l HCl was added and the mixture was MW irradiated (75% power, 5 min) so that all Se could be reduced to Se^{IV}. The mixture was then transferred to a volumetric flask and made up to a final volume of 25 ml with ultrapure water. At the same time, ultrapure water and a certified reference material for Se, GBW 08551 pork liver (Food Detection Science Institute, Ministry of Commerce, Beijing, P.R. China), digested by the same method, served as the blank and the standard control, respectively. Then, the treated sample was injected into the HCl carrier. After merging with the NaBH$_4$ stream, the volatile hydride was formed and swept out of the gas-li-quid separator by an argon stream into a chemically generated hydrogen diffusion flame. The flame was maintained by the excess of hydrogen produced in the reaction between NaBH$_4$ and HCl. The hydride was then atomized in the flame, and the atoms were detected by an atomic fluorescence spectrometer (AF-610A, Beijing Rayleigh Analytical Instrument Co., Ltd., Beijing, P.R. China).

Biochemical assays

Tissue samples were thawed at 4°C for 30 min and kept on ice thereafter. Then the samples were immediately homogenized in 9 volumes of homogenization buffer (0.86% sodium chloride) with an Ultra-Turrax (T8, IKA-Labortechnik, Staufen, Germany) for 10 s at 8000 rpm. This process was conducted on ice. The homogenate was centrifuged at 4000 rpm for 15 min at 4°C and the supernatant was used for analysis. GSH-Px, SOD, GSH, MDA, and total protein were determined using the method of Lowry et al. (1951), Beutler et al. (1963), Placer et al. (1966), Panckenko et al. (1975), and Lawrence and Burk (1976), respectively. The total antioxidant capability (T-AOC) was examined by assay kits purchased from Nanjing Jiancheng Institute of Bioengineering (Nanjing, Jiangsu, P.R. China). The spectrometric method was applied to determine T-AOC. In the reaction mixture, ferric ion was reduced by antioxidant reducing agents and the blue complex Fe^{2+}-TPTZ (2,4,6-tri(2-pyridyl)-s-triazine) was produced. Then this blue complex reacted with phenanthroline to generate a stable complex which could be monitored by the absorbance at 520 nm. Data were expressed as units per millilitre (U/ml) in serum and as units/milligram of protein (U/mg prot) in tissues. The enzyme activity of GSH-Px and SOD was expressed as specific activity (U/mg prot) in tissues and as U/ml in serum, respectively. The GSH and MDA concentrations were expressed as mg/g prot and nmol/mg prot in tissues and as mg/l and nmol/ml in serum, respectively.

Statistical analysis

The experimental data were analysed using the one-way analysis of variance (ANOVA) to compare means and the univariate general linear model (GLM) procedure of the SPSS 16.0 for Windows. Treatment contrasts for Se sources and the non-Se-fortified treatment group were evaluated by difference analysis using one-way ANOVA. The post hoc and option of univariate of GLM were conducted to examine main effects of two factors (Se source and time) and interaction effects between factors on drip loss and the Hunter a value of breast muscle. The least significant difference test of multiple comparisons was used to determine differences between means. The values of $P < 0.05$ were taken as significant. Replication was considered as the experiment unit for determined performance. The analytical data were presented as means ± standard deviation.

Table 2. Effects of different Selenium sources on the percentage of drip loss and the Hunter a value of breast muscle in broilers (49 days of age)

	Control	SS	Se-Met
Drip loss			
24 h	4.55 ± 0.82^a	2.79 ± 0.52^b	2.21 ± 0.28^c
48 h	7.78 ± 1.46^a	4.39 ± 0.87^b	3.46 ± 0.64^c
Hunter a value			
8 h	4.67 ± 0.61^b	5.61 ± 0.77^a	5.66 ± 0.61^a
16 h	4.38 ± 0.40^b	5.17 ± 0.89^a	5.46 ± 0.77^a

	Drip loss	Hunter a value
Basal diet vs others	$P < 0.01$	$P < 0.01$
Se source	$P < 0.01$	$P = 0.391$
Time	$P < 0.01$	$P = 0.062$
Se source × time	$P < 0.01$	$P = 0.832$

Results are presented as means ± SD, $n = 3$

SS = sodium selenite; Se-Met = selenomethionine; Hunter a value = redness

[a,b,c]means within rows with different superscript letters differ significantly ($P < 0.05$)

RESULTS

Compared with the control group, Se supplemented groups had the lower ($P < 0.05$) drip loss of breast muscle in 24 h and 48 h after slaughter but the effects were more noticeable ($P < 0.05$) in the Se-Met group. Besides, the time also had a significant ($P < 0.01$) effect on drip loss. Selenium supplementation elevated ($P < 0.05$) the Hunter a value of breast muscle in 8 and 16 h *post mortem* while the Se-Met group showed a slightly higher value (Table 2).

Compared with the control group, Se supplementation improved GSH-Px activity in serum and in the studied organs ($P < 0.05$). GSH-Px activities of pancreas and breast muscle were higher ($P < 0.05$) in the SS group than those in the Se-Met group. However, there were no differences with respect to GSH-Px activity in serum, liver, and kidney between the SS and Se-Met groups (Table 3).

Glutathione concentration in serum and in the studied organs was significantly higher ($P < 0.05$) after dietary Se supplementation while the Se-Met group showed the highest value ($P < 0.05$) (Table 3).

Liver, pancreas, and breast muscle SOD activities were significantly higher ($P < 0.05$) after dietary Se supplementation whereas the Se-Met group was found more effective than the SS group in breast muscle ($P < 0.05$). Serum SOD activity was improved ($P < 0.05$) only by Se-Met not by SS (Table 3).

Total antioxidant capability in serum and tissues (except for pancreas) was significantly improved ($P < 0.05$) by dietary Se supplementation while the Se-Met group showed a higher ($P < 0.05$) potential to improve the T-AOC in tissues (except for kidney) than the SS group. Total antioxidant capability in pancreas was improved ($P < 0.05$) only by Se-Met, but not by SS (Table 3).

The supplementation of Se decreased ($P < 0.05$) MDA concentration in serum and in the studied organs whereas the Se-Met group proved to be more effective than the SS group ($P < 0.05$) except for serum (Table 3).

The results in Table 4 indicate that dietary Se supplementation increased ($P < 0.05$) Se concentration in serum and in the studied organs while the Se-Met group showed the highest value ($P < 0.05$).

DISCUSSION

The concentration of Se in serum and in the studied organs was greatly increased by Se-Met supplementation compared with SS supplementa-

Table 3. Effects of different selenium sources on the antioxidant status of broilers (49 days of age)

	Treatment	GSH-Px[1]	SOD[1]	GSH[2]	T-AOC[1]	MDA[2]
Serum	Control	764.91 ± 140.68[b]	132.13 ± 12.96[b]	5.53 ± 0.89[c]	10.74 ± 1.63[c]	4.38 ± 0.22[a]
	SS	1402.11 ± 237.01[a]	136.34 ± 4.66[ab]	8.57 ± 1.12[b]	13.24 ± 1.24[b]	3.98 ± 0.39[b]
	Se-Met	1392.63 ± 180.87[a]	141.01 ± 9.12[a]	11.15 ± 1.08[a]	16.65 ± 2.02[a]	3.82 ± 0.60[b]
Liver	Control	20.53 ± 2.00[b]	115.38 ± 13.47[b]	2.50 ± 0.41[c]	2.35 ± 0.36[c]	0.81 ± 0.10[a]
	SS	71.73 ± 11.02[a]	134.55 ± 14.31[a]	2.90 ± 0.39[b]	3.43 ± 0.28[b]	0.55 ± 0.08[b]
	Se-Met	69.40 ± 15.01[a]	143.96 ±17.23[a]	3.44 ± 0.31[a]	4.00 ± 0.18[a]	0.40 ± 0.06[c]
Kidney	Control	23.44 ± 2.21[b]	13.58 ± 2.21	1.20 ± 0.17[c]	3.93 ± 0.32[b]	1.01 ± 0.14[a]
	SS	32.12 ± 2.20[a]	14.79 ± 2.37	1.77 ± 0.20[b]	4.44 ± 0.53[a]	0.83 ± 0.11[b]
	Se-Met	31.72 ± 1.94[a]	15.02 ± 1.36	2.22 ± 0.39[a]	4.58 ± 0.45[a]	0.58 ± 0.09[c]
Pancreas	Control	4.68 ± 0.52[c]	18.27 ± 1.59[b]	0.97 ± 0.11[c]	1.89 ± 0.09[b]	1.06 ± 0.10[a]
	SS	25.46 ± 4.01[a]	20.80 ± 3.62[a]	1.93 ± 0.24[b]	1.98 ± 0.27[b]	0.64 ± 0.07[b]
	Se-Met	14.28 ± 2.76[b]	21.54 ± 2.68[a]	3.87 ± 0.61[a]	2.39 ± 0.14[a]	0.55 ± 0.06[c]
Breast muscle	Control	9.19 ± 1.22[c]	10.58 ± 1.60[c]	1.61 ± 0.21[c]	0.14 ± 0.02[c]	0.80 ± 0.13[a]
	SS	22.03 ± 3.44[a]	14.29 ± 1.17[b]	2.29 ± 0.30[b]	0.22 ± 0.03[b]	0.53 ± 0.08[b]
	Se-Met	14.49 ± 1.62[b]	22.69 ± 2.24[a]	3.08 ± 0.44[a]	0.28 ± 0.04[a]	0.45 ± 0.04[c]

Results are presented as means ± SD, n = 3

SS = sodium selenite; Se-Met = selenomethionine; T-AOC = total antioxidant capability; SOD = superoxide dismutase; GSH-Px = glutathione peroxidase; GSH = glutathione; MDA = malondialdehyde

[a,b,c]means within rows with different superscript letters differ significantly ($P < 0.05$)

[1]GSH-Px, SOD, and T-AOC were expressed as specific activity (U/mg prot) in tissues and as U/ml in serum, respectively

[2]GSH and MDA concentrations were expressed as mg/gprot and nmol/mgprot in tissues and as mg/l and nmol/ml in serum, respectively

tion, which was in good agreement with findings of Moksnes and Norheim (1986) and Skřivan et al. (2008, 2010). It is known that organic Se has a higher bioavailability than inorganic Se for the Se deposition in the tissues (Mahan and Parrett, 1996).

This is probably due to their different absorption mechanisms: inorganic Se is passively absorbed from the intestine by a simple diffusion process, whereas organic Se is actively absorbed through the amino acid transport mechanisms (Wolfram et al.,

Table 4. Effects of different Selenium sources on serum and tissues Selenium concentrations of broilers (49 days of age)

	Control	SS	Se-Met
Serum (mg/l)	0.050 ± 0.001[c]	0.099 ± 0.002[b]	0.121 ± 0.003[a]
Liver (mg/kg)	0.236 ± 0.006[c]	0.509 ± 0.015[b]	0.565 ± 0.010[a]
Kidney (mg/kg)	0.449 ± 0.006[c]	0.610 ± 0.015[b]	0.665 ± 0.006[a]
Pancreas (mg/kg)	0.144 ± 0.007[c]	0.201 ± 0.007[b]	0.225 ± 0.004[a]
Breast muscle (mg/kg)	0.126 ± 0.004[c]	0.144 ± 0.005[b]	0.153 ± 0.006[a]

Results are presented as means ± SD, n = 3

SS = sodium selenite; Se-Met = selenomethionine

[a,b,c]means within rows with different superscript letters differ significantly ($P < 0.05$)

1989). On the other hand, the chemical similarity between Se-Met and Met allows the body to use them interchangeably in protein synthesis because tRNA^{Met} cannot discriminate between Met and Se-Met (Schrauzer, 2000, 2003). Therefore, any Se-Met that is not immediately metabolized is incorporated into organs with high rates of protein synthesis such as skeletal muscles, pancreas, liver, kidney, and the gastrointestinal mucosa (Schrauzer, 2000, 2003). This principal difference can also explain the more significant improvement of Se deposition by Se-Met than by SS.

Selenium is an important component of the selenoprotein enzyme GSH-Px in animal tissues (Arthur, 2000; Kohrle et al., 2000). The GSH-Px family of enzymes is a crucial player in the integrated antioxidant system, neutralizing potential threats to the integrity of cellular macromolecules by eliminating hydrogen peroxide and detoxifying lipid hydroperoxides (Brigelius-Flohe, 1999). In the present study, GSH-Px activity in serum and in the studied organs was greatly improved by dietary Se supplementation while the SS group had similar GSH-Px activity in serum, liver and kidney like the Se-Met group but higher in pancreas and breast muscle than the Se-Met group. These results were consistent with earlier reports of Cantor et al. (1975, 1982) and Payne and Southern (2005b). Less pronounced increases in GSH-Px activity by supplementation of Se-Met compared to SS are probably due to the fact that Se, regardless of its form, must be converted to Se-Cys before it can be incorporated into the selenoprotein enzyme GSH-Px (Forstrom et al., 1978). It was reported that SS was metabolized into Se-Cys more efficiently than Se-Met (Sunde and Hoekstra, 1980; Henry and Ammerman, 1995). The other likely possibility is that Se-Met can be incorporated into body proteins in place of Met. In another study of mammalian cells in culture (White and Hoekstra, 1979) ^{75}Se from Se-Met was found to be initially incorporated into a wide spectrum of cellular proteins and only later incorporated into GSH-Px, whereas Se from SS was rapidly incorporated into GSH-Px. Thus the competition with Met for incorporation in non-Se-requiring proteins possibly affects the availability of Se from Se-Met for the synthesis of GSH-Px and other specific Se proteins. In addition, the discrepancy of tissue Se concentration and GSH-Px activity might indicate that only a part of Se-Met in organs was adopted for selenoprotein synthesis, the other part was stored as Se-Met in substitution for Met in organs.

It was widely accepted that proper Se intake could improve the antioxidant status of the body. In general, organic Se showed a higher potential to improve the antioxidant status than inorganic Se (Mahan and Parrett, 1996; Mahan et al., 1999). Data collected in this trial indicated that the antioxidant capability of broilers was greatly improved by dietary Se addition while Se-Met was superior to SS 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. The outcome was in agreement with the results of Skřivan et al. (2008, 2010). These findings suggested that Se improved the antioxidant property of broilers by elevating activities of antioxidant enzymes and concentrations of antioxidant and reducing peroxidation products, and also implicated that Se-Met supplementation may have a more beneficial effect on oxidative stability than SS.

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 Dvorska, 2002) and thus it is not surprising that Se supplementation decreased drip loss in 24 and 48 h, while broilers receiving SS had a greater drip loss than those consuming Se-Met. These results were consistent with previous reports (Choct and Naylor, 2004; Choct et al., 2004). Mateo et al. (2007) reported that the drip loss of loins in 48 h in growing-finishing pigs was reduced only by SY supplementation not by SS supplementation. Zhan et al. (2007) found out that Se-Met was more effective in decreasing the drip loss of loin muscle than SS in finishing pigs. A possible reason for the more significant decrease in drip loss by organic Se may be that organic Se was superior to inorganic Se in increasing the antioxidant property of animals. However, Payne and Southern (2005a) reported that the 24 h breast moisture loss of broilers was not affected by Se supplementation (SY or SS) with the basal diet containing 0.12 mg Se/kg. This may be partially due to different Se levels and sources used.

In our experiment, an increase in the Hunter a value of breast muscle in 8 h and 16 h was observed with Se supplementation. These results were in agreement with Zhan et al. (2007). Meat colour is usually related to the muscle pH or its myoglobin content (James et al., 2002), and the change of its

redness is directly related to the oxidation of oxymyoglobin to metmyoglobin (Schaefer et al., 1995). In the present study, Se supplementation significantly increased the activities of antioxidant enzymes and concentrations of antioxidants and reduced the lipid peroxidation products in the breast muscle tissue. Therefore, we suppose that the function of Se to improve the meat quality is through enhancing its antioxidant ability to protect against deteriorative reactions during lipid peroxidation. However, Mateo et al. (2007) reported that the muscle colour of pigs was not improved by dietary Se (SY or SS) supplementation. These inconsistent results might be due to different Se sources and animals used.

In conclusion, compared with SS, Se-Met seems to be more effective in depositing Se in serum and tissues, enhancing the antioxidant status and reducing drip loss. These results have an important practical significance in broiler's Se supplementation from Se-Met for humans as broiler's meat and viscera are used as foods in China. These results also suggest that Se-Met is of the greater value to improve the meat quality and extend the shelf life of fresh meat than SS in broilers.

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