

## Effects of Different Selenium Sources on Performance, Carcass Characteristics, Plasma Glutathione Peroxidase Activity and Selenium Deposition in Finishing Hanwoo Steers

S. H. Lee, B. Y. Park<sup>1</sup>, J. M. Yeo, Sung S. Lee<sup>2</sup>, J. H. Lee, J. K. Ha<sup>3</sup> and W. Y. Kim\*

Department of Animal Science, Korea National Agricultural College, RDA, Suwon 445-893, Korea

**ABSTRACT :** This study was conducted to determine effects of different selenium (Se) sources on performance, carcass characteristics, blood measures (whole blood Se concentration and plasma glutathione peroxidase (GSH-Px) activity), and Se concentrations in tissues of finishing Hanwoo steers (Korean native steers). Twenty finishing Hanwoo steers (average body weight = 536±23.4 kg, average age = approximately 20 months) were allotted to treatments in four groups of five steers per pen for 16 weeks preceding slaughter. Treatments were control (CON), spent mushroom composts from Se-enriched mushrooms (Se-SMC), selenized yeast (Se-Y), and sodium selenite (SS). Dietary Se levels of all treatments except CON were 0.9 mg Se/kg on the dry matter basis. Body weight was measured at the first and final day of trial, and blood samples were collected to analyze whole blood Se concentration and plasma GSH-Px activity at 2, 4, 8, and 16 weeks. At the end of trial, steers were slaughtered to collect muscle and liver samples for their Se analyses, and carcass data were recorded. In terms of dry matter intake, body weight gain and carcass characteristics, no significant differences among treatments were observed. Whole blood Se concentrations were significantly higher ( $p<0.05$ ) for Se-SMC and Se-Y treatments than for CON at each collection period, with no significant difference between SS and CON. For weeks 2 and 8, there was no significant difference for whole blood Se concentration between Se-SMC and Se-Y, but for weeks 4 and 16, Se-Y treatments were significantly higher ( $p<0.05$ ) than Se-SMC. No differences were observed for plasma GSH-Px activity between Se-SMC and Se-Y. The Se concentrations in hind leg and liver were significantly different among treatments ( $p<0.05$ ) and those in both tissues ranked the greatest in Se-Y, followed by Se-SMC, SS, and CON treatments. However, tissue Se concentration for SS was not different from that for CON. These results showed that feeding organic Se sources such as Se-SMC and Se-Y enhanced Se concentration in tissues, while SS, the most common supplement of inorganic Se, was inefficient in Se deposition. Even though Se-Y had a higher Se concentration in tissues than Se-SMC, replacing Se-Y with Se-SMC in diets of beef steers would be an inexpensive way to increase Se concentration in beef. (**Key Words :** Se-SMC, Selenized Yeast, Sodium Selenite, Plasma GSH-Px, Se Deposition, Hanwoo Steers)

### INTRODUCTION

Increased selenium (Se) concentrations in animal products by supplementing Se sources in the diets of domestic animals may protect the health of human and animal from Se-dependent diseases via the expression of many kinds of selenoproteins in their bodies (Finley, 1999).

The extent of Se retention in the animal products is greatly dependent upon animal species and the chemical forms of the element. In a comparative study between ruminant and monogastric animals, Wright and Bell (1966) reported that monogastrics absorbed more than 2.5 times as much Se as ruminants, being attributable to microbial action in the rumen.

Furthermore, many results from feeding of different chemical forms of dietary Se to animals showed that organic Se was more bioavailable than inorganic Se, resulting in increased Se contents in milk (Ortman and Pehrson, 1999), tissues (Lawler et al., 2004; Lee et al., 2006) and eggs (Payne et al., 2005). Most of the organic Se sources used in many studies were selenized yeast (Se-Y), which was composed largely of selenomethionine (Kelly and Power, 1995). Unlike inorganic Se, organic Se may be a

\* Corresponding Author: W. Y. Kim. Tel: +82-31-229-5032, Fax: +82-31-229-5055, E-mail: wykim@rda.go.kr

<sup>1</sup> National Livestock Research Institute, RDA, Suwon 441-706, Korea.

<sup>2</sup> Division of Animal Science and Technology, Gyeongsang National University, Jinju 660-701, Korea.

<sup>3</sup> School of Agricultural Biotechnology, Seoul National University, Seoul 151-742, Korea.

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**Table 1.** Chemical compositions (g/kg of as-fed) of spent mushroom composts

Composition	Se-SMC <sup>1</sup>	SMC <sup>2</sup>
Dry matter	492.9	490.1
Crude protein	42.4	41.6
Crude fiber	133.3	145.2
Ether extracts	17.7	16.5
Crude ash	34.1	34.7
Nitrogen-free extracts	265.4	252.1
Se (mg/kg)	2.48	0.08

<sup>1</sup> Spent mushroom composts from Se-enriched mushrooms.

<sup>2</sup> Spent mushroom composts from normal mushrooms.

useful Se supplement because organic Se can be nonspecifically incorporated into body proteins (McConnell and Hoffman, 1972), which may serve as a Se storage capacity. However, the use of Se-Y in animal feeds is less favorable, as it is relatively expensive. In contrast with organic Se, inorganic Se, although it is inexpensive, is much less effective in the Se transfer to animal products. In particular, inorganic Se fed to ruminants has extremely low effectiveness because most of the inorganic Se is reduced to insoluble selenide in the rumen, which cannot be absorbed in the lower intestinal tract (Butler and Peterson, 1961; Hidiroglou et al., 1968), resulting in the excretion to feces.

In a recent study, by feeding spent composts of Se-enriched mushrooms (Se-SMC), which are byproducts from the production of Se-enriched mushrooms cultivated by adding inorganic Se to mushroom composts, to finishing Hanwoo steers (Korean native steers: *Bos taurus coreanae*), Lee et al. (2004) observed that Se-SMC supplementation during a 90-day period linearly increased whole blood and tissue Se concentrations, and plasma glutathione peroxidase (GSH-Px) activity as dietary Se level with Se-SMC increased. Moreover, Lee et al. (2005) showed that Se-SMC contained considerable amounts of organic Se converted by metabolic process of mushrooms and their mycelia. They concluded that supplementing Se-SMC to Hanwoo steers might be possible to fortify Se concentrations in edible bovine tissues.

In these respects, once comparative studies are lacking, it is speculated that differences between Se-SMC and Se-Y deserve to be compared. Therefore, this study was designed to determine effects of supplementing different Se sources including Se-SMC, Se-Y and sodium selenite (SS) on performance, carcass characteristics, plasma GSH-Px activity and Se deposition in finishing Hanwoo steers.

## MATERIALS AND METHODS

### Preparation of spent mushroom composts and experimental design

The SMC was obtained from two different mushroom farms where Se-enriched and normal mushrooms of the

same species (*Flammulina velutipes*) were cultivated under the same growth condition. The Se-enriched mushroom was produced by supplementing SS (2 mg Se per kg composts on the as-fed basis) in the composts, while normal mushroom was produced by the conventional method without SS supplementation. After about a 60-day period of mushroom growth, both the SMCs were transported into Hanwoo cattle farm, located at Chonnam province in Korea, to be utilized as a feed ingredient of experimental diets. Chemical compositions of both SMCs are presented in Table 1.

Steers were assigned randomly to one of four treatments: SMC (CON; without Se supplementation), Se-SMC, Se-Y and SS. Dietary Se levels for supplementation groups were 0.9 mg/kg on a dry matter basis. Twenty finishing Hanwoo steers (average body weight = 536±23.4 kg, average age = approximately 20 months), as similar as possible in age and body weight, were allotted to treatments in four groups of five steers per pen. Each diet was fed to steers in an individual gate feeding system.

### Experimental diets, feeding and management

Ingredients and chemical compositions of the experimental diets are presented in Table 2. For Se-Y treatment, Se-Y (Alltech, Inc. Nicholasville, KY; 1,000 mg Se/kg) equivalent to 0.9 mg Se/kg in the diet was added to control diet. For SS treatment, SS was dissolved in distilled water (0.9 mg Se/kg feed, DM basis) and then added to CON diets. Selenium contents in the treatment diets were within the range of expected concentrations, and CP and TDN contents (on DM basis) were similar among treatments as shown in Table 2. Thus, diets were isocaloric and isonitrogenous among treatments. The nutritional levels of experimental diets were determined on the basis of the official Korean feeding standard for Hanwoo beef cattle (MAF and NLRI, 2002). Due to the high concentration of moisture for SMC, the diets were formulated on the cycle of 2 weeks period to prevent unfavorable fermentation. The experimental diets were stored in the polyethylene vinyl envelope with 0.7×1.5 m size in order to keep anaerobic condition until fed to animals. Diets were analyzed for Se content to make sure that they contain the appropriate Se levels for each treatment after formulated and packed. All steers were conformed to the experimental environment and experimental diets for 2 weeks period in which animals were gradually switched from a conventional diet to the experimental diet and the main feeding trial was subsequently performed for 16 weeks. Treatment diets were provided for *ad libitum* intake twice daily at 07:00 and 19:00 h, and water was allowed to be accessible freely through the automatic water provider. The water contained undetectable concentration of Se (<2 ng/ml). Daily dry matter intake was recorded by the difference between the

**Table 2.** Ingredient and chemical composition of experimental diets

Item	Treatments <sup>1</sup>			
	CON	Se-SMC	Se-Y	SS
Ingredient composition (g/kg of as-fed)				
Se-SMC <sup>2</sup>	-	246.0	-	-
SMC <sup>2</sup>	246.0	-	246.0	246.0
Corn grain	555.4	555.4	555.4	555.4
Barley grain	54.0	54.0	54.0	54.0
Corn gluten meal	18.9	18.9	18.9	18.9
Tall fescue straw	47.4	47.4	47.4	47.4
Barley bran	18.9	18.9	18.9	18.9
Molasses, sugarcane	58.5	58.5	58.5	58.5
Sodium selenite (mg/kg) <sup>3</sup>	-	-	-	1.4
Selenized yeast (mg/kg) <sup>4</sup>	-	-	632.4	-
Vitamin/mineral mix <sup>5</sup>	0.9	0.9	0.9	0.9
Chemical composition (g/kg of dry matter)				
Dry matter (DM)	758.5	762.3	759.5	760.8
Crude protein (CP)	112.6	115.4	116.7	113.3
Crude fiber (CF)	129.2	129.6	129.3	129.7
Ether extracts (EE)	37.3	36.5	37.4	37.4
Crude ash (CA)	28.0	27.0	27.9	28.6
Nitrogen-free extracts (NFE)	692.9	691.5	688.7	691.0
Calcium	4.9	4.3	4.6	4.6
Phosphorus	1.8	1.9	1.8	1.9
Selenium (mg/kg)	0.082	0.905	0.898	0.909
TDN <sup>6</sup>	744.4	743.3	743.5	743.7

<sup>1</sup> CON: Control; Se-SMC: Spent composts from Se-enriched mushrooms; Se-Y: Selenized yeast; SS: Sodium selenite.

<sup>2</sup> See Table 1. <sup>3</sup> Sodium selenite was from Sigma Chemicals. <sup>4</sup> Selenized yeast was from Alltech Inc.

<sup>5</sup> Consisted of Ca 15%, P 6.8%, Mg 7.0%, Na 7.8%, Zn 5,000 mg/kg, Mn 4,000 mg/kg, Cu 500 mg/kg, I 300 mg/kg, Co 20 mg/kg, Se 0 mg/kg, vitamin A 400,000 IU/kg, vitamin D<sub>3</sub> 75,000 IU/kg, and vitamin E 500 mg/kg. <sup>6</sup> Total digestible nutrients (TDN) value was calculated according to the regression equation described by Wardeh (1981), whose equation is that TDN% equals  $40.2625 - (0.1969 \times CP\%) + (0.4228 \times NFE\%) - (1.1905 \times EE\%) - (0.1379 \times CF\%)$ .

supply and ort amounts, and initial and final body weights for all animals were measured to observe body weight gain on the daily basis throughout the experimental period. At the end of the experimental period, all animals were slaughtered in the slaughterhouse (National Agricultural Cooperative Federation, Chonnam, Korea).

#### Sample collection and analytical methods

Each treatment diet was sampled after manufactured and analyzed for nutritional components according to AOAC (1995). Blood samples were collected from the jugular vein into 10-ml heparinized tubes (Vacutainer tube, Becton-Dickinson, Inc., NJ, USA) at 2, 4, 8 and 16 weeks after feeding for the measurements of whole blood Se concentration and GSH-Px activity in plasma. Blood samples for whole blood Se analyses were frozen at -75°C and freeze-dried. Blood samples for GSH-Px activity were immediately centrifuged (1,500×g for 15 minutes) to obtain plasma, which was stored at -75°C until analysis.

Carcass characteristics (backfat thickness, ribeye area, marbling score, meat color, fat color, yield grade and quality grade) were assessed at 24 h postmortem by a carcass grader of Animal Products Grading Service (APGS, 2006) in Korea. A cut of about 1 kg from the hind leg and

liver taken from slaughtered animals was thoroughly minced, freeze-dried, and kept at -75°C until analysis. Selenium analyses for all samples (diets, whole blood and tissues) were determined by the fluorometric method of AOAC (1995). GSH-Px activity in plasma was assayed by the coupled enzymatic method of Lawrence and Burk (1976) by utilizing hydrogen peroxide as a substrate. One unit of GSH-Px activity equals 1 nanomole of NADPH oxidized per minute per milliliter of plasma.

#### Statistical analysis

Statistical analysis for all dependent variables was performed as a completely randomized design using the GLM program of SAS (Version 8.1; SAS Inst. Inc., Cary, NC, 2000). Dependent variables were performance, carcass characteristics, Se concentration in whole blood and tissues, and plasma GSH-Px activity. The model included treatments (df = 3) and steers within the treatment (df = 4). Steers within the treatment were used as error terms to test effects of treatments. Significant differences among treatments were determined by least significant differences test at a level of  $p < 0.05$  (Steel and Torrie, 1980).

**Table 3.** Animal performances and carcass characteristics of finishing Hanwoo steers fed different Se sources

Item	Treatments <sup>1</sup>				SEM <sup>2</sup>	Significance
	CON	Se-SMC	Se-Y	SS		
Final body weight (kg)	630.00	626.50	638.00	640.75	39.33	NS
Dry matter intake (kg/day)	9.46	9.56	9.54	9.59	1.21	NS
Total gain (kg)	99.00	98.50	98.00	95.75	21.87	NS
Average daily gain (g)	825.00	820.83	816.67	797.92	182.27	NS
Carcass weight (kg)	370.00	370.50	372.50	378.00	22.64	NS
Backfat thickness (mm)	11.00	10.20	12.20	12.80	4.77	NS
Ribeye area (cm <sup>2</sup> )	74.20	80.60	80.80	74.60	7.13	NS
Marbling score <sup>3</sup>	5.60	6.00	4.20	4.20	1.39	NS
Meat color score <sup>4</sup>	4.80	4.60	5.00	4.80	0.42	NS
Fat color score <sup>5</sup>	2.60	2.80	2.60	2.40	0.72	NS
Yield grade <sup>6</sup>	2.00	2.00	1.80	2.40	0.61	NS
Quality grade <sup>7</sup>	1.40	1.20	1.40	1.20	0.71	NS

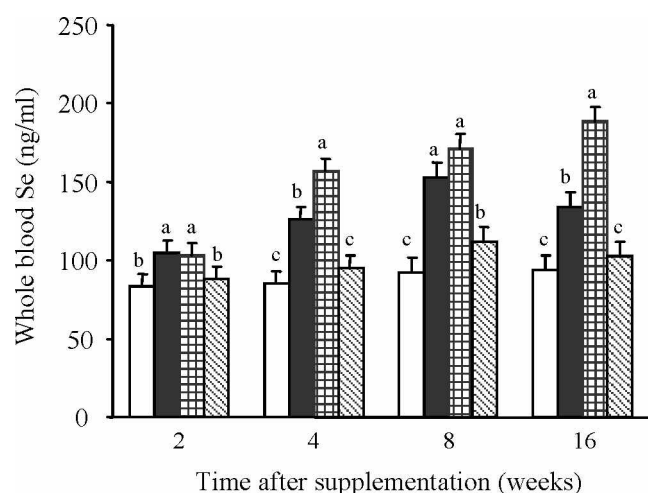
NS: Not significant.

<sup>1</sup> CON: Control; Se-SMC: Spent composts from Se-enriched mushrooms; Se-Y: Selenized yeast; SS: Sodium selenite.

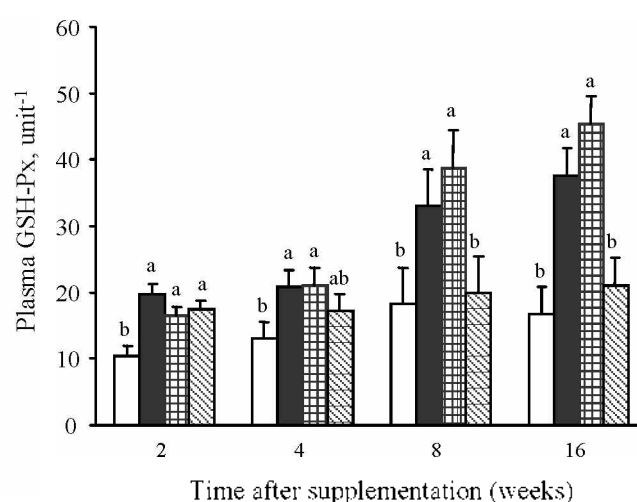
<sup>2</sup> Standard error of the mean.

<sup>3</sup> 1 = least small and 7 = most abundant. <sup>4</sup> 1 = brightest and 7 = darkest. <sup>5</sup> 1 = white and 7 = brown. <sup>6</sup> 1 = high, 2 = medium and 3 = low.

<sup>7</sup> Prime grade = 0, prime grade = 1, 2<sup>nd</sup> grade = 2 and 3<sup>rd</sup> grade = 3.



**Figure 1.** Whole blood Se concentrations of finishing Hanwoo steers fed different Se sources. Legend: CON (open bar), Se-SMC (solid bar), Se-Y (crosshatched bar) and SS (diagonal bar). <sup>a, b, c</sup> Within each time, bars with different letters are significantly different ( $p < 0.05$ ). Vertical bars represent standard error of the mean.



**Figure 2.** Plasma GSH-Px activities of finishing Hanwoo steers fed different Se sources. <sup>1</sup> One unit of GSH-Px activity equals 1 nanomole of NADPH oxidized/minute/milliliter of plasma. Legend: CON (open bar), Se-SMC (solid bar), Se-Y (crosshatched bar) and SS (diagonal bar). <sup>a, b</sup> Within each time, bars with different letters are significantly different ( $p < 0.05$ ). Vertical bars represent standard error of the mean.

## RESULTS

### Animal performance and carcass characteristics

The results of performance and carcass characteristics are presented in Table 3. Neither Se source nor dietary Se level affected performance measures such as final body weight, dry matter intake, total and daily gains. Regardless of source and level of dietary Se, no significant differences were also noted for all parameters of carcass characteristics among treatments.

### Blood measurements

Whole blood Se concentration was presented in Figure

1. The supplementation of dietary Se sources, except for SS treatments, increased whole blood Se concentrations as early as 2 weeks ( $p < 0.05$ ). Whole blood Se concentrations were significantly higher ( $p < 0.05$ ) for Se-SMC and Se-Y treatments than for control at all weeks (Figure 1). However, SS treatment, except for weeks 8, was not significantly different from control at all weeks.

For weeks 2 and 8, there was no significant difference between Se-SMC and Se-Y but for weeks 4 and 16, Se-Y treatments were significantly higher ( $p < 0.05$ ) than Se-SMC. In addition, as time increased, whole blood Se concentration for all treatments tended to increase.

**Table 4.** Selenium concentrations in the tissues of finishing Hanwoo steers fed different Se sources

Dry matter basis (ppm)	Treatments <sup>1</sup>				SEM <sup>2</sup>	Significance
	CON	Se-SMC	Se-Y	SS		
Hind leg	0.4505 <sup>c</sup>	0.7065 <sup>b</sup>	1.1062 <sup>a</sup>	0.4983 <sup>c</sup>	0.06	**
Liver	1.0990 <sup>c</sup>	2.3165 <sup>b</sup>	3.3613 <sup>a</sup>	1.5810 <sup>bc</sup>	0.36	*

\*  $p < 0.05$  and \*\*  $p < 0.01$ .<sup>1</sup> CON: Control; Se-SMC: Spent composts from Se-enriched mushrooms; Se-Y: Selenized yeast; SS: Sodium selenite.<sup>2</sup> Standard error of the mean.<sup>a, b, c</sup> Means within a row with different superscripts differ.

As with the whole blood Se concentration, plasma GSH-Px started to increase within 2 weeks (Figure 2). At 2 weeks, regardless of chemical forms of dietary Se, all of dietary Se sources significantly increased ( $p < 0.05$ ) plasma GSH-Px activity compared with control. At 4 weeks, except for SS treatments, Se-SMC and Se-Y treatments had a higher GSH-Px activity compared with control ( $p < 0.05$ ). However, from 4 up to 16 weeks, SS treatments were not significantly different from control. At 8 and 16 weeks, plasma GSH-Px activities were higher ( $p < 0.05$ ) for Se-SMC and Se-Y treatments than for control and SS treatments. Although Se-Y treatments had a little higher GSH-Px activity in plasma than Se-SMC, there were no significant differences between both treatments throughout the experimental period.

#### Selenium deposition in tissues

Selenium concentrations in hind leg and liver were the greatest in Se-Y followed by Se-SMC, SS, and control treatments (Table 4). As expected, steers fed control diets had the lowest concentration of tissue Se. Tissue Se concentrations for SS versus control diets were not different. The Se-SMC and Se-Y had significantly higher tissue Se concentrations than control and SS treatments did ( $p < 0.05$ ) but Se-Y was significantly higher in tissue Se concentration than Se-SMC ( $p < 0.05$ ). Selenium concentration of the liver within each treatment was 2 to 3 times higher than that of hind leg (Table 4).

## DISCUSSION

#### Animal performances and carcass characteristics

The Performance of the Hanwoo steers in the present study was unaffected by dietary sources or increased levels of Se (Table 3). In a similar study, Lawler et al. (2004) reported no differences in performances (final body weight, feed intake and average daily gain (ADG)) of steers fed supranutritional levels (2.8 mg/kg Se) or different forms of dietary Se. Likewise, Gunter et al. (2003) observed that DMI and body weight changes did not differ between the cows supplemented with Se and no Se, and with SS and Se-Y. Furthermore, Lee et al. (2004) showed no differences in performances between Hanwoo steers fed increasing levels of Se-SMC from 0 to 0.9 mg Se/kg. From the results of

studies above, it could be speculated that dietary Se levels and sources used in this study did not show negative effects on animal performances. However, in swine, Kim and Mahan (2001) reported that increasing levels of dietary Se from 5 to 20 ppm decreased ADG, feed intake and final body weight. Contrary to this, ruminants did not show toxic symptoms with up to 10 ppm of dietary Se (Cristaldi et al., 2005), suggesting that ruminants are less sensitive to a greater level of Se in the diet as compared with monogastrics.

Meanwhile, most of studies on dietary levels or sources of Se in both ruminants and monogastrics found no difference in carcass characteristics (Mahan et al., 1999; Lawler et al., 2004; Lee et al., 2004), as shown in the results of this study. It could be possible that Se supplements might improve meat color score since Se has a powerful antioxidant activity as with vitamin E (DeVore et al., 1983; Faustman et al., 1989; Gerloff, 1992). However, results from the present study showed that feeding dietary sources of Se including Se-SMC and Se-Y to Hanwoo steers did not positively influence the meat color score (Table 3). This was similar to the results of O'Grady et al. (2001), in which feeding Se to beef cattle did not affect oxymyoglobin and lipid oxidation that have influence on the color and storage of meat. In the present study, however, one cannot rule out the possibility that statistically non-significant differences on meat colors may be partially attributed to a small size of herd for steers subjected to this trial.

#### Blood measurements

Rapid increase in whole blood Se concentration for Se-Y and Se-SMC as early as 2 weeks was in accordance with results from Ortman and Pehrson (1999) and Lee et al. (2004), in which the supplement of Se-Y or Se-SMC in the diet of dairy cows or Hanwoo steers elevated the whole blood Se levels within 2 weeks. The intestinal absorption of Se is dependent upon chemical forms of the element (Jacobsson, 1966; van Ryssen et al., 1989; Gunter et al., 2003). In the present study, Se-SMC and Se-Y treatments elevated Se concentrations in whole blood but SS treatment was not different from control in all weeks except for weeks 8 (Figure 1). Gunter et al. (2003) reported that when beef cows were fed free-choice minerals with 26 mg/kg Se of either SS or Se-Y, both supplemented groups increased Se

concentrations in whole blood but whole blood Se concentrations were significantly higher for Se-Y than for SS. Likewise, van Ryssen et al. (1989) and Awadeh et al. (1998) reported that supplementation of organic Se (Se-Y or high-Se wheat) increased Se concentrations in whole blood compared with inorganic Se (SS). The Se-SMC and Se-Y used in this study had higher proportions of organic Se (Kelly and Power, 1995; Lee et al., 2005). Lee et al. (2005) reported that approximately 70% of Se present in Se-SMC was organic. Stefánka et al. (2001) demonstrated that inorganic Se added to mushroom compost was converted to organic Se and their predominant form of Se was mostly selenocystine.

In the present study, no significant difference between control and SS treatments may be attributed to conversion of most of SS into insoluble selenide due to the action of ruminal microorganisms. It has been reported that a considerable amount of inorganic Se was formed as insoluble selenide in the rumen, subsequently excreted into feces (Peterson and Spedding, 1963; Wright and Bell, 1966). While, in the study of Cristaldi et al. (2005), when wethers were fed various levels of dietary Se as SS, serum Se concentration was not significantly different between 0.2 ppm and 2 ppm throughout whole experimental period. In the present study, dietary Se level of SS treatment contained 0.9 ppm of Se and no difference between control and SS treatments was in accordance with Cristaldi et al. (2005). However, in the present study, whole blood Se concentrations in SS group tended to have the increased value more than those of control at all collection periods. Furthermore, at 8 weeks, SS treatments showed significantly higher whole blood Se concentration than control (Figure 1). In the present study, daily Se intake for SS treatment was approximately 8.8 mg a day (Tables 2 and 3) and Awadeh et al. (1998) reported that when prepartum cows were fed increasing levels of Se (2.4, 4.7 and 8.7 mg of Se as SS a day), cows fed 8.7 mg Se had a higher whole blood Se concentration than the other treatments. The findings from Awadeh et al. (1998) may support the significant increase of SS treatments at 8 weeks of this study.

In the present study, the trend for increased whole blood Se concentration within each treatment with increasing time was in accordance with Cristaldi et al. (2005), who reported that Se concentration in blood was dependent on the time of sampling. Similarly, this response was also shown in Lee et al. (2004), who reported that Se concentration in whole blood Se for Se-SMC groups was remarkably increased, as the supplementation period lasted.

In the present study, organic Se treatments resulted in higher activity for GSH-Px than SS (Figure 2). This was in accordance with many studies (Knowles et al., 1999;

Ortman and Pehrson, 1999; Gunter et al., 2003), which indicated that organic Se might result in a concurrent increase of GSH-Px activity in blood. However, Awadeh et al. (1998) reported that, in spite of greater Se concentrations of whole blood for Se-Y in contrast with inorganic Se, there were no differences for the concentrations of Se in serum and GSH-Px activities in blood between organic and inorganic Se.

Lee et al. (2004) demonstrated that the whole blood Se concentration was positively associated with GSH-Px activity in plasma. Overall, in the present study, the GSH-Px activity showed a similar pattern to whole blood Se concentration. However, at 2 and 4 weeks of this study, the changes of plasma GSH-Px activities for SS treatment were not consistent with those of whole blood Se concentrations for the same treatment (Figure 2). For this result, one cannot rule out possibilities of the influx of hemoglobin in plasma by any hemolysis and individual variations of animals subjected to this trial. On the other hand, since plasma GSH-Px is a short-term indicator of Se status and 98% of GSH-Px activity is associated with erythrocytes (Scholz and Hutchinson, 1979), GSH-Px activity of erythrocytes needs to be further elucidated.

In the present study, there was no significant difference in GSH-Px activity between Se-SMC and Se-Y, both treatments were superior to the SS in whole blood Se concentration and GSH-Px activity.

#### **Selenium deposition in tissues**

Selenium concentrations in tissues are affected by the dietary concentration and chemical form of Se (Kim and Mahan, 2001; Lawler et al., 2004). It is also well known that Se from organic sources is more efficiently incorporated into tissue than inorganic sources of Se (Ehlig et al., 1967; van Ryssen et al., 1989). In the present study, it was observed that steers consuming Se-Y and Se-SMC had higher tissue Se concentrations compared with steers on SS. Furthermore, Hintze et al. (2001) reported that in ruminants, skeletal muscle Se had a strong association ( $r = 0.66$ ) with whole blood Se. Therefore, in the present study, Se concentration for the hind leg of treatments showed a similar trend to the results from whole blood Se concentration.

The higher concentration of tissue Se for Se-Y compared with Se-SMC might be due to the difference in the extent or a predominant selenoamino acid of organic Se in diets between both treatments. Many researchers reported that Se distribution in tissues was dependent upon an organically bound source of Se fed to animals, and that this could be due to the molecular forms of Se present in organic Se sources (Wu et al., 1997; Lawler et al., 2004). The molecular form of Se for Se-SMC used in the present

study was not known and thus further research is needed on the Se speciation for the Se-SMC.

No significant difference of Se deposition for SS treatment versus control may be due to lower intestinal absorption, resulting from the greater reduction of SS to insoluble compounds by ruminal microorganisms (Whanger et al., 1968). In a similar study, Lawler et al. (2004) reported that, when fed supranutritional levels of sodium selenate to beef steers, Se concentrations of semitendinosus muscle were not affected, indicating that sodium selenate did not increase Se concentration in the skeletal muscle of steers.

In all treatments of this study, the liver within each treatment had around 2 to 3 time higher Se concentration than the hind leg (Table 4). This was similar to results from Lee et al. (2004), which indicated that a high Se concentration in the liver compared with muscle might result from the fact that liver acts as a major pool of Se in the body. Moreover, Combs and Combs (1986) reported that Se concentration usually ranked the highest in the kidney, followed by the liver, pancreas, heart, and the least in skeletal muscle.

## IMPLICATIONS

This study showed that supplementing Se-SMC or Se-Y in the diet for finishing Hanwoo steers enhanced Se concentrations in muscle and liver, compared with inorganic Se (SS). The SS showed the limitation in accumulating Se in tissues of steers by showing no significant increase compared with control.

Neither organic nor inorganic Se influenced growth performances and carcass characteristics without any negative effects. The Se-SMC resulted in high levels of whole blood Se concentration and plasma GSH-Px activity as high as Se-Y but Se-SMC had the lower tissue Se concentrations than Se-Y. Feeding of Se-SMC to Hanwoo steers could be an inexpensive way to increase Se concentration in their tissues.

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