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ARTICLE

Effects of Zn-L-Selenomethionine on Carcass Composition, Meat Characteristics, Fatty Acid Composition, Glutathione Peroxidase Activity, and Ribonucleotide Content in Broiler Chickens

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Abstract The effects of organic Zn-L-selenomethionine (Zn-L-SeMet) at 0.3 ppm on carcass composition, meat characteristics, fatty acid composition, glutathione peroxidase activity, and ribonucleotide content were compared against the commercial inorganic sodium selenite (Na-Se) and the combination of the two, in commercial broilers. A total of 540 one day-old chicks were assigned at random to 3 dietary treatments : i) commercial inorganic selenium as control or T1, ii) a 1:1 ratio of inorganic and organic selenium as T2, and iii) organic selenium as T3. Carcass composition, meat characteristics, cholesterol content, fatty acid composition, and ribonucleotide content were generally unaffected by treatments. However, discrepancy were significantly observed in glutathione peroxidase activity (GSH-Px) and water holding capacity, with organic selenium showing higher glutathione peroxidase activity ($p<0.01$) and lower shrinkage loss ($p<0.05$), respectively. These findings could be explained by the contribution of organic selenium in bioavailability of GSH-Px. However, having conducted in a commercial close house system with sufficient amount of nutritional supplementation, the present study demonstrated little or no effects of organic Zn-L-SeMet on meat characteristics, fatty acid composition, and ribonucleotide content (flavor characteristic) in broiler chickens.

Keywords selenium source, body composition, meat quality traits, cholesterol content, flavor

Introduction

A good nutritionally balanced diet that will provide appropriate bioavailable

quantities of nutrients required by the birds is the main goal of modern feed formulation. Energy and protein are principle nutrient component in the formulation. In addition, supplements providing minerals, vitamins, and specific amino acids must be added to the diets as they are essential for growth performance and health (Ravindran, 2013). Selenium is a vital element for maintaining balance and healthy diet for chickens. They can either be found naturally or been added in both inorganic and organic forms. The bioavailability of selenium in chicken is complexed whereby the metabolism is affected by numerous factors and these include types of selenium, heavy metals, vitamins, methionine, and thiols (Fairweather-Tait and Hurrell, 1996). The physiological and biochemical factors of the birds itself may also contribute to the requirement of the bioavailability such as in heat and stress conditions.

An adequate intake of selenium helps maintaining healthy broiler, immunocompetent, better meat quality, and longer shelf life as it is involved in the antioxidative system which is a part of selenium-dependent glutathione peroxidase (Colnago et al., 1984; Combs, 1981; Kuricová et al., 2003; Ryu et al., 2005; Yang et al., 2012; Yoon et al., 2007; Zelenka and Fajmonova, 2005). Selenium is involved in lipid metabolism of which, several studies reported that selenium, when supplemented in animal diets, remodeled the composition of fatty acid in meat (Netto et al., 2014; Zanini et al., 2004). The ribonucleotide monophosphates like inosine monophosphate (IMP) and guanosine monophosphate (GMP) enhance the intensity of meat flavor, as they elicit an umami taste (Dunford and Shahidi, 1998; Spurvey et al., 1998). Selenium has also been associated with meat flavor as Zhou and Wang (2011) documented higher IMP content in chickens treated with Nano-Se when compared to control group.

Inorganic sodium selenite (Na-Se) has been traditionally supplemented in commercial poultry diets to ensure an optimal supply for growth performance and productivity. Organic sources of selenium, for example Se-enriched yeast and synthesized L-selenomethionine (L-SeMet), are reported to be more suitable forms of selenium for dietary supplements according to their lower toxicity and higher bioavailability than inorganic form. (Delezie et al., 2014; Surai, 2007). L-SeMet is the major form of organic selenium presented in natural food and feed ingredients. Selenium enriched yeast has been commercially used as a practically affordable source of L-SeMet. However, the concentration of organically bound selenium in yeast can vary markedly among sources of Se-enriched yeast due to its ability to form L-SeMet from the selenite enriched media (Geraert et al., 2015; Whanger, 2002). Broilers supplemented with dietary L-SeMet had better efficiency of selenium deposition of in breast muscle than Se-enriched yeast, but L-SeMet appeared to be unstable when mixed with a standard premix (Geraert et al., 2015). More recently, organic selenium is available as Zn-L-selenomethionine (Zn-L-SeMet), which is 1:1 complex of essential metals and amino acids. Zn-L-SeMet has been designed to be highly soluble and of increased bioavailability of selenium (Ward, 2003). It is hypothesized that a more stable source of organic selenium as described by the producer, Zn-L-SeMet, has possible benefits from Se-enriched diets for animal production. The information on the utilization of Zn-L-SeMet in broiler chickens is limited. Therefore, this study aimed to examine the impacts of this organic selenium form (Zn-L-SeMet) against inorganic Na-Se and also their combination on carcass composition, meat characteristics, fatty acid composition, flavor associated ribonucleotides, and glutathione peroxidase activities in commercial broilers raised in a commercial closed house system.

Materials and Methods

Animal ethics

The handling and care of experimental animals in the research were approved by the institutional Animal Care and Use Committee at King Mongkut's Institute of Technology Ladkrabang (ACUC-RES/2019/003).

Animals

Five hundred and forty one day old chicks (Arbor Acre) were assigned at random to 3 dietary groups of 6 replicates, with 30 chicks per pen. The stocking density per pen was of 15 mixed-sex broilers/m^2 (measuring 2 m^2/pen). The birds received feed *ad libitum* through 3 phase feeding programs with continuous 24 h lighting (see Table 1). The treatment groups

Table 1. Formula of basal diets

Item	Starter (0–21 d)	Grower (22–30 d)	Finisher (31–37 d)
Ingredients			
Broken rice	28.60	34.96	38.85
Corn	30.00	30.00	30.00
Soybean meal	29.50	21.93	18.24
Fish meal	6.00	8.00	8.00
Vegetable oil	1.64	0.84	1.11
Monocalcium phosphate	1.35	1.24	1.00
Limestone	0.77	0.90	0.79
Premix[1,2)]	0.60	0.60	0.60
Salt	0.42	0.39	0.39
Lysine	0.39	0.41	0.40
DL methionine	0.29	0.26	0.25
L-Threonine	0.19	0.18	0.14
Choline chloride	0.14	0.14	0.14
Antifungal	-	0.10	0.10
Monensin sodium[3)]	0.05	0.05	-
Nutrient and energy level (calculated)			
Xanthophyl (ppm)	11.70	11.70	11.70
ME (kcal/kg)	3,100	3,100	3,150
Protein (%)	21.50	19.00	17.50
Ash (%)	4.38	4.06	3.58
Fat (%)	4.29	3.79	4.02
Fiber (%)	2.37	2.21	2.08
Calcium (%)	0.90	0.90	0.80
Total phosphorus (%)	0.72	0.67	0.60
Available phosphorus (%)	0.48	0.45	0.40
Salt (%)	0.44	0.42	0.42
Lysine (%)	1.28	1.15	1.06
Methionine (%)	0.52	0.47	0.45
Methionine+Cysteine (%)	0.91	0.83	0.79
Threonine (%)	0.96	0.86	0.79
Tryptophan (%)	0.22	0.19	0.25
Sodium (%)	0.20	0.19	0.19

[1)] Vitamin-mineral mixture provides the following (per kg of diet): 25,000 IU of vitamin A; 5,000 IU of vitamin D_3; 100 mg of vitamin E; 6 mg of vitamin K_3; 4 mg of vitamin B_1; 10 mg of vitamin B_2; 30 mg of vitamin B_3; 6 mg of vitamin B_6; 60 mg of nicotinamide; 2 mg of folic acid; 0.06 mg of vitamin B_{12}; 0.2 mg of biotin; 1,000 mg of choline chloride; 2 mg of Co, 4 mg of I, 120 mg of Mn, 40 mg of Fe, and 100 mg of Zn.
[2)] The T1, T2, and T3 treatment diet contained 0.3 ppm Na-Se, 0.15 ppm Na-Se+0.15 ppm Zn-L-SeMet, or 0.3 ppm Zn-L-SeMet.
[3)] Coccidiostat (Maxiban® for starter, Cygro® 1% for grower).
Zn-L-SeMet, Zn-L-selenomethionine.

comprised of: i) T1: inorganic sodium selenite (Na-Se) at 0.3 ppm; ii) T2: mixed organic and inorganic selenium, with combination of 0.15 ppm Na-Se and 0.15 ppm Zn-L-SeMet, and, iii) T3: organic selenium from Zn-L-SeMet at 0.3 ppm. The chicken were fasted for 12 h and weighed out before slaughter at 39 days old. Three birds per replicate in each group were sacrificed by cervical dislocation, scalded at 60℃ for approximately 3 min, following with defeathered for 2 minutes using a rotary drum picker, and eviscerated manually. Then the carcasses were chilled in ice water for 45 min and weighed after waiting for 1 h at 1℃ in a cold room aimed to strain water remains from the chilling process. The whole carcass was cut up into the form of breast, fillet, wing, and leg manually by knife. The weight of all dissected parts were documented in percentages to total carcass weight. The right side breast muscles from each carcass were used for quality traits analysis. Meanwhile, the breast muscle from left side carcass was taken from one chicken per each replicate for fatty acid composition, GSH-Px activity, and ribonucleotide content analysis.

Experimental diets

The experimental diets were formulated to meet nutrient requirement for broiler chicken recommended by the National Research Council (Table 1). The organic and inorganic selenium used for this experiment were incorporated into the diet as presented in Table 1. Infectious Bronchitis and Newcastle Diseases vaccinations to broilers were performed as stated in the manufacturer's instructions (Nobilis® MA5+Clone 30, Intervet International, Boxmeer, Netherlands).

Meat characteristics

pH measurement

Muscle pH of the right pectoralis major was inspected at 45 min, 24 h, and 4 d postmortem using a spear tip glass probe connected to a portable pH meter (SG2 - ELK Seven Go™, Mettler Toledo International, Shanghai, China).

Drip loss measurement

Meat samples were suspended in tightly sealed plastic bag filled with air and kept at 4 to 6℃ for 48 h (Honikel, 1998). Drip loss was calculated as a percentage of the weight loss after suspension**.**

Color measurement

Following to 30 minutes of blooming period, meat color (CIE L*a*b*) of pectoralis major was determined at 3 h postmortem at 25±2℃ using a handheld colorimeter (CR-400 chromameter, Konica Minolta Sensing, Osaka, Japan).

Water loss and shear force measurement

After taken from carcass, the breast muscles were weighed and kept for 4 d at 4℃ and then brought to 25℃ before weighing and calculating sample weight difference. The measurement were conducted before and after storage as a percentage of shrinkage loss. The 1 inch thick sample from each bird was cooked for approximately 20 min to 70℃ temperature internally in a water bath (One14, Memmert, Buchenbach, Germany). Core temperature of the end point was monitored by a thermometer (TM-19475D, Lutron Electronics, Taipei City, Taiwan). Cooked samples were left at room temperature to cool down before weighing. Weight loss after cooking was calculated and expressed as the percentage loss relative to the weight before cooking. Ten slices were cut parallel to the fiber orientation of the cooked sample. A Texture Analyser Machine (Model EZ-SX, Shimadzu, Kyoto, Japan) attached to a 50 kg load cell using 50 mm/min crosshead speed

was used to measure a Warner-Bratzler shear force. Signals were processed by Tapezium software (Shimadzu).

Fatty acid analysis

Fatty acid composition was determined according to the method of Raes et al. (2001). The lipid extraction with chloroform were performed as described by Folch (1957). The internal standard, methyl nonadecanoate (SFA-013N, Accu Standard, New Haven, CT, USA) was added during extraction process. The gas chromatography (7890B, Agilent, Santa Clara, CA, USA) with a fused silica capillary column (model SPTM-2560, Supelco, Bellfonte, PA, USA) for FAME (100 m×0.25 mm×0.2 μm film thickness) was used to analyse fatty acid methyl esters (FAME). Following was the gas chromatography conditions: injected temperature, 240℃; detector temperature, 260℃; carrier gas, He; split ratio, 10:1; temperature program, initial temperature 60℃, followed by an increase of 20℃/min to 170℃, 5℃/min to 220℃ then 2℃/min to 240℃. The peaks of fatty acid methylester were identified by comparison of retention times with authentic standards (F.A.M.E. Mix, C4-C24, Supelco) and quantified by an internal standard of nonadecanoic acid (C19:0).

Cholesterol analysis

Cholesterol measurement was performed using the method outlined by Du and Ahn (2002). The frozen samples (after immersion in liquid nitrogen) were pulverized using grinder (WSG30E, Waring, USA). Ground breast meat of 0.4 g was extracted with 10 mL of saponification reagent (ethanol: 33% KOH (w/v): 20 % ascorbic acid (94:6:0.5). A 50 μL of 5 α-cholestane solution (1 μg/μL in hexane) was subsequently added as an internal standard. The mixture were homogenized using a homogenizer (T25 Ultra-Turrax®, Ika, Rawang, Malaysia) before adding 10 mL of HPLC water and 10 mL of hexane, consecutively. The homogenate samples were then briefly vortexed (Vortex Genie 2 Mixer, Overstock Lab Equipment, Hampton, NH, USA), left for 15 h to allow sample to separate into phase, then centrifuged at 1,000×g at 4℃ for 15 min. The hexane layer containing unsaponifiables was carefully collected and evaporated by nitrogen blowdown. The dry sample was dissolved in 200 μL ethyl acetate and later analyzed using gas chromatography (7890B, Agilent).

Glutathione peroxidase activity assay

One gram of breast muscle samples, pulverized in liquid nitrogen, were homogenized in 2 mL of ice-cold glutathione peroxidase activity (GSH-Px) buffer using a homogenizer (T25 Ultra-Turrax®, Ika) at 23,319×g then centrifuged at 10,000×g for 15 min at 4℃. The supernatant was collected and kept at –20℃ for GSH-Px assays the next day. Glutathione peroxidase activity was measured according to the manufacturer protocols (Glutathione Peroxidase Colorimetric Assay Kit, Catalog Number #K762-100, Biovision, Milpitas, CA, USA).

Ribonucleotide analysis

According to the method of Tikk et al. (2006), one gram of pulverized breast muscle in 6 mL of cold 0.6 M perchloric acid was homogenized at 23,319×g for 10 sec (T25 Ultra-Turrax®, Ika). The homogenate was left on ice for 15 min and then neutralized by adding 5.4 mL of 0.8 M KOH and 0.25 mL of KH_2PO_4 buffer. The pH of mixed sample was adjusted to 7 with 0.8 M KOH and the volume was finally made up to 15 mL with HPLC water. After centrifugation at 10,000×g for 10 min at 4℃ (Scanspeed 1580R, Labogene, Lillerod, Denmark), 1 mL of supernatant was aspirated to a small tube and frozen at –80℃.

After thawing the frozen sample and centrifuging at 10,000×g for 5 min at 4℃ (Scanspeed 1580R, Labogene, Denmark), the supernatants were then analyzed for IMP, inosine, hypoxanthine, and GMP using the HPLC (Chromaster, Hitachi, Tokyo,

Japan) fitted with a UV detector (210 nm). A stationary phase was the TSK Gel Amide-80 column (Tosoh, Tokyo, Japan) while the eluent phase consisted of a buffer containing acetonitrile: KH_2PO_4, 70:30. The content of ribonucleotide was quantified based on a standard curve using external standards (57510 Inosine-5-monophosphate disodium salt hydrate, 14125 Inosine, H9377 Hypoxanthine, and G8377 Guanosine-5-monophosphate disodium salt hydrate, Sigma-Aldrich, St. Louis, MO, USA).

Statistical Analysis

Analyses of variance was analyzed using the GLM procedure (SAS Institute, Cary, NC, USA) where selenium sources were defined as treatment. Least square means were separated using the PDIFF option and differences were considered as significant if $p \leq 0.05$.

Results and Discussion

The live and carcass weight and the body and carcass composition of chickens from different dietary treatments are as shown in Table 2. The aforementioned parameters between the treatments showed no significant differences. In agreement with our finding, the supplementation of neither organic nor inorganic selenium have significant effect on live weight, carcass weight, and carcass composition in broilers by other researchers (Downs et al., 2000; Mikulski et al., 2009; Payne and Southern, 2005). Furthermore, no significant differences were occurred in samples of birds subjected to the combination of

Table 2. Effects of dietary selenium sources[1)] on body and carcass composition in commercial broiler chickens

Traits	T1	T2	T3	RMSE	p-value
Live weight (kg)	2.58	2.61	2.66	0.09	0.092
Carcass weight (kg)	2.08	2.09	2.92	0.07	0.251
Body composition (% of live weight)					
Carcass dressing	80.53	80.13	79.92	1.85	0.603
Abdominal fat	1.01	0.97	0.95	0.34	0.868
Liver	2.16	2.29	2.31	0.34	0.378
Gizzard	1.01	1.04	0.99	0.16	0.659
Heart	0.34	0.33	0.35	0.09	0.826
Spleen	0.07	0.06	0.06	0.02	0.579
Head	1.86	1.84	1.91	0.68	0.925
Neck	3.36	3.44	3.36	0.68	0.925
Carcass composition (% of carcass weight)					
Breast	26.41	26.83	26.48	1.93	0.783
Fillet	4.97	4.87	4.64	0.72	0.375
Wing	10.85	10.18	10.13	1.63	0.343
Leg	27.57	27.88	28.43	1.23	0.120

[1)] The T1, T2, and T3 treatment groups were fed diets containing 0.3 ppm Na-Se, 0.15 ppm Na-Se+0.15 ppm Zn-L-SeMet, and 0.3 ppm Zn-L-SeMet, respectively.
Zn-L-SeMet, Zn-L-selenomethionine.

organic and inorganic supplement at 0.3 ppm. In this study, sources of selenium did not affect ($p>0.05$) drip loss but significantly impacted on shrinkage loss between T1 and T3 ($p<0.05$), and cooking loss among T1, T2, and T3 ($p<0.0001$) at day 4 postmortem (Table 3). The lowest shrinkage was found in samples of organic selenium supplemented birds (T3). Meanwhile, the highest and lowest cooking loss after day 4 postmortem was observed in samples of T3 and T1, respectively (Table 3). The lower shrinkage loss noted in the T3 meat samples could be explained by a possible increase in antioxidant property as indicated by higher GSH-Px activity ($p=0.009$; Table 5) recorded in samples of birds subjected to the organic selenium supplementation (T3). This was explained by Zhan et al. (2007) who demonstrated higher meat water holding capacity in animals treated with SeMet than their counterparts which were assigned to inorganic Na-Se supplementation. Furthermore, Surai (2007) reported that selenium was crucial for both intra- and extra-cellular antioxidant system in the body. In present study, T3 showed higher cooking loss when compared to both T1 and T2. This could possibly be explained by higher water content in the samples upon cooking as resulted from lower shrinkage loss in the respective samples. Different mechanisms have been proposed by researchers on how antioxidant could influence drip loss and water holding capacity. These include the stabilization of membrane postmortem (Asghar et al., 1991), reducing proteolysis and protein oxidation which in turn influence moisture retention capacity in meat and meat products (Huff-Lonergan and Lonergan, 2005). Selenium sources did not affect meat color in this study. This conforms to the finding of Jiang et al. (2009) and Perić et al. (2009). Dietary selenium sources were also not significant effect on pH value at various storage times from 45 min to 4 days of postmortem in the current study ($p>0.05$) (Table 3). In contrast with our results, Li et al. (2018) presented that organic selenium-enriched yeast and selenomethionine supplementation resulted in increasing breast pH of broiler chickens at 45 min postmortem with no affect at 24 h postmortem. In the present study, shear force values were unaffected by the inorganic, organic, and the combination supplementation. However, Li et al. (2018) reported the lower shear force value of breast meat from chickens supplemented with organic selenium-enriched yeast and selenomethionine supplementation than those supplemented with inorganic sodium selenite. The improvement of the tenderness as the reduction in shear force value could be related to the higher intramuscular fat in chickens fed with organic selenium (Yoon et al., 2007).

Table 3. Effects of dietary selenium sources[1)] on meat quality traits of *Pectoralis major* m. broiler in commercial broiler chickens

Traits	T1	T2	T3	RMSE	p-value
Drip loss (%)	2.40	2.57	2.52	0.88	0.866
Shrinkage loss (%)	2.60[a]	2.15[ab]	1.80[b]	0.70	0.012
Cooking loss (%)	10.36[c]	12.23[b]	13.52[a]	1.66	<0.0001
L*	50.98	49.51	50.00	0.349	0.444
a*	2.12	1.80	2.13	0.74	0.321
b*	6.42	6.19	6.26	1.25	0.852
pH 45 min (unit)	6.55	6.6	6.54	0.34	0.838
pH 24 h (unit)	6.04	6.05	5.97	0.23	0.546
pH 4 d (unit)	5.93	5.96	5.97	0.12	0.615
Shear force (kg)	2.26	2.34	2.32	0.33	0.764

[1)] The T1, T2, and T3 treatment groups were fed diets containing 0.3 ppm Na-Se, 0.15 ppm Na-Se+0.15 ppm Zn-L-SeMet, and 0.3 ppm Zn-L-SeMet, respectively.
[a–c] LSMeans in the same row with different letters are significantly different ($p<0.05$).
Zn-L-SeMet, Zn-L-selenomethionine.

In this study, source of dietary selenium did not affect levels of cholesterol content and fatty acid composition in chicken breast. There were no previous studies reporting the association between selenium sources and cholesterol content in broiler meat. According to our findings, the amount of unsaturated fatty acid was not significantly different among treatments and, this may suggested that the internal oxidation against unsaturated fatty acid may not occur or in control. Although the content and composition of individual saturated fatty acid (SFA) and polyunsaturated fatty acid (PUFA) were similar, the total amount of SFA and PUFA in T2 broiler meat were less than in T1 and T3 resulting in the lower PUFA:SFA ratio (Table 4). Netto et al. (2014) and Zanini et al. (2004) stated that selenium involved in lipid metabolism by remodeling the fatty acid composition. In agreement with del Puerto et al. (2017), the most finding saturated fatty acids (SFA) in this study was palmitic acid (C16:0), while it was oleic acid (C18:1n9c) for monounsaturated fatty acids (MUFA).

In this study, sources of selenium supplemented in the diets affected GSH-Px activity (Table 5) and this was exhibited by higher GSH-Px activity ($p<0.01$) in the breast meat obtained from birds fed diets containing 0.3 ppm Zn-L-SeMet (T3-organic selenium) than those of birds fed with 0.3 ppm Na-Se (T1-inorganic selenium). The finding of increasing tissue antioxidant enzyme GSH-Px by organic selenium in this study were consistent with Zhang et al. (2014). This may be due to organic source of dietary selenium has a higher bioavailability and thus enhances the selenium retention, leading to the increasing of GSH-Px levels (Mahan et al., 1996; Surai, 2002; Zhang et al., 2014). In addition, Dalia et al. (2017) stated that bacterial organic selenium can be considered as an effective source of selenium in broiler chickens as it improved selenium deposition in tissue, antioxidant status, and glutathione peroxidase gene expression compared to those supplemented with

Table 4. Effects of dietary selenium sources[1)] on cholesterol content and fatty acid composition of *Pectoralis major* m. in commercial broiler chickens

Traits[2)]	T1	T2	T3	RMSE	p-value
Cholesterol	1.12	1.16	1.16	0.18	0.901
C14:0	0.10	0.09	0.11	0.05	0.881
C15:0	0.19	0.19	0.18	0.03	0.823
C16:0	5.01	4.27	5.18	1.76	0.642
C16:1	1.20	0.94	1.28	0.44	0.407
C18:0	1.21	1.19	1.29	0.40	0.905
C18:1n9c	6.28	5.88	7.59	2.70	0.534
C18:2n6c	4.89	3.77	4.79	1.61	0.433
C18:3n3	0.24	0.17	0.23	0.08	0.420
C23:0	0.54	0.47	0.48	0.11	0.507
SFA	7.05	6.21	7.23	2.26	0.712
MUFA	7.49	6.82	8.87	3.10	0.522
PUFA	5.12	3.94	5.02	1.69	0.433
n-6/n-3	21.02	21.52	20.82	0.93	0.421
PUFA: SFA	0.72[a]	0.64[b]	0.70[a]	0.04	0.014

[1)] The T1, T2, and T3 treatment groups were fed diets containing 0.3 ppm Na-Se, 0.15 ppm Na-Se+0.15 ppm Zn-L-SeMet, and 0.3 ppm Zn-L-SeMet, respectively.
[2)] mg/100 g.
[a,b] LSMeans in the same row with different letters are significantly different ($p<0.05$).
SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; PUFA: SFA, ratio of PUFA to SFA; Zn-L-SeMet, Zn-L-selenomethionine.

Table 5. Effects of dietary selenium sources[1] on glutathione peroxidase activity and ribonucleotides content of *Pectoralis major* m. in commercial broiler chickens

Traits	T1	T2	T3	RMSE	p-value
GSH-Px[2]	0.51[b]	0.62[ab]	0.77[a]	0.11	0.009
Hypoxanthine[3]	2.89	4.71	3.78	1.71	0.247
Inosine[3]	43.47	51.94	40.20	14.82	0.394
IMP[3]	229.85	190.40	175.66	42.62	0.136
GMP[3]	2.67	2.34	2.01	0.76	0.385

[1] The T1, T2, and T3 treatment groups were fed diets containing 0.3 ppm Na-Se, 0.15 ppm Na-Se+0.15 ppm Zn-L-SeMet, and 0.3 ppm Zn-L-SeMet, respectively.
[2] unit/mg protein.
[3] mg/100 g.
[a,b] LSMeans in the same row with different letters are significantly different ($p<0.05$).
GSH-Px, glutathione peroxidase; IMP, inosine monophosphate; GMP, guanosine monophosphate; Zn-L-SeMet, Zn-L-selenomethionine.

inorganic selenium. In accordance with Slavik et al. (2008) who found higher level of GSH-Px activity in beef cows fed with organic selenium (Se-enriched yeast) than those fed with inorganic selenium (sodium selenite). Whereas, Heindl et al. (2010) reported that the source of selenium did not affect GSH-Px activity in broiler chickens. However, the combination of 0.15 ppm Na-Se and 0.15 ppm Zn-L-SeMet (T2) did not result in any difference in GSH-Px activity when compared to T1 and T3. The ribonucleotides, mainly IMP and GMP contribute to meat flavor perception, as they hold umami taste characteristics (Dunford and Shahidi, 1998). Selenium might be involved in meat flavor as Zhou and Wang (2011) reported a higher IMP content in chickens fed with Nano-Se as compared with the control group. Nevertheless, in this study, there were no differences ($p>0.05$) in flavor related ribonucleotides (IMP, GMP, inosine, hypoxanthine) among the meat samples of birds supplemented with different sources of selenium (Table 5).

Conclusions

In general, the supplementation of selenium in any forms at 0.3 ppm (either as organic, combination of organic and inorganic, or inorganic) had no impact on carcass and fatty acid composition, other meat quality traits (drip loss, color, pH, and shear force), and ribonucleotide content of breast muscle in broiler chickens raised in a commercial closed house system. However, organic selenium improved GSH-Px activity and increased moisture retention capacity in meat as shown by lower shrinkage loss. Therefore, organic selenium could be considered as an effective source of selenium in broiler chicken diet especially in terms of biochemical benefits.

Conflict of Interest

The authors declare no potential conflicts of interest.

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Author Contributions

Conceptualization: Chaosap C. Data curation: Chaosap C. Formal analysis: Chaosap C. Methodology: Chaosap C, Takeungwongtrakul S, Zulkifli RM. Software: Chaosap C. Validation: Chaosap C. Investigation: Chaosap C, Takeungwongtrakul S, Zulkifli RM. Writing - original draft: Chaosap C, Zulkifli RM, Sivapirunthep P. Writing - review & editing: Chaosap C, Sivapirunthep P, Takeungwongtrakul S, Zulkifli RM, Sazili AQ.

Ethics Approval

The handling and care of experimental animals in the research were approved by the institutional Animal Care and Use Committee at King Mongkut's Institute of Technology Ladkrabang (ACUC-RES/2019/003).

References

Asghar A, Gray JI, Miller ER, Ku PK, Booren AM, Buckley DJ. 1991. Influence of supranutritional vitamin E supplementation in the feed on swine growth performance and deposition in different tissues. J Sci Food Agric 57:19-29.

Colnago GL, Jensen LS, Long PL. 1984. Effect of selenium and vitamin E on the development of immunity to coccidiosis in chickens. Poult Sci 63:1136-1143.

Combs GF. 1981. Influences of dietary vitamin E and selenium on the oxidant defense system of the chick. Poult Sci 60:2098-2105.

Dalia AM, Loh TC, Sazili AQ, Jahromi MF, Samsudin AA. 2017. The effect of dietary bacterial organic selenium on growth performance, antioxidant capacity, and selenoproteins gene expression in broiler chickens. BMC Vet Res 13:254.

Delezie E, Rovers M, Van der Aa A, Ruttens A, Wittocx S, Segers L. 2014. Comparing responses to different selenium sources and dosages in laying hens. Poult Sci 93:3083-3090.

Downs KM, Hess JB, Macklin KS, Norton RA. 2000. Dietary zinc complexes and vitamin E for reducing cellulitis incidence in broilers. J Appl Poult Res 9:319-323.

Du M, Ahn DU. 2002. Simultaneous analysis of tocopherols, cholesterol, and phytosterols using gas chromatography. J Food Sci 67:1696-1700.

Dunford E, Shahidi F. 1998. Flavour of fish meat. In Flavor of meat, meat products and seafoods. 2nd ed. Shahidi F (ed). Blackie Academic and Professional, London, UK. pp 131-158.

Fairweather-Tait S, Hurrell RF. 1996. Bioavailability of minerals and trace elements: Members of EC flair concerted action No. 10: Measurements of micronutrient absorption and status. Nutr Res Rev 9:295-324.

Folch J, Lees M, Stanley GHS. 1957. A simple method for the isolation and purification of total lipides from animal tissues. J Biol Chem 226:497-509.

Geraert PA, Briens M, Mercier Y, Liu YG. 2015. Comparing organic selenium sources. Available from: https://www.becfeedsolutions.com.au/wp-content/uploads/Comparing_Organic_Selenium_Sources.pdf. Accessed at May 5, 2019.

Heindl J, Ledvinka Z, Englmaierová M, Zita L, Tůmová E. 2010. The effect of dietary selenium sources and levels on performance, selenium content in muscle and glutathione peroxidase activity in broiler chickens. Czech J Anim Sci 55:572-578.

Honikel KO. 1998. Reference methods for the assessment of physical characteristics of meat. Meat Sci 49:447-457.

Huff-Lonergan E, Lonergan SM. 2005. Mechanisms of water-holding capacity of meat: The role of postmortem biochemical and structural changes. Meat Sci 71:194-204.

Jiang Z, Lin Y, Zhou G, Luo L, Jiang S, Chen F. 2009. Effects of dietary selenomethionine supplementation on growth performance, meat quality and antioxidant property in yellow broilers. J Agric Food Chem 57:9769-9772.

Kuricová S, Boldižárová K, Grešáková L, Bobček R, Levkut M, Leng L. 2003. Chicken selenium status when fed a diet supplemented with Se-yeast. Acta Vet Brno 72:339-346.

Li JL, Zhang L, Yang ZY, Zhang ZY, Jiang Y, Gao F, Zhou GH. 2018. Effects of different selenium sources on growth performance, antioxidant capacity and meat quality of local Chinese Subei chickens. Biol Trace Elem Res 181:340-346.

Mahan DC, Parrett NA. 1996. Evaluating the efficacy of selenium-enriched yeast and sodium selenite on tissue selenium retention and serum glutathione peroxidase activity in grower and finisher swine. J Anim Sci 74:2967-2974.

Mikulski D, Jankowski J, Zduńczyk Z, Wróblewska M, Sartowska K, Majewska T. 2009. The effect of selenium source on performance, carcass traits, oxidative status of the organism, and meat quality of turkeys. J Anim Feed Sci 18:518-530.

Netto AS, Zanetti MA, Claro GR, de Melo MP, Vilela FG, Correa LB. 2014. Effects of copper and selenium supplementation on performance and lipid metabolism in confined brangus bulls. Asian-Australas J Anim Sci 27:488-494.

Payne RL, Southern LL. 2005. Changes in glutathione peroxidase and tissue selenium concentrations of broilers after consuming a diet adequate in selenium. Poult Sci 84:1268-1276.

Perić L, Milošević N, Žikić D, Kanački Z, Džinić N, Nollet L, Spring P. 2009. Effect of selenium sources on performance and meat characteristics of broiler chickens. J Appl Poult Res 18:403-409.

del Puerto M, Cabrera MC, Saadoun A. 2017. A note on fatty acids profile of meat from broiler chickens supplemented with inorganic or organic selenium. Int J Food Sci 2017:1-8.

Raes K, de Smet S, Demeyer D. 2001. Effect of double-muscling in Belgian Blue young bulls on the intramuscular fatty acid composition with emphasis on conjugated linoleic acid and polyunsaturated fatty acids. Anim Sci 73:253-260.

Ravindran V. 2013. Poultry feed availability and nutrition in developing countries. Available from: http://www.fao.org/3/al707e/al707e00.pdf. Accessed at May 5, 2019.

Ryu YC, Rhee MS, Lee KM, Kim BC. 2005. Effects of different levels of dietary supplemental selenium on performance, lipid oxidation, and color stability of broiler chicks. Poult Sci 84:809-815.

Slavik P, Illek J, Brix M, Hlavicova J, Rajmon R, Jilek F. 2008. Influence of organic versus inorganic dietary selenium supplementation on the concentration of selenium in colostrum, milk and blood of beef cows. Acta Vet Scand 50:43.

Spurvey S, Pan BS, Shahidi F. 1998. Flavour of shellfish. In Flavor of meat, meat products and seafoods. 2nd ed. Shahidi F (ed). Blackie Academic and Professional, London, UK. pp 158-196.

Surai PF. 2002. Selenium in poultry nutrition 1. Antioxidant properties, deficiency and toxicity. Worlds Poult Sci J 58:333-347.

Tikk M, Tikk K, Tørngren MA, Meinert L, Aaslyng MD, Karlsson AH, Andersen HJ. 2006. Development of inosine monophosphate and its degradation products during aging of pork of different qualities in relation to basic taste and retronasal flavor perception of the meat. J Agric Food Chem 54:7769-7777.

Ward T. 2003. Looking beyond selenium yeast. Feed Technol 7:20-22.

Whanger PD. 2002. Selenocompounds in plants and animals and their biological significance. J Am Coll Nutr 21:223-232.

Yang F, Tang Q, Zhong X, Bai Y, Chen T, Zhang Y, Li Y, Zheng W. 2012. Surface decoration by spirulina polysaccharide enhances the cellular uptake and anticancer efficacy of selenium nanoparticles. Int J Nanomed 7:835-844.

Yoon I, Werner TM, Butler JM. 2007. Effect of source and concentration of selenium on growth performance and selenium retention in broiler chickens. Poult Sci 86:727-730.

Zanini SF, Torres CAA, Bragagnolo N, Turatti JM, Silva MG, Zanini MS. 2004. Effect of oil sources and vitamin E levels in the diet on the composition of fatty acids in rooster thigh and chest meat. J Sci Food Agric 84:672-682.

Zelenka J, Fajmonova E. 2005. Effect of age on utilization of selenium by chickens. Poult Sci 84:543-546.

Zhan XA, Wang M, Zhao RQ, Li WF, Xu ZR. 2007. Effects of different selenium source on selenium distribution, loin quality and antioxidant status in finishing pigs. Anim Feed Sci Technol 132:202-211.

Zhang L, Wang YX, 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 93:2210-2219.

Zhou X, Wang Y. 2011. Influence of dietary nano elemental selenium on growth performance, tissue selenium distribution, meat quality, and glutathione peroxidase activity in Guangxi Yellow chicken. Poult Sci 90:680-686.