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Comparison of dietary selenium fed to grower-finisher pigs from various regions of the United States on resulting tissue Se and loin mineral concentrations[1,2,3]

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North Central Regional Committee on Swine Nutrition (NCR-42) and Southern Regional Committee on Nutritional Systems for Swine to Increase Reproductive Efficiency (S-1012)[6]

ABSTRACT: A study was conducted to evaluate the mineral content of pork tissue with particular emphasis on Se between various states (regions) having different diet (grain) indigenous Se concentrations. The study involved 19 states in the north, central, and southern regions of the United States, with committee members of NCR-42 and S-1012 (formerly S-288). A total of 62 pigs were used, with collaborators sending 100-g samples each of loin, heart, and liver, and a 3- to 4-g sample of hair (collected along the topline) from two to five market-weight pigs to a common laboratory for analysis. Diets at each station were formulated with locally purchased soybean meal and grain that was either grown or normally fed to pigs within their state. Tissues were analyzed for Se, but only the loin was analyzed for the macro- and micromineral elements. Correlation of dietary minerals to the tissue element was determined. The results demonstrated differences in tissue Se among states ($P < 0.01$), with high correlations of dietary Se to loin (r = 0.84; $P < 0.01$), heart (r = 0.84; $P < 0.01$), liver (r = 0.83; $P < 0.01$), and hair Se (r = 0.90; $P < 0.01$) concentrations. The correlation of hair Se to the Se concentration of loin, heart, and liver tissues was high (r > 0.90; $P < 0.01$). States in the west-central region of the United States and west of the Mississippi river had higher dietary Se and tissue Se concentrations than states in the eastern section of the Corn Belt, east of the Mississippi river, and along the East Coast. Generally, states did not differ greatly in their loin macro- and micromineral concentrations. The simple correlation of dietary minerals to their corresponding loin mineral concentration was generally nonsignificant, but most macrominerals had decreasing mineral concentrations when the dietary mineral level was higher. These results indicate that regional differences in tissue Se were influenced more by the indigenous Se content of the diet (grain) fed to the pigs than from sodium selenite.

Key Words: Geographical Region, Pigs, Selenium

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[3]The experimental use of animals and procedures followed was approved at each university by their Animal Care and Use Committee.

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Introduction

The United States, Canada (Allaway et al., 1966; NRC, 1983), and many other countries of the world (Oldfield, 1999) produce grains and forages with a Se concentration that ranges from deficient to toxic. Plants do not have a recognized Se function, but Se accumulates in plant tissues based on soil Se content, soil factors favoring its uptake, and plant protein content (NRC, 1983). Except for accumulator plants, absorbed Se generally replaces the sulfur component of plant proteins. Generally, these are the AA methionine, cysteine, and the analogs in their metabolic pathway (NRC, 1983).

In contrast with plants, animals have a dietary Se requirement (NRC, 1998). Because nonruminants cannot synthesize methionine or Se-containing methionine (i.e., selenomethionine), both are proportionally incorporated into protein tissue based on their circulating level and the tissue requirement for methionine. Consequently, the Se status of animals is greatly influenced by the Se content of plant materials consumed. Although some selenomethionine is converted to selenocysteine for the production of seleno enzymes (e.g., glutathione peroxidase, etc.), much of it is directly deposited into tissue, whereas although sodium selenite is effective in producing the seleno enzymes, its resulting tissue Se deposition is lower (Mahan and Parrett, 1996).

Before FDA (1974) approved supplemental sodium selenite or selenate, Ku et al. (1972) demonstrated that the Se content of pork loin varied greatly depending on where grains were grown. Pigs consuming grains of high indigenous Se contents had greater loin Se concentrations than when grains had lower Se concentrations. Because sodium selenite has been added to swine feeds, no studies have determined the regional differences in the Se content of pork tissue. Our study evaluated tissue Se concentrations in the United States from pigs fed diets (grains) with different Se levels and supplemented with sodium selenite.

Experimental Procedures

Study collaborators collected an approximately 100-g sample each of loin, liver, and heart tissue from two to five market-weight pigs. A 3- to 4-g sample of hair along the topline over the shoulder area also was collected from each pig. Cereal grains grown in the region and soybean meal purchased locally constituted the base diet components fed to the pigs. Animals were to have been fed the same source of cereal grain and soybean meal throughout their grower-finisher period. When the cereal grain was not grown in the area, the pigs were to be provided the grain source that was commonly fed. After collection, tissue samples and diets were sent to a common laboratory (The Ohio State University) for Se analysis. There was no attempt to standardize diets, management, or slaughter weights among stations, so that the samples would reflect the conditions within that region. Each investigator was asked to submit the finisher diet and the corresponding tissues from the pigs after slaughter.

Diets and tissues were analyzed for Se according to the fluorometric method outlined by AOAC (2000), with an ultraviolet detector (Turner filter, fluorometer, model 112; Unipath, Mountain View, CA). A standard bovine liver sample from the National Institute of Standards and Technology (U.S. Dept. of Commerce, Gaithersburg, MD) was used to validate the analytical values and to establish consistency between analyses. Collected tissues were individually ground and homogenized using a Stimpson grinder (model 5412, Louisville, KY) before analysis. Analysis of Se was conducted with wet tissue. The ground loin samples were freeze dried, with DM determined, wet-ashed in nitric and perchloric acid, and analyzed for macro- and microminerals by inductively coupled plasma spectroscopic (model 137; Applied Research Laboratories, Valencia, CA) technology. After inductively coupled plasma spectroscopic analysis, loin mineral concentrations were calculated back to a constant wet-tissue basis. Hair samples were washed three times in 60°C distilled water, dried, digested in nitric and perchloric acid, and analyzed for Se as the other tissue.

Analysis of variance and the simple correlation of tissue mineral concentration to the respective dietary mineral were conducted using the Proc Mixed and Proc Corr analysis of SAS (SAS Inst., Inc., Cary, NC). The pig was considered the experimental unit, with state incorporated into the statistical model. Figures presented reflect the relationship of the Se content in the individual tissue samples to the dietary Se of the finisher diet. Correlations and regression equations were calculated on individual animals.

Results

A total of 19 stations contributed tissues and the finisher diets from 62 pigs at the time of slaughter. All diets contained soybean meal as the supplemental protein source, and with the exception of one station, corn was the cereal grain fed (Table 1). The amount of sodium selenite added varied from 0 to 0.30 mg of Se/kg, with the majority of stations (12 of 20) adding 0.30 mg of Se/kg diet as approved by FDA (1987).

The analyzed Se content of the diets provided by the investigator and the resulting tissue Se concentrations by state are reported in Table 1. The diets and the various tissue Se concentrations from the different states generally showed a wide range in Se concentrations. The simple correlation of dietary Se to individual loin Se presented in Table 2 was high ($r = 0.84$, $P < 0.01$), with the relationships of the two variables presented in Figure 1. The correlation of dietary Se to heart Se ($r = 0.84$; $P < 0.01$), liver Se ($r = 0.83$; $P < 0.01$), and hair Se ($r = 0.90$; $P < 0.01$) concentration also was high, as presented in Table 2, with the individual relationships presented in Figures 2, 3, and 4, respectively.

Table 1. Summary of individual state data for regional Se study

State	Pigs, No.	Pig BW, kg	Dietary Se (as-fed basis), mg/kg[a]	Selenite added, mg/kg[b]	Major cereal grain used[c]	Tissue Se (wet basis), mg/kg			
						Heart	Liver	Loin	Hair
Alabama	3	106	0.354	0.30	Corn and triticale	0.197	0.488	0.126	0.420
Arkansas	3	120	0.401	0.20	Corn	0.344	0.755	0.381	0.686
Florida	4	120	0.341	0.30	Corn	0.210	0.573	0.155	0.530
Georgia	3	127	0.296	0.30	Corn	0.177	0.473	0.116	0.347
Iowa	3	112	0.433	0.00	Corn	0.386	0.657	0.396	0.743
Illinois	3	112	0.321	0.26	Corn	0.197	0.486	0.123	0.318
Indiana	5	104	0.263	0.15	Corn	0.183	0.468	0.110	0.324
Kansas	2	105	0.625	0.30	Corn	0.473	0.877	0.510	1.170
Kentucky	3	117	0.304	0.30	Corn	0.184	0.512	0.094	0.311
Louisiana	4	109	0.462	0.30	Corn	0.281	0.562	0.250	0.701
Michigan	2	112	0.295	0.30	Corn	0.209	0.522	0.135	0.398
North Carolina	4	100	0.227	0.20	Corn	0.200	0.472	0.139	0.360
Nebraska	5	118	0.555	0.30	Corn	0.370	0.745	0.362	0.884
Ohio	4	121	0.352	0.30	Corn	0.219	0.524	0.155	0.400
Oklahoma	3	126	0.583	0.20	Corn	0.327	0.650	0.368	0.827
South Dakota	3	NR[d]	0.651	0.30	Corn	0.454	0.827	0.495	0.855
Texas	2	104	0.396	0.15	Corn	0.442	0.695	0.426	1.029
Virginia	2	107	0.290	0.30	Corn	0.161	0.471	0.098	0.292
Wisconsin	4	120	0.304	0.20	Corn	0.293	0.601	0.256	0.588

[a]Analyzed value.
[b]Reported value. Dietary Se was added as sodium selenite.
[c]Diet contained soybean meal as the supplemental protein source.
[d]NR = not reported.

Because of the high correlation that existed between dietary Se and hair Se, and because of the ease of collecting hair samples for potential use as a diagnostic tool to determine the Se status of the animal, the relationships of each tissue to hair Se concentration was calculated (Table 3). The correlations of hair Se to loin Se ($r = 0.95$; $P < 0.01$), liver Se ($r = 0.90$; $P < 0.01$), and heart Se ($r = 0.95$; $P < 0.01$) were high. Because liver is considered a labile tissue reservoir for many body minerals including Se, the relationship of these two variables presented in Figure 5 shows the linear relationship of hair Se to liver Se ($r^2 = 0.90$).

The mean, standard deviation, and minimal and maximal dietary macro- and microminerals levels provided in the finisher diet, as well as their resulting loin mineral composition, are presented in Table 4. Because there was no consistent trend with diet or relationship between the various states, the individual state values are not presented. Analysis of dietary minerals was close to or exceeded current NRC (1998) requirements.

The range in concentrations of the macro- and microminerals in the loin was within a relatively narrow range (Table 4) compared with the wider range of Se in this tissue (Table 1). Consequently, the correlation of each dietary mineral, except Se, to its specific element concentration in the loin tissue was low. In those cases where the correlation was significant (Ca, $P < 0.01$; Na, $P < 0.05$; and Fe, $P < 0.01$), the resulting negative correlation indicated that the tissue mineral concentrations decreased when the dietary mineral level was higher.

When Fe and Cu are fed at NRC (1998) requirement levels, most of the Fe and Cu in the body are bound with specific proteins and are involved in oxygen transport or the antioxidant system (Hill and Spears, 2001). Because of the potential prooxidant properties of high Fe and Cu, the correlation of loin Se to these two microminerals in loin tissue was determined (Table 3). The correlation of loin Se to loin Cu or loin Fe was positive but relatively low and nonsignificant (Table 3).

Table 2. Analytical values and simple correlation of dietary Se to tissue Se concentrations

Item	Mean	SD (State)	SD (sample)	Minimum	Maximum	r	*P*-value
Diet Se, mg/kg[a]	0.394	—	—	0.263	0.651	—	—
Tissue Se, mg/kg[b]							
Heart	0.270	0.102	0.094	0.149	0.493	0.84	0.01
Loin	0.238	0.143	0.135	0.086	0.518	0.84	0.01
Liver	0.589	0.127	0.125	0.422	0.979	0.83	0.01
Hair	0.580	0.263	0.257	0.278	1.188	0.90	0.01

[a]A total of 19 diets was analyzed, with values expressed on an as-fed basis.
[b]A total of 62 tissues (wet) was analyzed and correlated to dietary Se (as-fed basis) level.

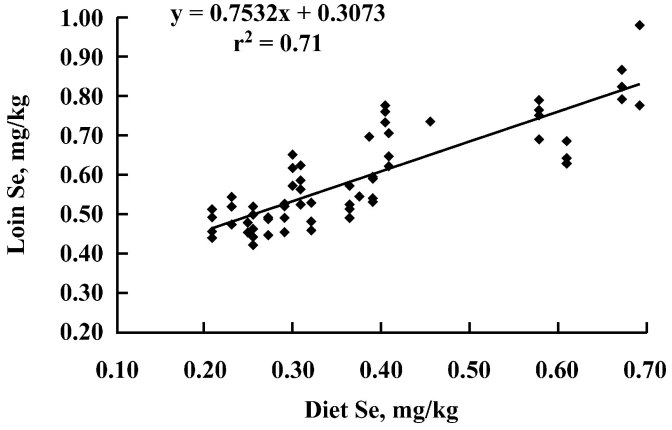

Figure 1. Regression of loin Se (wet-tissue basis) on dietary Se (as-fed basis) from individual samples (n = 62), and r^2.

Discussion

Cereal grains and oilseed meals absorb Se from the soil, where it is incorporated into plant proteins largely as selenomethionine or as one of its various analogs (NRC, 1983). In this process, Se effectively replaces S in the chemical structure of the various proteins synthesized. In regions of the United States where soil Se is high and soil conditions favor its uptake by the plant, a greater relative amount of the element is incorporated in the protein component of the grain. Olson et al. (1970) demonstrated that more than 50% of the Se in wheat was present as selenomethionine, with the remaining organic forms being in the various metabolites of the S-containing AA. Our study demonstrated a wide variation in the Se concentration in the diets, even though selenite was added, suggesting that the organic component was the major difference in Se concentrations among diets.

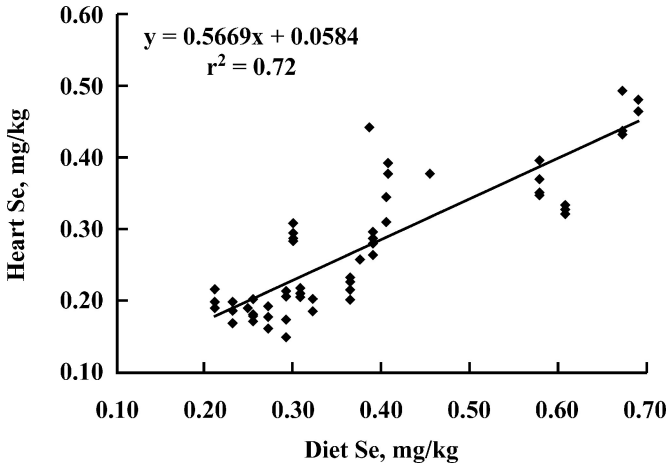

Figure 2. Regression of heart Se (wet-tissue basis) on dietary Se (as-fed basis) from individual samples (n = 62), and r^2.

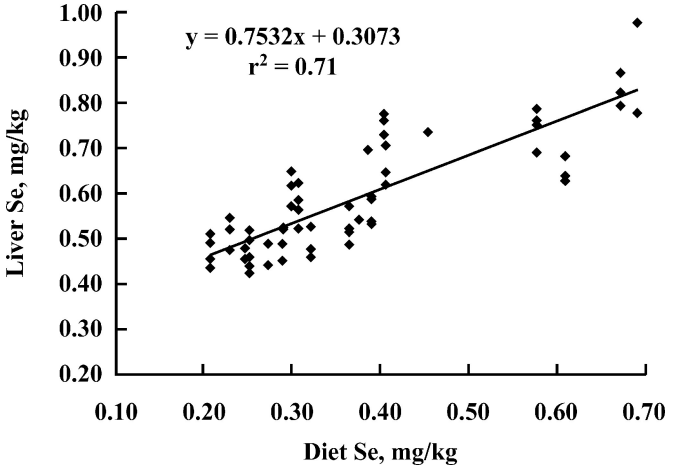

Figure 3. Regression of liver Se (wet-tissue basis) on dietary Se (as-fed basis) from individual samples (n = 62), and r^2

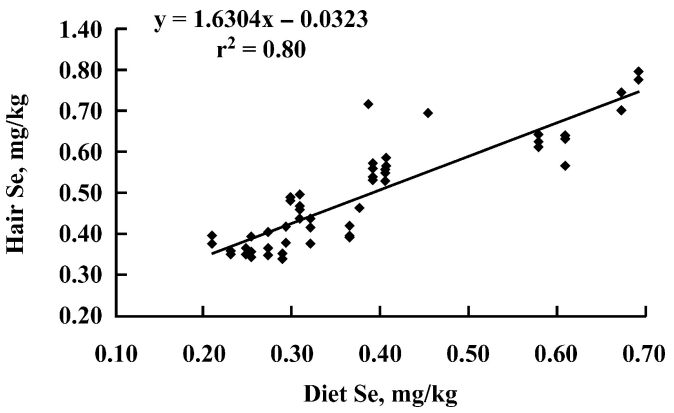

Figure 4. Regression of hair Se (wet-tissue basis) to dietary Se (as-fed basis) from individual samples (n = 62), and r^2.

Table 3. Simple correlation of loin Se or hair Se concentrations to various tissue minerals[a]

Item	r	*P*-value
Loin Se to:		
Loin Fe	0.27	0.20
Loin Cu	0.32	0.52
Liver Se	0.91	0.01
Hair Se to:		
Liver Se	0.90	0.01
Heart Se	0.95	0.01
Loin Se	0.95	0.01

[a]A total of 62 samples was used in each correlation analysis with values of each expressed on a wet-tissue basis.

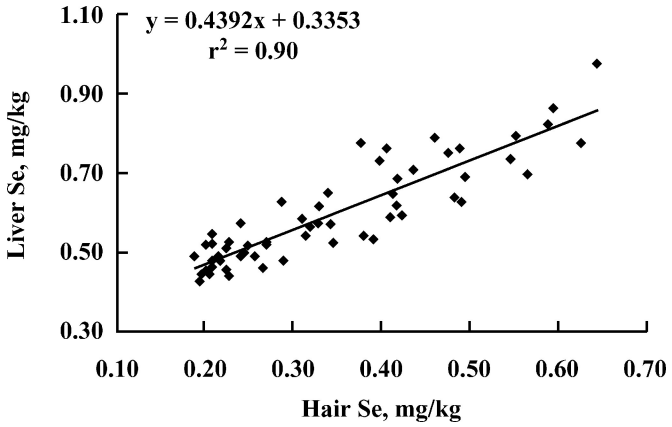

Figure 5. Regression of liver Se (wet-tissue basis) to hair Se (wet-tissue basis) from individual samples (n = 62), and r^2.

When Se was high in the diet (IA, KS, NE, OK, SD, and TX), greater tissue Se concentrations were noted compared with those states where the diets (grains) Se concentrations were less (IL, IN, KY, MI, and OH). In areas along the East Coast (AL, FL, GA, NC, and VA), where grains are generally low in Se or where much of the corn fed to swine is generally imported from the eastern section of the Corn Belt, the resulting tissues also had low tissue Se concentrations. For samples from southern states west of and adjacent to the Mississippi river (AR and LA), where imported grains of moderate to high Se grain concentrations occur, resulting tissue Se concentrations were high. States along the middle to upper portion, but east, of the Mississippi River (IL and WI) had dietary Se and tissue Se concentrations that were intermediate to low, whereas northern states west of the Mississippi (IA and SD) had high dietary and tissue Se concentrations. The tissue Se variation by state undoubtedly reflected the soils Se availability to plant tissue. The NCR-42 committee (Cromwell et al., 1999) previously showed that corn and soybean meal Se contents also varied by state and region in a manner similar to the results of this study.

Selenium seems to be somewhat unique in its deposition in body tissue compared with other minerals. Both selenite and selenomethionine seem to be equally effective as a Se source for the synthesis of the essential seleno proteins, but when the organic (grain or selenized yeast) form is fed, a large proportion is deposited in body proteins (Mahan and Parrett, 1996; Mahan et al., 1999). The dietary Se in this experiment from grain and soybean meal sources was as an organic indigenous constituent of the dietary protein, whereas supplemental Se was present in an inorganic (sodium selenite) form.

Ku et al. (1972) demonstrated somewhat lower loin Se concentrations than the analyzed loin Se concentrations from our study, but showed the same regional trends as our study. Most investigators (12 of 20) in our study supplemented the diets with inorganic sodium selenite to the maximal allowable level (FDA, 1987). The addition of selenite to most pigs' diets in our study, generally at 0.30 mg of Se/kg of diet, seemed to have a small effect on tissue Se concentration. The lower deposition of inorganic Se into muscle tissue was previously demonstrated (Mahan and Parrett, 1996), and may be the reason for the lack of increase in loin tissue Se by region when selenite was added to the diet. This could help explain the lower dietary Se to loin Se correlation we obtained (r = 0.84) compared with the higher correlation (r = 0.95) demonstrated by Ku et al. (1972). The latter study was conducted before the dietary addition of sodium selenite or selenate to swine diets was approved (FDA, 1974).

Differences would be expected in the ability of various tissues (loin, heart, liver, hair) to retain and mobilize

Table 4. Analytical values and simple correlation of dietary and tissue minerals[a]

	Diet[b]				Loin[c]					
Item	Mean	SD	Minimum	Maximum	Mean	SD	Minimum	Maximum	r	*P*-value
Macrominerals, %										
Ca	0.632	0.083	0.512	0.789	0.007	0.005	0.002	0.028	–0.49	0.01
P	0.488	0.050	0.414	0.589	0.197	0.014	0.132	0.218	–0.08	0.50
K	0.693	0.088	0.506	0.870	0.366	0.019	0.304	0.411	–0.09	0.46
Mg	0.127	0.012	0.110	0.163	0.022	0.006	0.015	0.025	0.03	0.79
Na	0.123	0.032	0.068	0.186	0.034	0.004	0.022	0.044	–0.25	0.05
Microminerals, mg/kg										
Al	111	60	59	304	1.121	0.741	0.418	5.093	0.07	0.62
B	9	2	6	12	0.135	0.219	0.064	0.327	0.07	0.52
Cu	17	5	11	25	0.624	1.140	0.299	2.515	0.19	0.13
Fe	168	37	100	251	5.002	1.129	3.275	8.705	–0.31	0.01
Mn	35	9	23	54	0.146	0.113	0.049	0.835	0.05	0.70
Se	0.390	0.121	0.263	0.651	0.238	0.134	0.086	0.518	0.78	0.01
Zn	114	30	67	158	13.550	2.984	7.723	26.758	–0.02	0.83

[a]Means, SD, and minimum and maximum values are based on individual samples.
[b]Diet minerals (n = 19 samples) are expressed on an as-fed basis.
[c]Loin minerals (n = 62 samples) are expressed on a wet-tissue basis.

deposited Se. Hair Se is unavailable for further body utilization, as its nutrient components would not be expected to reenter body circulation. This site can be considered as essentially inert and can thereby largely be considered as an excretory route for Se. Loin tissue is somewhat labile, but because of the slower turnover of protein in this tissue and the reutilization of AA within the muscle cell with turnover, large Se reserves would not be expected to be readily mobilized unless the tissue was substantially catabolized. Liver is considered the tissue of greater labiality, and liver has been shown to be rapidly depleted of its Se reservoir under conditions of Se inadequacy (Mahan et al., 1975). Consequently, pigs fed diets higher in organic Se would be expected to have a higher Se concentration in all tissues.

Hair Se concentration may be a tool to determine the body Se stores, but whether it can accurately assess the changing Se status of an animal has been questioned. Our results demonstrate a high correlation of hair Se to the Se content of other body tissue in the growing animal, suggesting that hair Se may be effective in evaluating the Se status of growing pigs. However, in a recent sow study (Mahan and Peters, 2004) involving the dietary addition of sodium selenite or selenized yeast as sources of Se, hair Se concentration over a four-parity period did not decrease as parity progressed within each of the Se sources fed, whereas there was a decrease in milk Se concentration. Although the results of Mahan and Peters (2004) demonstrated that hair Se was associated with the form of the element provided in the diet, hair concentration did not reflect the changing Se status of the sow as did the milk. The results of this experiment suggest that with grower-finisher pigs, hair Se may reflect Se tissue concentration and the level of dietary organic Se consumed, but would probably not reflect a changing Se status.

Most of the other dietary minerals did not seem to be highly correlated to the dietary level fed to the pigs. Those minerals that were significantly correlated (i.e., Ca, Fe) to the dietary mineral level seemed to have lower loin mineral concentrations when the dietary mineral level increased.

In conclusion, regional differences in tissue Se concentrations exist in grower-finisher pigs and are largely attributable to the indigenous Se content in the diets fed, and most probably to the grains used rather than to the sodium selenite added. Although tissue Se concentrations values might be somewhat greater after sodium selenite was added to diets, compared with earlier studies, regional differences in tissue Se concentration still exist. A high correlation of dietary Se to body tissues (loin, liver, heart, hair) existed with similar correlations for the various tissues. Dietary Se was highly correlated ($r \geq 0.83$) to the tissues, but the high relationship was attributed more to the indigenous organic Se from the grain source, not from sodium selenite.

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