Effects of High Dietary Levels of Selenium-Enriched Yeast and Sodium Selenite on Macro and Micro Mineral Metabolism in Grower-Finisher Swine[a,b]

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ABSTRACT : Thirty six barrows with an initial body weight of 28 kg were used to determine the effect of two dietary Se sources and a wide range of Se levels encompassing 0.3, 1.0, 3.0, 5.0, 7.0, and 10.0 mg/kg Se. The organic Se form was a Se-enriched yeast product, whereas the inorganic Se source was sodium selenite. The experiment was a 2×6 RCB design conducted in three replicates. Each barrow was placed in an individual metabolism crate and provided their dietary treatment and water on an *ad libitum* basis for a minimum 2 wk period, whereupon feed intake was adjusted to a constant intake within replicate at approximately 90% of intake for a 4 d adjustment period. Urine and feces were subsequently collected for a 7 d period and analyzed for Se and minerals. The results demonstrated that urinary Se was approximately 25% higher when pigs were fed sodium selenite ($p<0.01$), whereas fecal Se was lower by 25% ($p<0.01$). Se retention tended to be higher when organic Se was provided ($p>0.15$). Urinary Se increased as dietary Se level increased for both Se sources but increased more and at a high rate when sodium selenite was fed resulting in an interaction response ($p<0.01$). Fecal Se increased linearly as the dietary level of both Se sources increased, but the fecal Se from organic Se increased at a faster rate resulting in an interaction response ($p<0.01$). Se retention increased linearly ($p<0.01$) as dietary Se increased for both Se sources. The apparent digestibility of Se increased by Se level when pigs were fed sodium selenite, but not when the organic Se source was provided resulting in an interaction response ($p<0.05$). Retention of consumed Ca, Zn increased when pigs were fed organic Se ($p<0.05$) whereas P and Na retention were higher when the inorganic Se was provided. Mineral retention was not affected by dietary Se level except P. These results suggest that Se excretion by urine was the main route of excretion when pigs were fed sodium selenite but the fecal route when Se-enriched yeast was provided. The excretion of Fe, Zn, Mn, and Cu via urine and feces was not affected by high dietary Se level or dietary Se sources. (*Asian-Aust. J. Anim. Sci. 2001. Vol. 14, No. 2 : 243-249*)

Key Words : Selenium, Digestibility, Retention, Pigs

INTRODUCTION

It is known that there are several routes of Se excretion such as urine, feces, and exhalation in swine. Urine is the major pathway of excretion of Se in nonruminant animals and humans when inorganic Se is provided (Groce et al., 1971, 1973; NRC, 1983; Janghorbani et al., 1990; Mahan and Parrett, 1996). However, more Se was excreted in the feces of weanling pigs when the Se source was derived from grain (Hitchcock et al., 1978). Mahan and Parrett (1996) demonstrated that fecal Se excretion was higher than urinary Se in grower pigs when Se-enriched yeast (selenomethionine) was provided. Janghorbani et al. (1990) suggested that pathways other than urinary and fecal excretion route might account for a substantial portion of Se loss. At high doses of Se, much more of Se is eliminated via the lungs as volatile dimethyl selenide (Hirooka and Galambos, 1966; Diplock, 1976; Medinskey et al., 1981) but bile Se is considered to be only a minor route of excretion of Se (Levander and Bauman, 1966). However, the amount and distribution of Se eliminated is not clear when a toxic or sub-toxic level of Se is provided to grower pigs. In addition, there are numerous interactions of Se and other chemical substances which affect their distribution in the body, retention and toxicity (Diplock, 1976). Djujić et al. (1995) demonstrated that high level of Se-enriched yeast in diet caused decrease the concentration of essential micro-minerals such as Fe, Zn, Cu and Mn of rat tissue.

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Therefore this experiment was conducted to evaluate the aspect of Se, macro and micro minerals digestibilities and excretion according to the dietary levels of Se intake and sources for grower swine.

MATERIALS AND METHODS

This experiment was conducted to evaluate the effects of high dietary levels of two sources of Se on macro and micro mineral digestibilities in grower-finisher pigs. Each of two sources of Se (Se-enriched yeast [Sel-Plex 50, Alltech Biotechnology Center, Nicholasville, KY] or sodium selenite) was added to the diet at 0.3, 1.0, 3.0, 5.0, 7.0, and 10.0 mg/kg Se. The experiment was a 2×6 factorial experiment in a randomized complete block (RCB) design conducted in three replicates. A total of 36 barrows weighing an average 28.4 kg BW were allotted to treatments on the basis of litter and weight at three different periods. The diets were a corn-SBM mixture with added L-lysine · HCl and formulated to provide 0.80% lysine (table 1). Both Se sources were premixed in ground corn, analyzed for Se, and added to diets at the appropriate treatment level.

All pigs were placed in individual stainless steel metabolism crates measuring 0.5×1.5 m. Pigs were adjusted to the crates and to a constant feed intake (90% of *ad libitum*) for a 14-day period. Basis for 2 weeks, feed intake of last 4 days was measured from pigs fed 10.0 mg/kg of inorganic Se diet and adjusted all pigs to their intake. A 7-day digestibility trial was subsequently conducted with pigs provided their treatment diet in equal quantities twice daily with water added while pigs consumed their ration. Additional water was provided to appetite twice daily. Urine samples were collected into plastic containers covered by a colander lined with glass wool. Collection vessels contained 10 mL of 4 N H_2SO_4, which was added to each container to prevent bacterial growth and subsequent ammonia release. Urine samples were collected daily at 0700 h and diluted with water to a constant volume of 4000 ml for all groups. A 100 mL aliquot was taken and compiled daily for a week and subsamples were filtered a second time through glass wool to remove any contaminates and frozen, pooled for the 7-day collection period, and later analyzed for Se and minerals.

Fecal samples were collected daily at 0700 h, retained in a freezer (-20℃) and composited weekly for subsequent analysis. Both urine and fecal samples were kept frozen throughout the duration of the trial. Fecal samples were thawed for 12 h, and mixed in a Hobart mixer, a subsample was obtained and dried at 95℃ for 48 h for water content determination. The dried sample was ground in a cyclotec 1093 sample mill (Tectator, Hoganas, Sweden) with a 1 micron screen. Selenium and mineral contents (Ca, P, Na, K, Mg, Al, Cu, Mn, Zn) of urine and fecal samples were analyzed.

Table 1. Percentage composition of experimental diets (as fed)

Ingredient	Grower[a,b]
Corn	79.30
Soybean meal, 44% CP	17.50
Lysine · HCl	0.20
Salt	0.50
Dicalcium phosphate	1.30
Limestone	0.85
Trace mineral[c]	0.05
Vitamin mix[d]	0.20
Antibiotic[e]	0.10

[a] Sodium selenite or the Se-enriched yeast (Sel-Plex 50) was premixed in corn and add to the diet at the appropriate treatment level at the expense of corn.
[b] Formulated to 0.80% lysine, 0.65% Ca, and 0.55% P.
[c] Supplied per kilogram diet: 10 mg of Cu (copper oxide); 100 mg of Fe (ferrous sulfate); 0.2 mg of I (calcium iodate); 40 mg of Mn (manganese oxide); 120 mg of Zn (zinc oxide).
[d] Supplied per kilogram diet: 1,750 IU of vitamin A; 200 IU of vit. D_3; 11 IU of vitamin E; 0.5 mg of vitamin K; 3.0 mg of riboflavin; 10 mg of pantothenic acid; 13 mg of niacin; 0.3 mg of folacin; 0.05 mg of biotin; 15 μg of vitamin B_{12}; 0.4 g of choline and 66 mg of BHT.
[e] Tylosin was added at 22 mg per kilogram diet for the growing period.

Analytical methods

Feed, feces, and urine Se analyses were conducted by the fluoremetric method of AOAC (1995) after samples were wet ashed with perchloric and nitric acid. Except for Se, the macro- and micro-minerals in the feed, feces and urine were analyzed by the Inductively Coupled Photometer (ICP) method (AOAC, 1995).

Statistical analyses were performed using the GLM procedure of SAS (1985) evaluating each trial as a RCB design. The different periods in which the trial was conducted were included in the statistical model for each experiment. Experimental data were calculated on a daily basis with the individual pig serving as the experimental unit. Treatment contrasts compared the two Se sources by single df analysis, and Se level was evaluated by regression analysis.

RESULTS AND DISCUSSION

Apparent digestibility of Se was higher when the inorganic Se was provided compared to organic Se

($p<0.01$; table 2). As the dietary level of Se increased, the apparent digestibility increased linearly ($p<0.01$) but it was decreased at 10.0 mg/kg Se in both Se sources. The averaged apparent digestibility of Se was 83.3% when pigs were fed inorganic Se and was 59.8% when the organic Se was provided. Mahan and Parrett (1996) demonstrated that the apparent digestibility increased as the dietary Se level increased, particularly from the inorganic Se source. The lower apparent digestibility of organic Se suggests that organic Se was dependent on digestive processes of protein in the small intestine and the subsequent absorption of the respective seleno amino acid analogs (Mahan and Parrett, 1996).

Fecal Se excretion increased as the dietary Se level increased and was higher when the organic Se was provided, resulting in an interaction response ($p<0.01$). In contrast, approximately 50% of consumed Se was excreted via urinary route when the inorganic Se was fed, compared with 20% when pigs were fed the organic Se. These results suggested that Se excretion by urine was the main route of excretion for inorganic Se but the fecal route when the organic Se was provided. Previous research demonstrated that urinary Se was the main route of excretion when pigs were fed the inorganic Se (Groce et al., 1971, 1973; Hitchcock et al., 1978; Mahan and Parrett, 1996). In addition, more Se was lost in the feces of weanling pigs when the Se source was derived from grain (Hitchcock et al., 1978).

When the total amount of excreted Se from both in urine and feces are combined, approximately 68% of consumed Se from inorganic Se was excreted, whereas 64% was excreted when the organic Se was provided. Mahan and Parrett (1996) demonstrated that 16 to 19% less Se was excreted when the Se-enriched yeast product was fed within the dietary levels of 0.1 to 0.5 mg/kg Se.

Selenium retention tended to be higher ($p>0.15$) when organic Se was provided compared to inorganic Se. The retention of Se increased as the dietary Se level increased and was higher when the organic Se

Table 2. Treatment effects of dietary inorganic and organic selenium source and level on selenium digestibility

Se source:	Inorganic						Organic						
Se level mg/kg:	0.3	1.0	3.0	5.0	7.0	10.0	0.3	1.0	3.0	5.0	7.0	10.0	SEM
Item													
No. of pigs	3	3	3	3	3	3	3	3	3	3	3	3	-
Weight, kg													
Initial	28.7	28.2	29.2	28.1	30.4	27.0	28.6	27.8	28.4	27.9	26.9	29.3	1.0
Final	34.4	33.7	36.2	35.1	37.2	34.0	35.5	34.6	35.7	35.0	33.3	36.6	1.1
ADG, g	273	259	336	332	323	332	327	327	350	336	305	345	50
ADFI, g	1068	1066	1070	1069	1068	1067	1067	1067	1069	1063	1067	1067	2
Se intake, mg/d	0.32	1.07	3.21	5.34	7.45	10.98	0.32	1.07	3.21	5.32	7.47	10.67	0.21[b]
Se in feces (F)													
Per day, mg	0.07	0.20	1.70	2.91	4.15	4.52	0.06	0.25	0.84	1.30	2.04	2.64	0.18[abc]
% of intake	21.83	19.09	52.83	53.99	55.24	41.22	18.51	22.99	25.91	24.43	27.50	24.67	2.21[ab]
Se in urine (U)													
Per day, mg	0.15	0.57	1.70	2.91	4.15	4.52	0.06	0.25	0.84	1.30	2.04	2.64	0.18[abc]
% of intake	48.44	53.78	52.83	53.99	55.24	41.22	18.51	22.99	25.91	24.43	27.50	24.67	2.21[ab]
Apparent dig., %	78.17	80.91	86.19	86.06	88.02	80.46	55.10	57.68	60.41	64.02	65.54	55.88	3.13[ab]
Se retention													
Per day, mg	0.09	0.29	1.07	1.69	2.41	4.41	0.12	0.37	1.10	2.09	2.85	3.34	0.19[bc]
% of intake	29.73	27.12	33.36	32.08	32.79	39.24	36.59	34.69	34.51	39.60	38.04	31.21	4.00
% of absorb.	36.41	32.59	38.71	37.27	37.05	48.25	66.38	60.13	56.61	61.47	58.04	55.55	3.69[a]
Se excretion													
U+F, mg/d	0.22	0.78	2.14	3.65	5.06	6.57	0.20	0.69	2.10	3.23	4.62	7.33	0.27[b]
% of intake	70.27	72.88	66.64	67.92	67.21	60.76	63.41	65.31	65.49	60.40	61.96	68.79	4.00

[a] Dietary Se source response ($p<0.01$).

[b] Dietary Se level response ($p<0.01$).

[c] Dietary Se level × source interaction ($p<0.01$).

was provided, resulting in interaction response ($p<0.01$). When averaged across Se levels, 38.4% of absorbed Se was retained when pigs were fed inorganic Se, compared with 59.7% when the organic Se was provided. Selenium retention expressed as percentage of intake or percentage of absorbed Se was not affected by dietary Se level. Although the apparent digestibility was higher in inorganic Se treatment, organic Se was retained more efficiently compared to inorganic Se ($p>0.15$). Consequently, Se concentrations in serum and liver at 14 wk were increased as the dietary Se level increased and were higher when pigs were fed organic Se compared to inorganic Se (Kim, 1999; figure 1). Blood Se can be an indicator of Se intake and body status when excess dietary Se is consumed (Meyer et al., 1981; Goehring et al., 1984) whereas, liver is generally regarded as the major labile Se storage site in the body because it declines most rapidly upon periods of Se depletion (Mahan et al., 1975; Mahan and Kim, 1996).

Calcium retention expressed as percentage of absorption increased when the organic Se was provided ($p<0.05$) but was not affected by dietary Se level (table 3). Urinary P decreased as the dietary Se level increased ($p<0.05$) and was lower when the inorganic Se was provided ($p<0.01$; table 3). Consequently the retained P percentage of absorbed was increased as the dietary Se level increased ($p<0.05$), particularly when pigs were fed inorganic Se ($p<0.01$).

The main excretion route of Na and K was urine. Retention of Na was not affected by dietary Se level or Se sources (table 3). The apparent digestibility of K was 93% in both Se treatment sources, and retention was higher when inorganic Se was provided ($p<0.05$; table 3).

Magnesium retention and excretion were not affected by dietary Se level or Se sources but urinary Mg increased as dietary Se level increased ($p<0.05$; table 3).

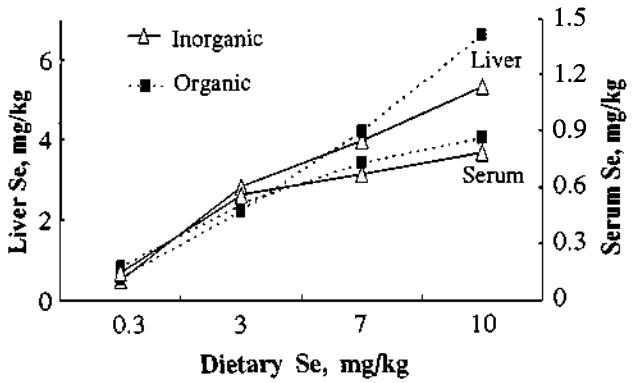

Figure 1. Effect of dietary selenium source and selenium level on serum and liver selenium concentrations of grower-finisher pigs (14wk)

Micro-minerals (Al, Cu, Mn, Zn) excretion by feces was the main route of excretion regardless of Se sources and was not affected by dietary Se level or Se sources (table 4). The interaction between Cu and Se has been reported previously (Ahmed et al., 1985). In this experiment, Cu excretion or retention was not affected by dietary Se level or Se sources. This difference can be explained by the concentration of Cu in experimental diets because the dietary Cu concentration in this experiment was 10 mg/kg. Ahmed et al. (1986) demonstrated that there was clear evidence that high dietary Cu (200 mg/kg) reduces the Se content of tissues, modified Se turnover and generally decreased tissue GSH-Px activities. In addition, high level of selenite caused the increase of the hepatic Cu content, and the body accumulation of Se was a greater factor in the mortality from selenite toxicity among rats than the protein-calorie malnutrition associated with selenite toxicity (Kezhou et al., 1987).

Djujić et al. (1995) demonstrated that supplementation with Se-enriched yeast not only induced increased retention of Se in all tissues but also changes in distribution and retention of Cu, Zn, Mn and Fe in male Wister rats. High levels of Se-enriched yeast in diet caused decreased Fe, Zn, Mn, and Cu content in different tissues of rats. Interaction between Zn and Fe may be indirectly affected by Cu because Zn is antagonist to Cu absorption, while Cu is essential for normal Fe metabolism (Djujić et al., 1995). The low level of Cu in diet may not cause the interaction among Zn, Fe, and Cu in this experiment. In previous experiment showed that Zn, Fe, Mg contents in bile increased as dietary Se level increased although these minerals intakes were lower from the reduced feed intakes in high Se treatments (Kim, 1999). The loss of essential trace-minerals for body metabolism resulted from hepatic degeneration at high dietary Se levels. This result suggests that an increase in the excretion of several essential trace-minerals may occur and precipitate other deficiency.

IMPLICATIONS

The apparent digestibility of inorganic Se was approximately 25% higher than that of organic Se. Retention of Se however, was higher when the organic Se was provided compared to inorganic Se. Urine was the main route of Se excretion when the inorganic Se was fed whereas, the fecal route when the organic Se was provided. The excretion of Fe, Zn, Mn, and Cu via urine and feces was not affected by high dietary Se level or dietary Se source when these minerals

Table 3. Main effects of dietary selenium source and selenium level on macro-mineral digestibility

Item	Se source		SEM	Se level, mg/kg						SEM
	Inorganic	Organic		0.3	1.0	3.0	5.0	7.0	10.0	
No. of pigs	18	18	-	6	6	6	6	6	6	-
						Ca				
Ca intake, g/d	7.26	7.25	0.01	7.26	7.25	7.27	7.25	7.26	7.26	0.01
Ca in feces, % of intake	33.0	31.1	1.3	31.9	32.9	32.5	29.9	32.5	32.8	2.2
Ca in urine, % of intake	2.8	2.1	0.3	2.1	2.2	1.9	2.6	3.0	2.9	0.5
Retention, % of intake	64.2	66.8	1.2	66.0	64.9	65.6	67.5	64.5	64.3	2.1
Retention, % of absorption	95.8	96.9	0.4[a]	96.8	96.5	97.2	96.3	95.6	95.8	0.7
Apparent dig., %	67.0	68.9	1.6	68.1	67.1	67.5	70.1	67.6	67.2	2.4
Excretion (urine+feces), g/d	2.59	2.39	0.09	2.44	2.51	2.49	2.36	2.56	2.57	0.16
Excretion, % of intake	35.8	33.2	1.2	34.0	35.1	34.4	32.5	35.5	35.8	2.1
						P				
P intake, g/d	6.19	6.18	0.01	6.19	6.19	6.20	6.18	6.19	6.19	0.01
P in feces, % of intake	37.9	38.0	1.4	39.3	40.3	38.1	36.2	34.9	39.0	2.4
P in urine, % of intake	2.4	4.2	0.5[b]	4.8	2.8	7.7	2.5	2.8	2.2	0.8[c]
Retention, % of intake	59.8	57.7	1.4	55.9	57.0	57.1	61.4	52.3	58.8	2.4
Retention, % of absorption	96.1	93.0	0.7[b]	92.1	95.2	92.3	96.1	95.8	95.9	1.2[c]
Apparent dig., %	62.1	62.0	1.4	60.8	59.7	61.9	63.8	65.1	61.0	2.4
Excretion (urine+feces), g/d	2.48	2.60	0.08	2.72	2.64	2.66	2.38	2.32	2.54	0.15
Excretion, % of intake	40.2	42.3	1.4	44.1	43.0	42.9	38.6	37.7	41.2	2.4
						Na				
Na intake, g/d	2.24	2.24	0.01	2.24	2.24	2.24	2.24	2.24	2.25	0.01
Na in feces, % of intake	14.7	15.3	1.3	14.5	15.2	11.9	14.5	14.6	19.4	2.2
Na in urine, % of intake	51.8	57.0	3.2	65.6	51.6	60.0	43.6	55.1	50.4	5.5
Retention, % of intake	33.5	31.9	3.1	32.4	33.2	28.1	42.0	30.4	30.3	5.4
Retention, % of absorption	39.1	37.1	3.5	37.7	38.8	31.7	48.6	35.1	36.7	6.0
Apparent dig., %	85.3	84.7	1.3	85.5	84.8	88.1	85.5	85.5	80.7	2.2
Excretion (urine+feces), g/d	1.49	1.51	0.07	1.51	1.50	1.62	1.28	1.56	1.55	0.12
Excretion, % of intake	66.5	68.1	3.1	67.6	66.8	71.9	58.0	69.6	69.7	5.4
						K				
K intake, g/d	6.73	6.72	0.01	6.73	6.72	6.73	6.71	6.72	6.72	0.01
K in feces, % of intake	6.1	7.0	0.4	6.4	6.4	6.1	5.8	7.7	7.0	0.8
K in urine, % of intake	9.5	10.1	0.2	10.6	9.6	9.7	10.0	9.5	9.5	0.4
Retention, % of intake	84.5	82.8	0.5[a]	83.0	84.0	84.3	84.3	82.9	83.5	0.9
Retention, % of absorption	89.9	89.1	0.3[a]	88.7	89.8	89.7	89.4	89.7	89.8	0.4
Apparent dig., %	93.9	93.0	0.4	93.6	93.6	93.9	94.3	92.3	93.0	0.9
Excretion (urine+feces), g/d	1.04	1.14	0.03[a]	1.13	1.07	1.05	1.04	1.14	1.10	0.05
Excretion, % of intake	15.6	17.2	0.5[a]	17.0	16.0	15.8	15.7	17.2	16.5	0.9
						Mg				
Mg intake, g/d	1.60	1.60	0.01	1.60	1.60	1.60	160	1.60	1.60	0.01
Mg in feces, % of intake	58.5	60.8	2.3	61.7	63.0	58.7	57.3	55.5	61.5	4.0
Mg in urine, % of intake	5.7	5.2	0.5	4.6	4.3	5.6	4.7	7.0	6.3	0.8[b]
Retention, % of intake	35.9	34.0	2.3	33.7	32.6	35.7	38.0	37.5	32.2	4.0
Retention, % of absorption	85.6	85.8	1.4	87.4	87.3	85.9	88.2	82.9	82.6	2.5
Apparent dig., %	41.5	39.2	2.3	38.3	37.0	41.3	42.7	44.5	38.5	4.0
Excretion (urine+feces), g/d	1.03	1.05	0.04	1.05	1.07	1.03	0.99	1.00	1.09	0.06
Excretion, % of intake	64.1	66.0	2.3	66.3	67.4	64.3	62.0	62.5	67.8	4.0

[a] Dietary Se source response ($p<0.05$).

[b] Dietary Se source response ($p<0.01$).

[c] Dietary Se level response ($p<0.05$).

Table 4. Main effects of dietary selenium source and selenium level on trace-mineral digestibility

Item	Se source		SEM	Se level, mg/kg						SEM
	Inorganic	Organic		0.3	1.0	3.0	5.0	7.0	10.0	
No. of pigs	18	18	-	6	6	6	6	6	6	-
						Al				
Al intake, g/d	171.94	171.74	0.16	171.89	171.73	172.14	171.60	171.85	171.82	0.28
Al in feces, % of intake	76.8	81.8	3.1	78.2	83.5	84.1	78.5	73.1	78.4	5.3
Al in urine, % of intake	0.3	0.3	0.1	0.2	0.2	0.2	0.4	0.3	0.5	0.1
Retention, % of intake	22.9	17.9	3.1	21.5	16.3	15.6	21.1	26.6	21.2	5.4
Retention, % of absorption	100.0	99.3	5.3	99.2	100.0	99.2	100.0	99.1	99.1	9.3
Apparent dig., %	23.2	18.2	3.1	21.8	16.5	15.9	21.5	26.9	21.6	5.3
Excretion (urine+feces), μg/d	131.40	139.52	5.28	133.02	142.21	145.13	134.02	124.92	133.46	9.12
Excretion, % of intake	77.1	82.2	3.1	78.5	83.7	84.4	78.9	73.4	78.9	5.4
						Cu				
Cu intake, g/d	12.81	12.80	0.01	12.81	12.80	12.83	12.79	12.81	12.80	0.21
Cu in feces, % of intake	79.9	85.0	2.9	82.0	84.7	80.1	81.1	80.0	86.7	5.1
Cu in urine, % of intake	0.6	0.6	0.0	0.6	0.6	0.6	0.6	0.6	0.6	0.0
Retention, % of intake	19.4	14.4	2.9	17.4	14.4	19.3	18.3	19.3	12.7	5.1
Retention, % of absorption	90.8	97.9	4.1	95.5	84.1	94.6	90.5	100.0	100.0	7.1
Apparent dig., %	20.1	15.0	2.9	17.9	15.3	19.9	18.9	20.0	13.4	5.1
Excretion (urine+feces), μg/d	10.34	10.92	0.37	10.53	10.93	10.36	10.43	10.39	11.13	0.64
Excretion, % of intake	80.6	85.6	2.9	82.6	85.6	80.7	71.8	80.7	87.3	5.1
						Mn				
Mn intake, g/d	25.63	25.60	0.02	25.62	25.60	25.66	25.58	25.62	25.61	0.02
Mn in feces, % of intake	83.5	86.2	3.2	86.9	87.8	82.6	83.5	83.2	85.4	5.5
Mn in urine, % of intake	0.5	0.4	0.1	0.5	0.4	0.5	0.5	0.5	0.5	0.1
Retention, % of intake	16.1	13.4	3.2	12.7	12.2	16.9	16.1	16.3	14.2	5.5
Retention, % of absorption	100.0	98.1	2.4	95.0	100.0	100.0	100.0	100.0	98.0	4.2
Apparent dig., %	16.5	12.2	3.2	13.4	12.2	17.4	16.5	11.8	14.9	5.6
Excretion (urine+feces), μg/d	21.55	22.21	0.82	22.31	33.52	21.37	21.45	21.60	22.04	1.41
Excretion, % of intake	84.0	86.7	3.2	87.3	88.2	83.1	83.9	83.7	85.9	5.6
						Zn				
Zn intake, g/d	114.27	114.14	0.11	114.24	114.13	114.40	114.04	114.21	114.19	0.19
Zn in feces, % of intake	69.9	70.5	2.5	72.4	73.2	68.7	67.1	68.2	71.8	4.4
Zn in urine, % of intake	3.5	2.4	0.5	3.7	3.8	3.0	2.8	1.8	2.4	0.8
Retention, % of intake	26.6	27.1	2.4	23.9	23.0	28.3	30.0	30.0	25.8	4.2
Retention, % of absorption	85.2	90.8	1.9[a]	86.0	80.4	89.2	89.1	93.9	89.2	3.3[b]
Apparent dig., %	30.1	29.5	2.5	27.6	26.9	31.3	32.9	31.8	28.2	4.4
Excretion (urine+feces), μg/d	83.93	83.00	2.67	86.63	87.52	82.15	79.73	80.14	84.61	4.61
Excretion, % of intake	73.4	73.0	2.4	76.1	77.0	71.7	70.0	70.1	74.2	4.2

[a] Dietary Se source response ($p<0.05$).

[b] Dietary Se level × Se source interaction ($p<0.01$).

content in diet was very low.

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