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Comparison of Bioavailability of Organic Selenium Sources in Finishing Pigs*

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ABSTRACT : This experiment was conducted to evaluate the bioavailability of different organic selenium (Se) products in finishing pigs. A total of 48 growing pigs, average body weight 47.6 kg±0.05, were allotted to four different treatments in a randomized complete block (RCB) design in three replicates with four pigs per pen. Three different organic Se products, Se-enriched yeast (treatments A and B) and Se-proteinate (treatment C), were used in conjunction with a basal diet with no added Se as a control treatment. In growing period, pigs were fed the same diet but finishing pigs were fed each treatment diet containing organic Se products for 6 weeks. During the experimental period, feed intake and body weight were measured and blood samples were collected to determine the Se concentration. At the end of this experiment, 3 pigs per treatment were killed and various tissues (loin, liver, kidney, pancreas and spleen) were collected to analyze the Se concentration. The body weight, and average daily feed intake (ADFI) were similar among treatments, but the average daily gain (ADG) was increased on Se-proteinate treatment ($p<0.01$) and gain-to-feed ratio (G/F ratio) was improved on Se yeast B or Se-proteinate treatment ($p<0.01$). The tissue Se content was also increased when pigs were fed organic Se sources, and Se was retained efficiently in loin ($p<0.01$) and kidney ($p<0.05$) when Se yeast B was provided. The serum Se concentration was increased when organic Se was provided and was higher when pigs were fed Se-proteinate ($p<0.01$); subsequently liver Se was also higher on Se-proteinate treatment than other treatments. The Se yeast A treatment did not show any increment of Se concentration both in serum and tissues. This result demonstrated that Se retention and bioavailability in finishing pigs were varied by Se products although organic sources were provided. Consequently, each organic Se product should be evaluated before it is used as a supplement in animal feed. (**Key Words :** Selenium, Se-proteinate, Se-enriched Yeast, Se Retention, Pig)

INTRODUCTION

It is commonly known that selenium (Se) is an essential micro-mineral of the body because it is a component of GSH-Px, an antioxidant material in the cell, similar to vitamin E (Mahan and Kim, 1999). Recently, feed companies have shown an interest in the use of organic forms of Se in animal feed to reduce the excretion of undigested portions of Se and to increase the accumulation of Se in the bodies of animals (Kim, 2000). Various sources of organic selenium such as Se-enriched yeast, Se-proteinate and Se-amino acid have been introduced to the animal feed industries. A Se-enriched yeast product has been produced by feeding a yeast strain with a high S requirement with sources of inorganic and organic selenium. Yeast was used because it can be produced in high quantities under controlled conditions and is known to contain a highly bioactive organic form of selenium (Gerhard, 2001). The use of selenium yeast in swine diets is approved by the FDA from 2001. Another organic Se sources were developed to improve the bioavailability of Se products in animals and Se-proteinate is one of these organic Se sources which is produced with enzymatically hydrolyzed soy protein. Generally organic forms of Se can be utilized more efficiently than inorganic Se in the body (Kim and Mahan, 2001a, b, c). However, the efficacy and bioavailability of numerous organic Se products have yet to be evaluated. The availability and quality of each product can be varied due to the different manufacturing processes and its concentration. Without additional knowledge of different organic Se products, feed companies are reluctant to use organic Se sources instead of inorganic Se sources which are widely used in feed industry. Consequently, the

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object of this study was to evaluate and compare the bioavailability of different organic Se products in finishing pigs based upon the growth performance, serum and tissue Se contents.

MATERIALS AND METHODS

Experimental design and housing

This experiment was conducted to evaluate the efficacy of three different organic Se products in finishing pigs. A total of 48 crossbred ([Landrace×Yorkshire]×Duroc) pigs, averaging 47.60±0.05 kg body weight, were allotted to four treatments on the basis of sex and body weight. This experiment was conducted by randomized complete block (RCB) design in three replicates with four pigs (2 female pigs and 2 male pigs) per pen. Pigs were housed in a conventional facility with a half-slatted concrete floor. They were reared in growing (1.26×2.55 m^2) and finishing (1.60 ×3.00 m^2) facilities and feed and water were provided *ad-libitum* throughout the experimental period. Body weight and feed intake were recorded at the end of growing, finishing I and finishing II periods to calculate the average daily gain (ADG), average daily feed intake (ADFI) and gain-to-feed ratio (G/F ratio).

Experimental diets and selenium supplementation

Pigs were fed the same diet (3,268 kcal of ME/kg and 0.95% of total lysine) in growing period for 2 weeks then experimental diets were provided for 6 weeks to finishing pigs both in finishing I (60 to 80 kg) and finishing II periods (80 to 100 kg), respectively. The basal diet was formulated to contain 3,291 and 3,314 kcal of ME/kg and total lysine contents were 0.75 and 0.60% for the finishing I and finishing II periods, respectively (Table 1). All other nutrients were formulated to meet or exceed the NRC standard (1998). The selenium content in the basal diet was analyzed and its content was 0.110 mg/kg. Three different organic Se sources were supplemented in each treatment diet during finishing periods. The treatments included i) Control: a basal diet without Se supplementation ii) A: a basal diet+Se-enriched yeast A, iii) B: a basal diet+Se-enriched yeast B, iv) C: a basal diet+Se-proteinate (B-TRAXIM®Se, Pancosma S.A., Switzerland). The selenium products were supplemented to basal diet at 0.3 mg Se/kg by each product at the expense of corn. The two types of Se-enriched yeast contained 1,000 mg/kg of selenium, and the Se-proteinate had 11,000 mg/kg of selenium from enzymatically hydrolyzed soy protein. Selenium contents in diets, serum and tissues were analyzed via the fluorometric method of the AOAC (1995).

Sampling

Blood samples were collected from the anterior vena cava of two randomly selected pigs per pen (6 pigs per each treatment). The collected blood samples were centrifuged at 3,000 rpm at 4°C for 15 min, then the sera were separated, frozen, and the Se concentration was analyzed. At the end of the experiment, 3 pigs per treatment were selected by sex and body weight (average 106.3±5.1kg) and killed by exsanguination, and samples of the loin, liver, kidney, pancreas, and spleen were collected, frozen, and analyzed for Se concentration.

Table 1. Formula and chemical composition of the experimental diets

Ingredients	Grower	Finisher-I	Finisher-II
Corn	69.68	76.39	82.64
Soybean meal (46)	27.74	21.32	15.34
L-lysine·HCl	0.06	0.01	0.00
Limestone	0.76	0.53	0.66
Dicalcium phosphate	1.16	1.15	0.76
Vitamin mix[1]	0.10	0.10	0.10
Mineral 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 composition[4]			
ME (kcal/kg)	3,268.19	3,291.01	3,314.10
CP (%)	18.00	15.50	13.20
Lys (%)	0.95	0.75	0.60
Met (%)	0.30	0.27	0.24
Ca (%)	0.60	0.50	0.45
Total P (%)	0.50	0.48	0.40
Proximate analysis[5]			
Crude protein (%)	17.87	15.48	13.01
Crude fat (%)	3.44	3.68	2.96
Ash (%)	4.35	3.56	3.05
Ca (%)	0.50	0.42	0.38
P (%)	0.50	0.44	0.40

[1] Provided the followings by per kg vitamin and mineral mixture respectively: vitamin A, 8,000 IU; vitamin D_3, 31,6000 IU; vitamin E, 17 IU; vitamin K, 32 mg; vitamin B_2, 3 mg; vitamin B_{12}, 24 μg; Ca pantothenate, 8 mg; Biotin, 0.1 mg; Niacin, 16 mg; Ethoxyquin, 6,612 mg.
[2] Provided the followings by per kg vitamin and mineral mixture respectively: Fe, 95.95 mg; Mn, 85.46 mg; Zn, 90.55 mg; Cu, 24.26 mg; Co, 1.29 mg; Ca, 2.08 mg; I, 13.20 mg.
[3] Avilamycin (20 mg/kg) was added.
[4] Calculated values. [5] Analyzed values.

Statistical analyses

A statistical analysis of all of the collected data related to growth performance (ADG, ADFI, and G:F ratio) was carried out in which means were compared in least significant difference (LSD) multiple range tests using the General Linear Model (GLM) procedure of SAS (SAS Institute, 2004). The pen was considered the experimental

unit for the growth performance data.

RESULTS AND DISCUSSION

Growth performance

The effect of different organic Se products on the growth performance was shown in Table 2. There were no significant differences on the average body weight at each phase (Initial, 47.6 kg; finishing I, 60.3 kg; finishing II phase, 81.2 kg; and final body weight 100.7 kg, respectively). The ADFI was also not affected by dietary Se sources during whole finishing period but ADG was improved in Se-proteinate group ($p<0.05$) and the gain-to-feed ratio was improved by Se yeast B or Se-proteinate treatment ($p<0.01$).

The final average daily feed intake was not influenced by dietary Se treatments, but the gain-to-feed ratio during the finishing II period was improved when Se yeast B or Se-proteinate was provided. There was no improvement in growth performance when pigs were fed Se yeast A product ($p<0.01$). The gain-to-feed ratio was improved ($p<0.01$) by 5.5% and 9.4% when pigs were fed Se yeast B and Se-proteinate treatment diets, respectively ($p<0.01$). The ADFI, numerically reduced in the Se yeast B treatment, was partly responsible for its improved gain-to-feed ratio. When animals were fed organic Se supplemented diets, their immunity and anti-oxidative effect were improved because of increase activity of GSH-Px and immune cells by Se supplementation (Abd El Ghany and Tórtora-Pérez, 2010). However, many previous reports were suggested that the selenium supplementation had no effect on growth performance (Mahan et al., 1999; Mateo et al., 2007). In this study, growth performance was not improved but Se concentrations in serum and tissues were increased which were generally consistent with previous researches (Kim and Mahan, 2001a, b, c; Tian et al., 2006a, b). Interestingly, improved gain-to-feed ratio was observed when pigs were fed Se yeast B or Se-proteinate compared to Se yeast A. And the Se-proteinate treatment showed higher ADG during whole experimental period. Presumably, this result indicated that the availability of selenium could be varied by products although similar organic Se products were provided.

Serum selenium concentration

When pigs were fed organic Se products, serum Se was increased and was higher as Se-proteinate treatment diet was provided compared to control treatment (Table 3, $p<0.01$). Interestingly, serum Se was decreased although pigs were fed the Se yeast A treatment diet. However, in the finishing period, an increase in the serum Se content was observed in the Se-proteinate treatment at 3 weeks after supplemented organic selenium (finishing I, $p<0.01$). The serum Se concentration was higher than other treatments when pigs were fed Se-proteinate treatment diet during whole experimental period ($p<0.01$). Serum Se concentration at the end of this experiment did not show any difference compared to control group when pigs were fed Se yeast A or Se yeast B treatment diet. On the other hand, serum Se concentration in Se-proteinate treatment

Table 2. Effect of dietary Se products on growth performance of growing-finishing pigs*

Item	Control	Se-enriched yeast		Se-proteinate	SEM[1]	p-value
		A	B	C		
ADG (g)						
48 to 60 kg	928	947	998	847	28.01	0.170
60 to 80 kg	955	948	1,012	1,036	16.78	0.163
80 to 100 kg	929	876	899	1,017	28.94	0.142
60 to 100 kg	940[b]	912[b]	955[b]	1,027[a]	16.44	0.015
ADFI (g)						
48 to 60 kg	2,390	2,513	2,470	2,363	63.70	0.853
60 to 80 kg	2,768	2,822	2,825	2,741	54.96	0.974
80 to 100 kg	3,323	3,151	3,039	3,332	56.14	0.230
60 to 100 kg	3,046	2,986	2,932	3,037	37.19	0.639
G/F ratio						
48 to 60 kg	0.389	0.377	0.407	0.362	0.013	0.124
60 to 80 kg	0.345	0.336	0.359	0.381	0.008	0.117
80 to 100 kg	0.280[d]	0.276[d]	0.295[cd]	0.305[c]	0.006	0.042
60 to 100 kg	0.309 [b]	0.305[b]	0.326[a]	0.338[a]	0.005	0.009

* Control: basal diet, A = Se yeast A (1,000 mg/kg), B = Se yeast B (1,000 mg/kg), C = Se-proteinate (11,000 mg/kg). Three different organic Se sources were provided in the diet during the finishing period and Se was supplemented to basal diet at 0.3 mg Se/kg by each product at the expense of corn.

[1] Standard error of mean.

[ab] Means data with different superscripts in the same row significantly differ ($p<0.01$).

[cd] Means data with different superscripts in the same row significantly differ ($p<0.05$).

Table 3. Effect of dietary organic Se on serum Se concentration (mg/kg)*

Items	Control**	Se-enriched yeast		Se-proteinate	SEM[1]	p-value
		A	B	C		
Initial***	0.15[ab]	0.15[a]	0.13[b]	0.11[c]	0.003	0.001
Finishing I	0.12[b]	0.14[b]	0.13[b]	0.19[a]	0.005	0.001
Finishing II	0.14[bc]	0.14[c]	0.16[ab]	0.18[a]	0.004	0.001

* The selenium concentration was 0.136 mg/kg at the beginning of the experiment.
**Control: basal diet, A = Se yeast A (1,000 mg/kg), B = Se yeast B (1,000 mg/kg), C = Se-proteinate (11,000 mg/kg). Three different organic Se sources were provided in the diet during the finishing period and Se was supplemented to basal diet at 0.3 mg Se/kg by each product at the expense of corn.
*** At the beginning of finishing period
[1] Standard error of mean.
[abc] Means data with different superscripts in the same row significantly differ ($p<0.01$).

was increased by 23.1% compared to the control treatment ($p<0.01$).

It is well known that the serum selenium concentration can be used as a short-term indicator of Se status in growing pigs (Kim, 2000). This result demonstrated that the Se status of pigs can be improved within a short period of time when pigs were fed Se-proteinate treatment diet compared to other organic Se sources.

Tissue and organ selenium concentration

When the pigs were fed a basal non-Se-fortified diet, the highest tissue Se concentration was observed in the kidney and was followed by the liver, pancreas, spleen and loin (Table 4). Oh et al. (1976) demonstrated that the liver Se concentration was increased more than the kidney as the dietary intake of Se was increased.

The kidney selenium concentration was the lowest when Se-proteinate was provided. The pigs fed the diet of Se-proteinate showed a kidney Se concentration reduction of 7.0% ($p<0.05$). Generally the kidney of the pig contains higher Se levels than the liver or muscle (Milan, 1989). When the pigs fed higher level of selenium, Se in the body should be excreted as the form of urine subsequently Se in kidney was increased (Thomson and Robinson, 1986). Not only excretion route of excessive Se, kidney plays an important role in selenium balance and synthesizing GSH-Px for protecting cellular membranes involved in blood filtration and urine production (Oster et al., 1988; Arthur, 1992; Chu et al., 1992). As kidney is one of the most important organs for excretion and utilization of Se, the Se content of kidney is generally higher than any other tissues. Consequently a higher serum Se with low excretion rates of Se was observed when pigs were fed Se-proteinate treatment diet, representing higher Se bioavailability in finishing pigs.

The liver is a labile organ because absorbed Se is transported and retained for a while before Se is distributed to other organs and tissues in the body (Kim and Mahan, 2001b). The liver selenium concentration was the highest when the Se-proteinate or Se yeast B was provided; however, it was not increased in the Se yeast A treatment. When pigs were fed organic Se supplemented diets, the liver Se concentration in Se yeast B and Se-proteinate treatments was increased approximately 53.1% and 57.1% compared to control treatment, but loin Se concentration was the highest in Se yeast B treatment diet ($p<0.01$). Although higher serum and liver Se were observed as pigs were fed the Se-proteinate treatment, the loin Se content was not increased in proportional to the level of liver Se. Selenium in blood and urine is very responsive to short-term changes of Se intake (Willett, 1987), but the tissue Se content represents long-term Se levels in animals (Kim and Mahan, 2001a). This result demonstrated that Se retention in the body can be varied by Se products regardless of its

Table 4. Effect of dietary organic Se on tissue Se concentration after slaughtered (mg/kg)*

Items	Control	Se-enriched yeast		Se-proteinate	SEM[1]	p-value
		A	B	C		
Loin	0.18[b]	0.20[b]	0.29[a]	0.19[b]	0.01	0.001
Liver	0.37[b]	0.34[b]	0.57[a]	0.59[a]	0.03	0.002
Kidney	1.58[A]	1.59[A]	1.62[A]	1.47[B]	0.02	0.025
Pancreas	0.60	0.54	0.39	0.44	0.03	0.078
Spleen	0.27	0.18	0.30	0.24	0.02	0.420

* Control: basal diet, A = Se yeast A (1,000 mg/kg), B = Se yeast B (1,000 mg/kg), C = Se-proteinate (11,000 mg/kg). Three different organic Se sources were provided in the diet during the finishing period and supplemented to basal diet at 0.3 mg Se/kg by each product at the expense of corn.
[1] Standard error of mean.
[ab] Means data with different superscripts in the same row significantly differ ($p<0.01$).
[AB] Means data with different superscripts in the same row significantly differ ($p<0.05$).

sources. This can be explained by considering the different proportions of seleno-amino acid in each yeast strain and in terms of the difference in quality caused by the different manufacturing processes (i.e., the fermentation time, purification method and/or strain of yeast) of Se-enriched yeast.

It is known that selenomethionine is a major component that comprises approximately 40% of Se-enriched yeast; additionally, selenocysteine accounts for 15% of Se-enriched yeast (Kelly and Power, 1995). The chemical forms of Se in the Se-proteinate treatment may be different from those found in other organic Se sources. Consequently, more time may be needed for it to be retained in loin tissue, although Se levels in serum and liver were higher than any other organic Se sources.

Retained Se in loin tissue is seldom utilized for the metabolic needs of the body owing to the relative slow turnover rate compared to other organs. Although loin Se shows very low level, the Se content in the loin represents the largest total amount of Se in the body, reflecting the large muscle mass of the animal (Kim and Mahan, 2001b). The loin Se content was increased as organic Se sources were provided and was higher when pigs were fed Se yeast B treatment diet ($p<0.05$). When pigs were fed the Se yeast B diet, there was a high correlation between dietary and tissue Se. The serum Se concentration can be utilized as an indicator of the loin Se content at finishing I period however the serum Se content at finishing II period was a more reliable indicator for tissue Se.

When the pigs were provided the Se-proteinate treatment, liver selenium retention was the highest while kidney selenium retention was the lowest. This result demonstrated that Se-proteinate is more effective form of Se to provide for the metabolic needs of growing pigs compared to other treatments. However, the loin Se content in the Se-proteinate treatment was not higher than that in the Se-enriched yeast treatments. Mahan et al. (2005) demonstrated that dietary Se is highly correlated to Se levels in body tissue but that the high correlation was due to the endogenous organic Se from grain sources.

The Se yeast A treatment group showed the lowest Se concentrations in the serum, loin and liver subsequently there was no beneficial response by supplementation of this source. Presumably, this product contained less available Se forms compared to the other products.

IMPLICATION

The results of this study demonstrated that Se retention was varied by Se products although organic Se sources were provided. The Se yeast B improved the Se status in serum, resulting in increasing the Se accumulation in muscle tissues. When pigs were fed Se-proteinate treatment diet, feed efficiency and Se status both in serum and liver were improved, while there was no beneficial response when Se yeast A was provided to growing and finishing pigs. This study demonstrated that Se-proteinate was superior bioavailability to other organic Se sources. Consequently, each organic Se product should be evaluated before its supplementation in animal feed. In addition, the supplementation period of Se should be determined based upon the chemical forms and sources of Se to maximize the retention of Se in tissues or produce Se-fortified animal products as a functional food.

REFERENCES

Abd El Ghany Hefnawy and J. L. Tórtora-Pérez. 2010. The importance of selenium and the effects of its deficiency in animal health. Small Rumin. Res. 89(2):185-192.

AOAC. 1995. Official methods of analysis (16th ed). Association of official analytical chemists. Washington, DC.

Arthur, J. R. 1992. Selenium metabolism and function. Proceedings of the Nutrition Society of Australia. 17:91-98.

Chu, F. F., R. S. Esworthy and J. H. Doroshow. 1992. Expression of plasma glutathione peroxidase in human liver in addition to kidney, heart, lung, and breast in humans and rodents. Blood 79:3233-3238.

Gerhard N. Schrauzer. 2001. Nutritional selenium supplements: product types, quality, and safety. J. Am. Coll. Nutr. 20:1-4.

Kelly, M. P. and R. F. Power. 1995. Fractionation and identification of the major selenium compounds in selenized yeast. J. Dairy Sci. 78(Suppl. I):237.

Kim, Y. Y. and D. C. Mahan. 2001a. Effects of high dietary levels of selenium-enriched yeast and sodium selenite on macro and micro mineral metabolism in grower-finisher swine. Asian-Aust. J. Anim. Sci. 14:243-249.

Kim, Y. Y. and D. C. Mahan. 2001b. Prolonged feeding of high dietary levels of organic and inorganic selenium to gilts from 25 kg body weight through one parity. J. Anim. Sci. 79:956-966.

Kim, Y. Y. and D. C. Mahan. 2001c. Comparative effects of high dietary levels of organic and inorganic selenium on selenium toxicity of growing-finishing pigs. J. Anim. Sci. 79:942-948.

Kim, Y. Y. 2000. Differences in biological activity and metabolism of selenium due to its chemical form. J. Anim. Sci. Technol. (Kor.) 42(6):835-848.

Mahan, D. C., J. H. Brendemuhl, S. D. Carter, L. I. Chiba, T. D. Crenshaw, G. L. Cromwell, C. R. Dove, A. F. Harper, G. M. Hill, G. R. Hollis, S. W. Kim, M. D. Lindemann, C. V. Maxwell, P. S. Miller, J. L. Nelssen, B. T. Richert, L. L. Southern, T. S. Stahly, H. H. Stein, E. van Heugten and J. T. Yen. 2005. Comparison of dietary selenium fed to grower-finisher pigs from various regions of the United States on resulting tissue Se and loin mineral concentrations. J Anim. Sci. 83: 852-857.

Mahan, D. C. and Y. Y. Kim. 1999. The role of vitamin and minerals in the production of high quality pork. Asian-Aust. J. Anim. Sci. 12(2):287-294.

Mahan, D. C., T. R. Cline and B. Richert. 1999. Effects of dietary levels of selenium enriched yeast and sodium selenite as selenium sources fed to growing-finishing pigs on performance, tissue selenium, serum glutathione peroxidase activity, carcass characteristics and loin quality. J. Anim. Sci. 77:2172-2179.

Mateo, R. D., J. E. Spallholz, R. Elder, I. Yoon and S. W. Kim. 2007. Efficacy of dietary selenium sources on growth and carcass characteristics of growing-finishing pigs fed diets containing high endogenous selenium. J. Anim. Sci. 85:1177-1183.

Milan Ihnat. 1989. Occurrence and distribution of selenium. Boca Raton Fla. CRC Press. p.134.

NRC. 1998. Nutrient requirements of swine, 10th ed. National Academy Press, Washington, DC.

Oh, S. W., R. A. Sunde, A. L. Pope and W. G. Hoekstra. 1976. Glutathione peroxidase response to selenium intake in lambs fed a torula yeast-based, artificial milk. J. Anim. Sci. 42:977-983.

Oster, O., G. Schmiedel and W. Prellwitz. 1988. The organ distribution of selenium in German adults. Biol. Trace Elem. Res. 15:23-45.

SAS. 2004. User's guide statistics, SAS Inst. Inc. Cary. NC. 27513.

Tian, J. Z., M. S. Yun, W. S. Ju, H. F. Long, J. H. Kim, D. Y. Kil, J. S. Chang, S. B. Cho, Y. Y. Kim and In K. Han. 2006a. Effects of dietary selenium supplementation on growth performance, selenium retention in tissues and nutrient digestibility in growing-finishing pigs. Asian-Aust. J. Anim. Sci. 19:55-60.

Tian, J. Z., M. S. Yun, C. S. Kong, L. G. Piao, H. F. Long, J. H. Kim, J. H. Lee, , J. S. Lim, C. H. Kim, Y. Y. Kim and In K. Han. 2006b. Effects of different products and levels of selenium on growth, nutrient digestibility and selenium retention of growing-finishing pigs. Asian-Aust. J. Anim. Sci. 19:61-66.

Thomson, C. D. and M. F. Robinson. 1986. Urinary and fecal excretions and absorption of a large supplement of selenium: superiority of selenate over selenite. Am. J. Clin. Nutr. 44:659-663.

Willet, W. 1987. Nutritional epidemiology: issues and challenges. Int. J. Epidemiol. 16:312-317.