Effects of Dietary Selenium Supplementation on Growth Performance, Selenium Retention in Tissues and Nutrient Digestibility in Growing-finishing Pigs*

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ABSTRACT : This experiment was conducted to investigate the effects of selenium (Se) sources and levels on growth performance, nutrient digestibility and Se retention in growing-finishing pigs. A total of 56 crossbred pigs ([Landrace×Yorkshire]×Large White) with average 28.5±0.2 kg BW were allotted to 7 treatments on the basis of sex and weight in two replicates and four pigs per pen. A 2×3 factorial arrangement of treatments was used in a randomized complete block (RCB) design. Two sources of Se (selenite Se or Se-enriched yeast) were added at 0.1, 0.3 and 0.5 mg/kg to each treatment diet. A basal diet without Se supplementation was the seventh treatment group. Three pigs per treatment were randomly selected and samples of loin, liver, pancreas and a kidney were collected, frozen and later analyzed for Se. The digestibility trial was conducted to evaluate the apparent absorption and retention of Se and availability of other nutrients. Growth performance was not affected by dietary sources and levels of Se. No growth retardation was observed in the 0.5 mg/kg dietary Se treatment group regardless of Se sources. The Se concentration of serum in Se supplemented groups was increased compared with the control group ($p<0.01$). During the growing and finishing phase, Se in serum was clearly increased when organic Se was provided ($p<0.01$). Interaction of Se source×Se level was observed in Se concentration of loin, liver and pancreas of the pigs at the end of experiment. Selenium retention in the liver, kidney, pancreas and loin of pigs was increased as dietary Se level increased and was higher when pigs were fed organic Se resulting in an interaction response ($p<0.01$). Nutrient digestibilities were not affected by dietary Se sources or levels. No dietary Se source×Se level interaction was observed in nutrient digestibility. The results from this experiment indicated that dietary Se sources and levels affected the distribution of Se in the body of growing-finishing pigs. Organic source of Se, such as Se-enriched yeast resulted in higher serum and tissue Se concentration compared to inorganic form, while no beneficial effects on nutrient digestibility were observed from dietary Se supplementation in growing-finishing pigs. ***(Asian-Aust. J. Anim. Sci. 2006. Vol 19, No. 1 : 55-60)***

Key Words : Selenium, Growth Performance, Nutrient Digestibility, Selenium Source and Level, Se Retention, Pigs

INTRODUCTION

Dietary Se has to be metabolically transformed into assumed common intermediate selenide (Se^{2-}) to be synthesized into selenoprotein. Liver and pancreas, where protein synthesis take place actively, take up dietary Se efficiently. Shiobara et al. (2000) reported that the retention of exogenous selenite was the highest in liver, followed by kidney and brain in the mouse. Also, the retention of exogenous selenite in brain was relatively small and slow. Muscle, as the proliferating organs, showed normally lower Se concentration than in the liver or kidney, and accounted for the highest proportion of Se related to total body content as the tissue presents the greatest amount in the body. Consequently, muscle is regarded as a major Se storage compartment of the body (Whanger et al., 1993).

Selenomethionine has been found to represent over 50% of the total Se in plants (Olson et al., 1970). Se-enriched yeast contains Se-containing amino acids and analogues and selenomethionine was proved to contain over 40% of the total selenium (Kelly and Power, 1995). Transport of inorganic forms of Se across the intestinal brush border occurs by passive processes, and inorganic Se competes with inorganic sulphur compounds for absorption (Oldfield, 1992). In contrast, absorption of selenomethionine occurs as an active process using the same enzyme system as methionine, competition for uptake occurred with methionine and its seleno analogues (McConnell and Cho, 1965).

According to the report at the 1983 Korean Nutrition Organization, the daily intake of Se by Koreans is 40 μg/d, far below the World Health Organization (WHO) recommended amount of 50-200 μg/d or the American Diabetic Association (ADA) recommendation of 50-70 μg/d.

It is very well known that an adequate level of dietary Se consumption (200 μg of organic Se) could prevent numerous diseases especially prostatic and colorectal cancers in men (Clark et al., 1996). To find adequate Se

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Table 1. Formula and chemical composition of the experimental diets in growing and finishing phases

Ingredients	Growing	Finishing-I	Finishing-II
Corn	68.70	76.72	83.91
SBM	28.07	20.85	14.24
Tallow	0.93	0.42	0.02
Limestone	0.85	0.73	0.75
DCP	0.85	0.68	0.48
Vit. Mix[1]	0.10	0.10	0.10
Min. mix[2]	0.10	0.10	0.10
Salt	0.30	0.30	0.30
Antibiotics[3]	0.10	0.10	0.10
Total	100.00	100.00	100.00
Chemical compositions			
ME (kcal/kg)	3,265	3,265	3,265
CP (%)	18.00	15.50	13.20
Lys (%)	0.97	0.79	0.62
Met (%)	0.29	0.26	0.23
Cys (%)	0.33	0.29	0.26
Ca (%)	0.60	0.50	0.45
Total P (%)	0.53	0.48	0.42
Non-phytate P (%)	0.23	0.19	0.15
Se (mg/kg)	0.06	0.06	0.06

[1] Provided the followings by per kg vitamin mixture respectively: vitamin A, 8,000.00 IU; vitamin D, 31,600.00 IU; vitamin E, 17.40 IU; vitamin K, 32.40 mg; vitamin B_2, 3.20 mg; Ca pantothenate, 8.00 mg; Niacin, 16.00 mg; Biotin, 0.06 mg; ethoxiquin, A 6,612.00 mg; vitamin B_{12}, 24.00 μg.

[2] Provided the followings by per kg mineral mixture respectively: Fe, 95.95 mg; Cu, 24.26 mg; Zn, 90.55 mg; Mn, 85.46 mg; Co, 1.29 mg; Ca, 2.08 mg; I, 13.20 mg.

[3] Virginiamycin (10 mg/kg) was added for the grower and finisher diets.

sources and levels for the highest retention of Se in pork is very important for the health of human beings when we are able to get adequate levels of Se by consumption of animal product, our health status may be improved or certain diseases prevented. Consequently, the object of this study was to investigate the effect of dietary Se sources and levels on growth performance, nutrient digestibility and Se retention in grower-finisher pigs.

MATERIALS AND METHODS

A total of 56 crossbred pigs ([Landrace×Yorkshire]× Large White) with average 28.52 kg BW were allotted to treatments on the basis of sex and weight with 2 replicates, 4 pigs per pen. The experiment was conducted as a 2×3 factorial arrangement of treatments in a randomized complete block (RCB) design. The first factor was Se source (inorganic or organic form), three dietary levels of Se (0.1, 0.3, 0.5 mg/kg) regarded as the second factor and non-Se-fortified basal treatment serving as the negative control group.

A mixture of corn and soybean was used to formulate the diets with 0.95%, 0.79% and 0.63% lysine for the growing, early-finishing and late-finishing periods, respectively. Sodium selenite was diluted with 100 ml distilled water and added to treatment diets at the appropriate level at the expense of corn. Selenium-enriched yeast was premixed to corn and mixed to treatment diets. Other vitamins and minerals met or exceeded the NRC (1998) requirements. The chemical composition of the basal diets for the growing and finishing pigs is shown in Table 1.

All pigs were housed in conventional facilities using winch curtain with half-slotted concrete floored pens (1.2×2.6 m^2 for 20 to 50 kg BW, 1.6×3.1 m^2 for 50 to 115 kg BW). Feed and water were provided *ad libitum* throughout the whole experimental period. Body weight and feed intake were measured at 3, 6, 9 and 12th weeks from the beginning of experiment and average daily gain (ADG), average daily feed intake (ADFI) and gain/feed (G/F) ratio were calculated.

Initial blood samples from 5 randomly selected pigs were collected from the anterior vena cava with 3 week interval. Collected blood samples were centrifuged at 3,000×g at 4°C, serum was separated, frozen and analyzed for Se concentrations. Three pigs per treatment were killed at a local abattoir and samples of loin, liver, pancreas and a kidney were collected, frozen and later analyzed for Se.

The apparent digestibility trial was conducted to evaluate the apparent absorption of Se or other nutrient digestibilities by dietary Se sources and levels. A total of 21 barrows (48.15±0.49 kg of BW) were allotted to each treatment in three replicates on the basis of BW. Total urine was collected daily in a plastic container containing 20 ml of 1.25 N HCl to minimize the N loss by evaporation of ammonia. Collected samples were filtered through glass wool to remove any contaminates and frozen, pooled for the 5 days collection period, and later analyzed for Se. During the experiment, diet was provided twice per day at 08:00 and 20:00. Fecal samples were collected for 5 days after 7 days of adaptation period, and this process was repeated three times for the 36-day experiment. Total amount of feed consumed and excreta were recorded daily. Collected excreta was pooled, sealed in plastic bags and stored at -20°C then dried in an air-forced drying oven at 60°C for 72 h. Dried fecal samples were ground with 1 mm Wiley mill for chemical analysis. Chemical analyses of proximate nutrients in diets, feces and urine were conducted according to the method of AOAC (1995). Diet, serum and the various tissues were analyzed for their Se content with the fluorometric method of AOAC (1995).

Statistical analyses were performed with the two-way analysis of variance procedures with the GLM procedure of SAS (1985) evaluating each trial as a RCB design. The pen was considered the experimental unit for performance data. The main effect of Se source, which excluded the non-Se-fortified basal diet, was evaluated with a single degree of freedom. Regression analysis for Se level and the Se level×Se source interaction response included the basal diet within each Se group. Simple correlations were conducted

Table 2. Main effects of dietary Se sources and levels on growth performance of growing-finishing pigs

	Control	Inorganic Se (mg/kg)			Organic Se (mg/kg)			SEM
		0.1	0.3	0.5	0.1	0.3	0.5	
Body weight (kg)								
Initial	24.65	24.68	24.69	24.65	24.54	24.63	24.75	0.26
3 wk	38.43	37.73	37.18	37.95	39.74	38.43	39.90	0.53
6 wk	51.40	50.83	51.93	52.28	56.94	53.99	55.43	0.89
9 wk	69.41	71.79	71.48	69.74	77.26	73.03	74.92	1.04
12 wk	90.13	91.42	95.41	92.73	99.83	92.30	97.73	1.36
ADG (g)								
0-3 wk	663	621	639	677	724	657	721	16.86
3-6 wk	737	778	702	710	819	741	739	18.15
0-6 wk	700	706	649	658	771	699	730	15.34
6-9 wk	948	916	1,029	919	1,069	1,002	1,026	22.29
9-12 wk	901	853	1041	924	981	838	992	21.22
0-12 wk	779	791	842	811	896	806	869	15.01
ADFI (g)								
0-3 wk	1,390	1,470	1,380	1,558	1,449	1,515	1,635	16.37
3-6 wk	2,229	2,128	2,042	2,224	2,375	2,434	2,306	20.06
0-6 wk	1,820	1,805	1,711	1,891	1,912	1,974	1,971	16.23
6-9 wk	2,932	2,819	2,833	2,760	3,096	2,968	2,987	22.45
9-12 wk	2,962	2,872	3,375	3,155	3,187	2,836	2,981	31.75
0-12 wk	2,461	2,315	2,408	2,389	2,572	2,438	2,477	20.65
G/F								
0-3 wk	0.48	0.42	0.47	0.43	0.50	0.43	0.44	0.01
3-6 wk	0.33	0.37	0.34	0.32	0.35	0.30	0.32	0.01
0-6 wk	0.39	0.39	0.38	0.35	0.40	0.35	0.37	0.01
6-9 wk	0.32	0.32	0.36	0.33	0.35	0.34	0.34	0.01
9-12 wk	0.30	0.30	0.31	0.29	0.31	0.29	0.33	0.01
0-12 wk	0.32	0.34	0.35	0.33	0.35	0.33	0.35	0.01

between individual pig's serum constituents and Se tissue contents collected from three pigs per treatment.

RESULTS AND DISCUSSION

Growth performance

Growth performance of grower-finisher pigs was not affected by dietary Se sources or levels. No growth retardation was observed in 0.5 mg/kg dietary Se treatment groups in both Se sources (Table 2). Mahan et al. (1999) reported that no differences in growth performance (ADG, ADFI, G/F and final body weight) were observed when pigs were fed 0.05 or 0.5 mg/kg Se of diet added as sodium selenite or Se-enriched yeast. These results demonstrated that 0.5 mg/kg of Se level did not negatively affect growth performance of growing-finishing pigs regardless of Se sources when pigs were fed corn-soybean meal diets.

Serum selenium

The Se concentration of serum was higher in Se supplemented groups compared to the control group. As the pigs grew older, pigs consumed more dietary Se by increased feed intake, and serum Se concentration increased during the whole experimental period. No dietary Se source×Se level interaction was observed in serum Se concentration as results of similar increasing patterns between organic and inorganic Se treatments (Table 3). During growing and early finishing phases, serum Se was more effectively increased when pigs were fed organic Se, but during the late finishing phase, serum Se showed similar values regardless of Se sources. Mahan et al. (1999) indicated serum Se concentration was higher in inorganic Se treatment compared to organic Se treatment pigs fed at low concentration (e.g. 0.05 mg/kg), whereas pigs fed organic Se showed greater serum Se concentration when pigs were fed at more than 0.05 mg/kg dietary Se level. In an investigation with cows, Ortman and Pehrson (1999) demonstrated that the whole blood Se level in the group supplemented with Se-enriched yeast was higher than in groups supplemented with selenite or selenate within 2 weeks. Twelve weeks after Se supplementation began, the concentration of whole blood Se was approximately 25% higher in Se-enriched yeast group than in the selenite and selenate groups and was 60% higher than that of the control group. Likewise, Gunter et al. (2003) observed that whole blood Se concentrations in cows supplemented with Se-enriched yeast were 23% greater than in cows supplemented with sodium selenite. They also concluded that calves from cows supplemented with Se-enriched yeast showed higher whole blood Se concentrations at birth than calves from

Table 3. Main effects of dietary Se sources and levels on serum Se concentration in growing-finishing pigs

	Con	Inorganic Se (mg/kg)			Organic Se (mg/kg)			SEM
		0.1	0.3	0.5	0.1	0.3	0.5	
Initial	0.0853							
3 wk	0.1087	0.1295	0.1375	0.1614	0.1642	0.1876	0.2029	0.0060[abcg]
6 wk	0.1111	0.1498	0.1565	0.2086	0.1659	0.1855	0.2421	0.0060[abeh]
9 wk	0.1337	0.1558	0.1890	0.2371	0.1816	0.2350	0.2671	0.0061[abdf]
12 wk	0.1584	0.1978	0.2252	0.2453	0.1761	0.2534	0.2639	0.0060[bd]

[a] Dietary Se source response ($p<0.01$). [b] Dietary Se level response ($p<0.01$). [c] Linear inorganic Se (include basal) response ($p<0.01$).
[d] Quadratic inorganic Se (include basal) response ($p<0.05$). [e] Cubic inorganic Se (include basal) response ($p<0.05$).
[f] Linear organic Se (include basal) response ($p<0.01$). [g] Quadratic organic Se (include basal) response ($p<0.01$).
[h] Cubic inorganic Se (include basal) response ($p<0.05$).

Table 4. Main effects of dietary Se sources and levels on tissue Se concentration in finishing pigs (mg/kg)

Items	Con	Inorganic Se (mg/kg)			Organic Se (mg/kg)			SEM
		0.1	0.3	0.5	0.1	0.3	0.5	
Loin	0.0777	0.1038	0.1082	0.1192	0.1588	0.3418	0.7023	0.0332[abcdf]
Liver	0.5181	0.5439	0.6313	0.6477	0.5671	0.6273	0.8315	0.0174[abcdf]
Pancreas	0.2812	0.3440	0.4178	0.4321	0.3501	0.5552	0.6353	0.0193[abde]
Kidney	0.9974	1.3521	1.6147	2.3342	1.4095	2.0347	2.5627	0.0891[abcdg]

[a] Dietary Se source response ($p<0.01$). [b] Dietary Se level response ($p<0.01$)
[c] Dietary Se Source × level interaction ($p<0.01$). [d] Linear inorganic Se (include basal) response ($p<0.01$).
[e] Linear organic Se (include basal) response ($p<0.01$). [f] Quadratic organic Se (include basal) response ($p<0.01$).
[g] Cubic organic Se (include basal) response ($p<0.01$).

cows supplemented with sodium selenite. However, Anita et al. (2004) demonstrated whole blood Se and erythrocytic GSH-Px were not affected by Se injection to buffaloes. Whole blood Se concentration reflected the long-term status of pigs, whereas serum Se value represented the short-term status of the animal (Mahan, 2001).

Selenomethionine, comprising more than 40% of Se-enriched yeast, was better retained in muscle during the early growth period than inorganic Se. When body protein catabolism or turnover took place, selenoproteins remaining in the tissue were catabolized and the released Se was diverted to the body Se pool, converted to selenocysteine or excreted (Mahan, 2001). On the other hand, the catabolism pathway of selenomethionine, was more complex than inorganic Se which is directly reduced to selenide or excreted (Suzuki and Ogra, 2002). Consequently these results demonstrated that more metabolites of organic Se were retained in the animal body compared to inorganic Se, which mechanism would affect Se concentration in serum or tissues of the pigs.

Tissue Se concentration

Se concentration was generally the highest in the kidney, followed by liver, pancreas and loin. Per unit of tissue, Se being distributed to various tissues was affected by dietary Se sources and levels resulting in an interaction response in loin, liver and pancreas of pigs (Table 4). Combs et al. (1986) had summarized similar results concerning tissue Se concentrations. Selenium retention in the liver, kidney, pancreas and loin of pigs was greater when Se was provided as the organic form compared with inorganic forms at same dietary Se level. There were some differences observed in increasing patterns of Se concentrations of the tissues measured between two forms of dietary Se source. In the inorganic Se treatment groups, Se concentrations in all tissues were increased linearly ($p<0.01$) as dietary Se level increased, notwithstanding while in organic Se treatment groups, tissue Se concentration responded to dietary Se level quadratically or cubically, except for pancreas, where Se concentration increased linearly as dietary Se level increased. Panter et al. (1996) demonstrated that tissue Se concentrations showed similar patterns caused by dietary Se levels and Se in the liver, kidney and spleen of swine was greater when Se was provided as seleno-DL-methionine than sodium selenate or *Astragalus bisulcatus* treatment. Within the tissues, liver was regarded as a large storage reservoir of labile Se in the animal body and the tissue contained several forms of Se of which could be transformed to intermediates of selenoproteins, so that, liver retained various forms of Se for Se metabolism in the animal body (Mahan and Peters, 2004).

Mahan et al. (1999) reported that when either inorganic or organic Se sources were fed to pigs, finishing pigs had higher liver Se concentrations when organic Se was provided, but in growing pigs liver had a similar Se concentration between Se sources. Selenium distribution in the loin, liver and pancreas was linearly increased as dietary Se level increased in both Se sources, and tissue Se concentration was higher when pigs were fed organic Se compared to the inorganic form at the same level (Mahan et al., 1999).

Table 5. Main effects of dietary Se sources and levels on nutrients digestibility in finishing pig (%)

Items	Con	Inorganic Se (mg/kg)			Organic Se (mg/kg)			SEM
		0.1	0.3	0.5	0.1	0.3	0.5	
Crude protein	87.43	87.29	87.38	87.94	87.69	87.43	88.78	0.50
Dry matter	88.63	89.04	89.18	89.17	88.60	88.53	89.67	0.33
Crude ash	64.02	60.00	65.75	64.34	60.74	58.82	62.34	1.12
Crude fat	62.30	51.67	67.17	62.25	61.43	61.75	69.77	1.20
Nitrogen retention	57.01	54.61	51.49	59.16	50.44	54.71	52.23	1.05

Table 6. Main effects of dietary Se sources and levels on Se balance of growing pigs (mg/day)

Se balance (mg/d)	Con	Inorganic Se (mg/kg)			Organic Se (mg/kg)			SEM
		0.1	0.3	0.5	0.1	0.3	0.5	
Intake	0.4877	0.5881	0.6087	1.3284	0.6763	0.8727	1.1680	
Feces	0.0472	0.0731	0.0943	0.1175	0.0828	0.0878	0.1669	0.0098[beh]
Urine	0.0779	0.1130	0.2429	0.3158	0.1063	0.1733	0.2495	0.0227[bdj]
Retention	0.3626	0.4020	0.2715	0.8951	0.4873	0.6115	0.7516	0.0485[abcfh]
Retention (%of intake)	74.35	68.35	44.61	67.38	72.05	70.07	64.35	2.37[abcgi]

[a] Dietary Se source response ($p<0.05$). [b] Dietary Se level response ($p<0.05$).
[c] Dietary Se Source×level interaction ($p<0.01$). [d] Linear inorganic Se (include basal) response ($p<0.01$).
[e] Linear inorganic Se (include basal) response ($p<0.05$). [f] Cubic inorganic Se (include basal) response ($p<0.01$).
[g] Cubic inorganic Se (include basal) response ($p<0.05$). [h] Linear organic Se (include basal) response ($p<0.01$).
[I] Linear organic Se (include basal) response ($p<0.05$). [j] Quadratic organic Se (include basal) response ($p<0.05$).

The present result regarding kidney Se concentration disagreed with Mahan and Parrett (1996) who reported that dietary inorganic Se was more effectively retained in kidney than organic Se at 0.5 mg/kg. Similar results were reported by Mahan and Kim (1996), who demonstrated that kidney Se was numerically lower when the Se-yeast was provided to pigs, but the response was not significant. The lack of similarity presumably, could be due to the different genetic types in pig and/or natural Se content in experimental diets.

It has been recommended that Se might have a protective effect against some types of cancer in human beings (Clark et al., 1996; Combs, 1997). There may be, therefore, some interest in enhancing the Se status of human beings in Se-deficient areas of world by increasing the concentration of Se in selected food. Muscle, a typical edible tissue of pig (e.g., loin) retained most of the organic Se, because of the relative large mass to other tissue in the pig. Tissue selenomethionine can be catabolized and release Se to the body Se pool, in which various selenoproteins act as antioxidant substances when the body protein catabolizes or turnover takes place. Dietary supplementation of selenite, which improves the Se status of farm animals might be questioned because of its pro-oxidative characteristics (Levander and Burk, 1986). To increase the content of Se in muscle for improving animal and human health, Combs and Combs (1986) suggested selenomethionine had more effects on digestibility and retention of Se in the animal body, similarly, Beilstein and Whanger (1988) also concluded that selenomethionine was more available than selenite in the rat. Likewise, Ammerman and Miller (1975) demonstrated higher bioavailability of the organic form of Se for plants and animals.

Nutrients digestibility and selenium retention

Nutrient digestibility was not affected by dietary Se sources and levels. No dietary Se source×Se level interaction was observed in nutrient digestibility (Table 5). When pigs were fed selenite, there was no pathological change in the pancreas (Ewan et al., 1969). Niyo et al. (1977) also reported that dietary Se had no effect on activity of pancreatic enzymes. However, Thomson and Scott (1970) demonstrated that necrosis of the pancreas and decreasing enzyme activity were observed when pigs were exposed to Se deficiency. Noguchi (1973) confirmed that pathological changes were observed in the pancreas in Se deficient pigs.

Adkin and Ewan (1984) observed a linear increase in apparent digestibility of dry matter and N retention in young pigs fed inorganic Se, even though there was no positive effect of Se on activity of pancreatic enzymes. Moreover, Glienke and Ewan (1977) suggested that Se supplementation resulted in increased N retention at 0.1 mg/kg, especially in pigs that experienced Se deficiency. However, in the present experiment, no differences in nutrient digestibility were observed following Se supplementation.

During metabolic trial periods, more Se was retained when pigs were fed organic Se compared to inorganic Se treatment groups and was higher as the dietary Se level increased, resulting in an interaction response ($p<0.01$, Table 6). As the dietary Se level increased, more Se was excreted through urine in inorganic Se treatment groups compared to organic Se treatment groups, resulting in an interaction response ($p<0.01$). When organic Se was provided, however, fecal Se was higher compared to inorganic Se treatment groups, resulting in a Se source×level interaction response ($p<0.01$). From these

results, the urine was the main excretion route of inorganic Se, whereas feces was the major excretion route for the organic Se form. Kim and Mahan (2001) observed that Se excretion by the urinary route was higher than the fecal route when pigs were fed sodium selenite. Hitchcock et al. (1978) also demonstrated that weanling pigs excreted more Se through feces when pigs supplemented with grain derived Se compared with sodium selenite, whereas urinary Se increased more when inorganic Se was provided.

The results from this experiment indicated that dietary Se sources and levels affected body Se retention in growing-finishing pigs. Moreover, organic Se source, such as Se-enriched yeast could be retained more efficiently both in serum and tissues, while no beneficial effects were observed on nutrient digestibility by Se levels and sources.

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