Adding Value to the Food Chain Through Selenium Supplementation

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Today we are faced with a number of dichotomies when it comes to food, its production and processing. In developed nations, where there are sufficient quantities of food, society's food concerns are centered on quality, nutrient make-up, how food is produced and its impact on the environment. In developing nations, food shortages and distribution are of greater concern than food quality and the environmental impacts of production. The differences in food quality and availability between developing and developed nations is highlighted by the contrasting levels of malnutrition and obesity. For example, in the USA there are over 58 million overweight people spending in excess of $33 billion annually on weight reduction products and services (Mokdad *et al*., 2001). Contrast this to the 150 million children under 5 years of age in developing countries who are malnourished (UNICEF, 2001).

Malnutrition is associated with about half of all child deaths worldwide. Malnourished children have lowered resistance to infections and are more likely to die from common childhood ailments like diarrheal diseases and respiratory infections. Those that survive are locked into a vicious cycle of recurring sickness, faltering growth and diminished learning ability. Conversely, obesity has major impacts on human health by increasing the incidence of diabetes, cardiovascular disease, joint ailments and cancer.

The growing global population requires an intensification of both plant and animal agriculture together with increases in land use to supply the increasing demand for food. The long-term effects of land use intensification will most likely result in more marginal land being drawn into production, with increases in soil erosion, nutrient deficiencies and imbalances. These soil nutrient deficiencies and imbalances have occurred despite the expanded use of animal manure, artificial fertilizers and soil conditioners (Figure 1). The impact of these soil changes is reflected in the nutrient quality of foodstuffs, which appears to be declining.

Many reasons have been attributed to the decline in nutrient quality of harvested crops in the USA. Some of the factors contributing to this decline are attributed to the average annual soil loss from croplands of between 6 – 10 tons per acre in the USA. Re-mineralization rates are unable to keep up with the nutrient loss and current fertilizer practice focuses on N, P and K replacement, and to a lesser degree, on the other 14 essential minerals required for plant growth. Other agronomic practices like monoculture (Table 1), the removal of crop and animal products from the land, increases in soil acidity and irrigation have resulted in both soil and crop nutrient depletion.

In the USA crop yields have steadily increased over the past 40+ years (Table 2) due to nutrition, genetics, management, mechanization and irrigation (Tisdale *et. al*., 1999). Despite the dramatic increases in yield, product nutrient quality appears to be regressing.

For example, if one reviews the nutrient content of produce over time (Table 3), the levels of Ca, Mg and K have declined (Lyne and Barak, 2000).

Table 1. Cotton yield and soil organic matter from either monoculture, legume or fertilizer rotation between 1986 and 2002.

Cotton Lint Yield (pounds/acre)			
Cropping system	**1986-1995 average**	**1996-2002 avg.**	**Average soil organic matter (%)**
No N + No winter legume	350 d	360 b	0.8 e
+ winter legumes	850 ab	1010 a	1.8 c
+ 120 lbN/acre	710 c	1030 a	1.6 d

Table 2. Average yields of major crops in the United States (Tisdale *et. al*., 1999)

Year	**Corn (bu/acre)**	**Wheat (bu/acre)**	**Soybean (bu/acre)**	**Alfalfa (ton/acre)**
1950	37.6	14.3	21.7	2.1
1992	128.7	41.4	37.0	3.6

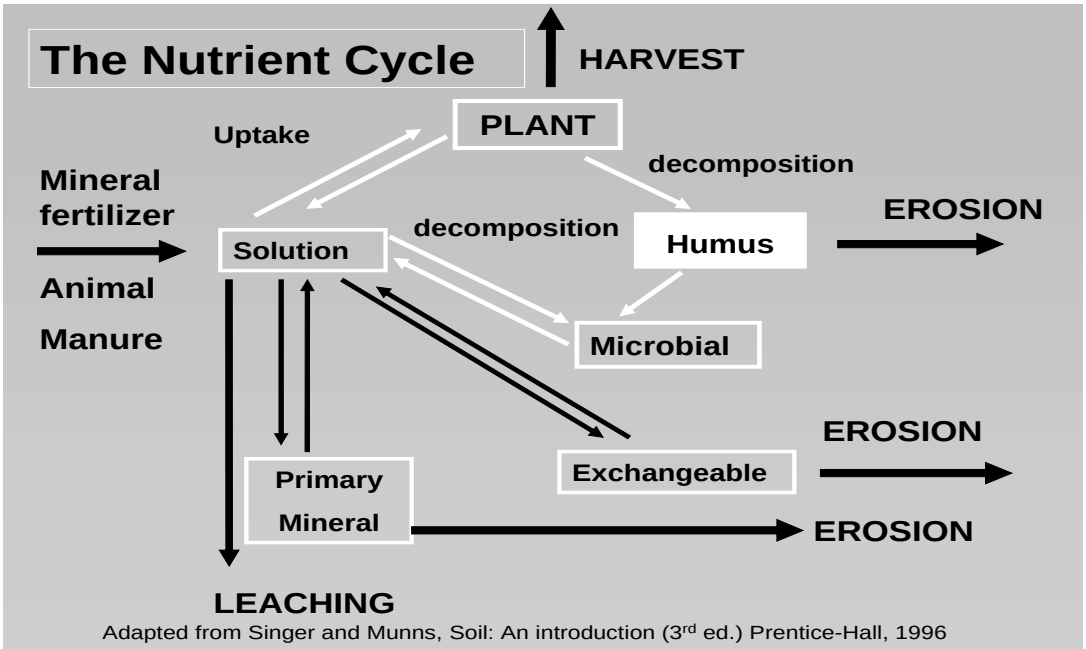
Table 3. A comparative analysis of the nutritional value (mg/100g) of produce between 1963 vs. 1999 (Lyne and Barak, 2000)

Produce	**Ca**		**Mg**		**K**	
	1963	**1999**	**1963**	**1999**	**1963**	**1999**
Beans, raw	56	37	32	25	243	209
Broccoli, raw	103	48	24	25	382	325
Carrots, raw	37	27	23	15	341	323
Oranges, raw	41	40	11	10	200	181
Peaches, raw	9	5	10	7	202	197
Tomatoes, red	13	5	14	11	244	222

The importance of Ca for both animals and humans is well understood for healthy bone and tooth formation and muscle function. For example, between 1963 and 1999 there has

been a 56% decline in the Ca content of Broccoli. The implication is that in order to get the same amount of Ca from Broccoli as in 1963, one would have to consume twice as much broccoli today. Reductions in Ca intake can result in a number of health issues. Since pastures and crops form the base of the food chain, deficiencies in their nutrient status affects the nutrient composition of meat, milk and eggs, and ultimately the nutrient status of the people consuming them.

Figure 1. Soil nutrient cycle and factor affecting the nutrient composition of crops



Adapted from Singer and Munns, Soil: An introduction (3rd ed.) Prentice-Hall, 1996

For the purpose of this paper, I will focus on Se and the impact that deficiencies of Se in the food chain have on human health status. Furthermore, I will suggest a strategy that can be used to increase Se levels throughout the food chain and the implications this can have on society.

Selenium is a naturally occurring element that is widely distributed throughout the earth's crust (Se<0.1 mg/kg). The concentration of Se in the soil is dependent on the parent material and speciation factors like soil pH, redox condition and salinity. For example, soils low in Se (Se<0.1 mg/kg) originate from pre-cretaceous sedimentary rocks, volcanic ash deposits and coastal deposits. High Se soils (Se between 10-1000 mg/kg) originate from cretaceous shales. Mineralization of these parent materials releases Se into the soil and water, where it is taken up by plants and animals, and eventually into people eating those plants and animals.

Selenium uptake and the form that Se is stored in plants are dependent on the plant species (Bauer, 1997). Plants known as Se accumulators are typically found growing in high Se soils. Plants like Astragalus, Aster, Grindella and Manzella will contain levels of Se ranging from 50 to 1000 mg Se/kg DM in the form of Se-methylselenocysteine, a water soluble form of Se. Other plant species storing Se in this water-soluble form are

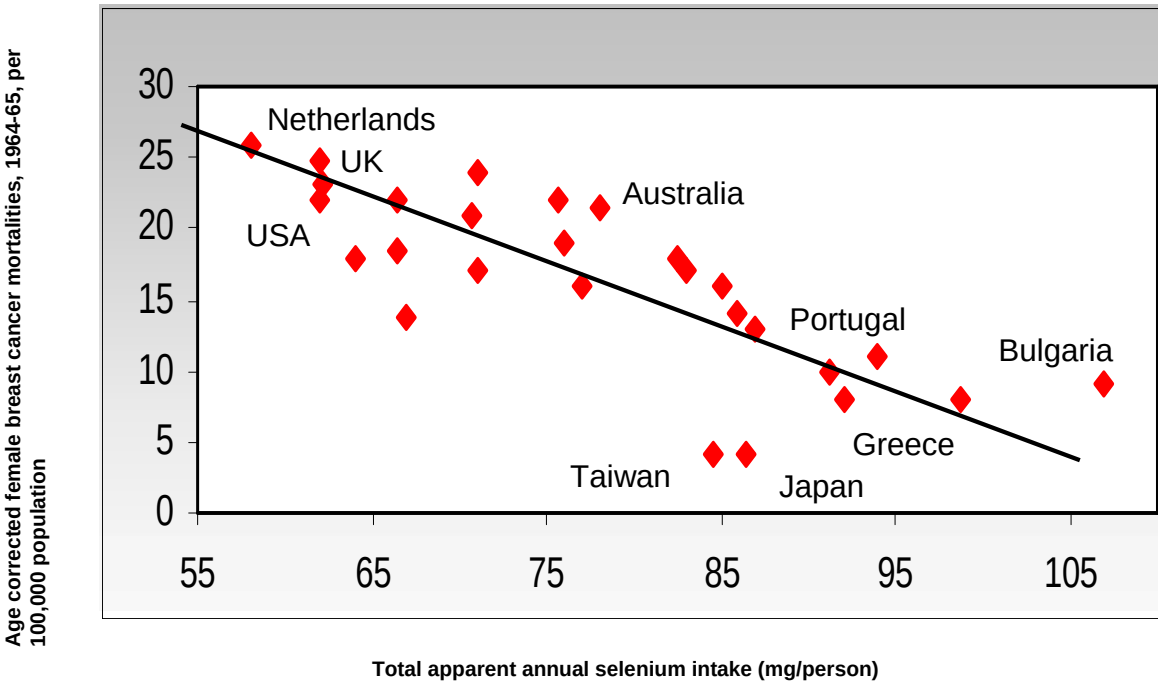
garlic, broccoli, onions and leeks (17 to 20 mg Se/kg DM). Plants known as non-accumulators (Se<50 mg/kg DM) are Buchloe, Trifolium and cereal grains. Other non-accumulators include cabbage, peas, beans, tomatoes, beets and potatoes (Se 4 to 7 mg/kg DM). These non-accumulators store Se mainly in the selenomethionine and selenocysteine forms, which are not water-soluble. Animals consuming plants containing the water-soluble form of Se are more likely to show toxicity symptoms than the selenoprotein storage forms of Se. Martin (1973) provides a brief overview of the toxicity symptoms and how Se poisoning in livestock grazing Se accumulator plants may have shaped history.

Until recently Se has been viewed as a toxic element, and its value as a nutrient has only become evident over the past 57 years. The discovery of Se value as a nutrient has shifted the focus from geographic regions with toxic levels of Se to regions with Se deficiencies. Human dietary intakes also range from high to low according to geography and reflect regional disease incidence. For example, in regions of China where the soils are extremely low in Se, human Se-deficient diseases like Keshan (endemic cardiomyopathy) and Keshin-Beck (deforming arthritis) disease were first identified (Reilly, 1996).

In a study conducted by Schrauzer *et al.,* 1977, dietary intake of Se in 27 countries was found to correlate inversely with total-age-adjusted cancer mortality (Figure 2). Closer to home, Clark *et al*., 1991, showed an inverse relationship between high cancer mortality rates to low Se countries.

Selenium deficiency in animals has been linked to muscular dystrophy, exudative diathesis, hepatic necrosis, mulberry heart disease, poor reproduction rates, lowered immunity, mastitis and growth depression. In humans, Se deficiency contributes to the aetiology of the disease process and in some cases; Se deficiency may be an outcome of the condition itself and may exacerbate disease progression (Rayman, 2000). The health effects of reduced Se intake include loss of immuno-competence, increased susceptibility to disease and viral infection, reduced fertility, increased atherosclerosis and cancer incidence.

Figure 2. The relationship of Se intake & breast cancer mortalities. (Schrauzer, G., White, D. and Schneider, C. 1977. Bioorganic Chemistry, vol. 7, p. 36.)



To emphasize the importance of Se as a nutrient, and the necessity of finding ways to increase the Se intake by the general population, this paper will focus on the importance of Se and its impact on the incidence and severity of HIV and Cancer.

Taylor *et al*., 1997, demonstrated the link between the occurrence, virulence, and disease progression of some viral infections to Se deficiency. For example, Se is a critical inhibitor of HIV replication, and plasma Se levels are a strong predictor of HIV progression (Look *et al*., 1997). The decline in plasma Se levels parallels the loss of CD4 T-cells in HIV-1 infections. Baum *et al*., 1997 showed that Se-deficient (Se <85 µg/l) HIV patients are nearly 20 times more likely ($p<0.0001$) to die from HIV-related causes than those patients with adequate Se levels. Low plasma Se levels are a greater risk factor than low helper T-cells by a factor of 16. Furthermore, Sappy *et al*., 1994 demonstrated that glutathione peroxidase activity declines with falling plasma Se levels, resulting in greater oxidative stress on the body. Campa *et al*., 1999 showed that low plasma Se status in HIV-infected children was significantly related to mortality rates (relative risk 5.96; $p=0.02$) and the pace of disease progression. These reports clearly indicate that enhancing the Se status of people infected with HIV can reduce the progression of the disease.

Whanger, 2004 in his review of the role of Se, and its relationship to cancer, referred to a number of epidemiological studies conducted in the USA and in other parts of the world. Strong evidence was presented indicating that low serum Se levels are a pre-diagnostic indicator of cancer risk (thyroid, oral cavity, prostate, esophageal, gastric, colorectal, liver, breast and lung cancers) (Willett *et al.,* 1991).

Table 4. Human trials conducted in different regions of the world in which the impact of supplementing Se was evaluated on different cancers. Adapted from Whanger, 2004.

# People	Location	Se Level	Source	Duration	Result
20,800	QiDong (’97)	30-50 µg/d	NaSe	8 yrs.	46% ↓ liver cancer
	China (’97)	200 µg/d	Se-yeast	2 yrs.	45% ↓ liver cancer
3,698	Linxian (’91)	50 µg/d	Se-yeast	7 yrs.	Modest ↓ Oesophageal
29,584	China (’93)	50 µg/d + Vit. A	Se-yeast	2 yrs.	50% ↓ lung
298	India (’95)	100µg/d + Vit. A, Zn, Riboflavin	Selenate/Se-yeast	1 yr.	95% ↓ oral lesions, 72% ↓ DNA adducts
304	Italy (’98)	200µg/d + Zn, Vit. A, C, E	L-SeMet	5 yr.	49.1% ↓ new adenomatous polyps
1312	USA (’96) Clarke et al	200 µg/d	Se-yeast	4.5 yrs.	64%↓ prostate, 58% ↓ colon, 46% ↓ Lung

A number of mechanisms have been suggested, by which Se-compounds are effective as chemo-preventative agents, in inhibiting tumor cell growth and apoptosis. These include the effect of Se on DNA damage repair, tumor inhibition, carcinogen metabolism and the way Se acts as an anti-angiogenic agent. In addition, the anti-oxidative contribution of the Seleno-enzymes can't be underestimated. Based on these data, Whanger, 2004 suggests that on average there could be a 50% reduction in the incidence of cancer through the increased ingestion of Se by humans. The societal impact of a 50% reduction in the 50,000 colorectal cancer, 41,800 prostate cancer and 43,000 breast cancer deaths per year would make a significant contribution to human health and quality of life.

The recent clearance by the FDA of Se-yeast as an alternative to sodium selenite as a source of Se in animal feeds has provided a unique opportunity to enhance the level of Se in meat, milk and eggs. Particularly since, more than 54% of the Se intake in western diets comes from eggs, meat and dairy products (Table 5.) In 1997 the average Se intake was reported to be 43 µg/d (Yaroshenko *et al*., 2003). This is below the recommended RDI of 55 µg/day for both men and women.

Table 5. Estimated Se intake percentage from different food sources in the UK.

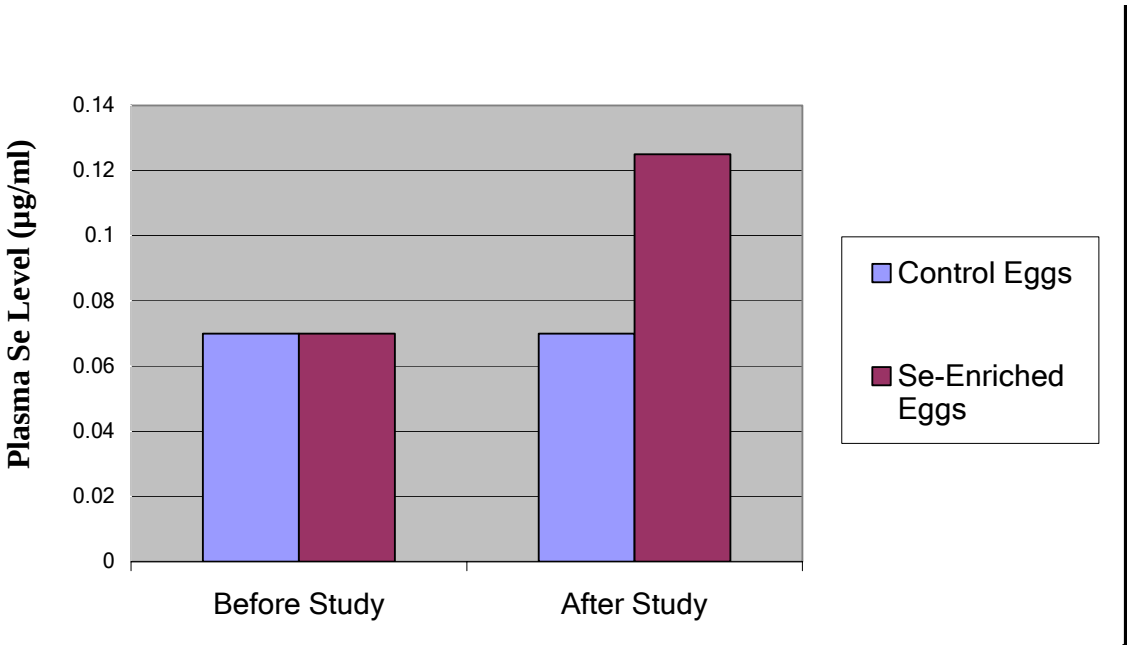
FOOD	% of Total Intake
Meat and meat products	32
Dairy products and eggs	22
Bread and cereals	22
Fish	13
Vegetables	6
Other foods	5

In a number of trials in which Sel-Plex® (Se-yeast from Alltech) replaced the inorganic form of Se in dairy, swine and poultry diets, Se levels in the meat, milk and eggs were significantly increased (Table 6). The increase in Se levels was attributed to the increased bioavailability and bioactivity of Sel-Plex® when compared to sodium selenite.

Table 6. The percent increase in the Se content of meat, milk and eggs when animals were fed Sel-Plex® vs. sodium selenite.

Food	% Increase	Reference
Milk	> 100%	Knowles *et al*., 1999. Ortman and Pehrson, 1997 & 1999, Pehrson and Arnesson, 2003.
Cheese	> 200%	Pehrson, 2004
Meat		
Beef	˜ 75 to 100%	Simek, 2002. Ortman and Pehrson, 1997.
Swine	˜ 75%	Mahan and Kim, 1996. Mahan and Parett, 1996. Mahan *et al*., 1999. Mellor, 2004
Chicken	˜ 100%	Downs et al, 2000. Leng *et al*, 2003
Eggs	>100%	Surai 2002. Paton, N.D. *et al*, 2000

Figure 3. The effect of consumption of Se-enriched eggs on Se level in plasma.



Based on these data (Table 6), an improvement in the Se level of products produced by production animals when supplemented with Sel-Plex®, results in an increase in the Se intake of man. For example, Surai *et al*., 2004 showed that humans consuming eggs from hens supplemented with Sel-Plex® had significantly higher plasma Se levels when compared to the people consuming eggs from hens fed sodium selenite (Figure 3). A shift from inorganic Se to organic Se would contribute to a significant change in the Se status of people consuming these Se enriched products. Pehrson, 2004 suggests that this change would elevate the Se status of North Americans and Europeans from sub-optimal to adequate. The social and health implications of shifting the Se status of the general population cannot be under estimated and should be the responsibility of all who have an impact on the human food chain.

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