Drumming up selenium and sulphur in Africa: improving nutrition with *Moringa oleifera*

By

Graham Lyons[1], Christopher Gondwe[1], Gary Banuelos[2], Maria Clemencia Zambrano Mendoza[2], Anna Haug[3] and Olav Albert Christophersen[3]

[1] *School of Agriculture, Food & Wine, University of Adelaide, Waite Campus, Glen Osmond, SA 5064, Australia*

[2] *USDA-ARS, Water Management Unit, Parlier, CA USA*

[3] *Department of Animal and Aquacultural Sciences, The Norwegian University of Life Sciences, 1432 Aas, Norway*

The relevance of Goldschmidt's concepts for agriculture, nutrition and medicine

Victor Moritz Goldschmidt (1888-1947), the father of modern geochemistry, introduced the term *biophile* for elements found at high absolute or relative concentrations in living organisms. They include nitrogen, sulphur, phosphorus, potassium, selenium, iodine, zinc, boron and bromine.

Goldschmidt was also interested in how different elements are transported and become fractionated relative to each other because of geological processes (*e.g.* volcanism, weathering and erosion), both inside the earth and at its surface. For this he used the term *geochemical cycles*, to describe how the transport processes are often cyclic, forming closed loops. Combining his concept of geochemical cycles with biophile elements is useful for understanding problems of mineral nutrient depletion in soils due to environmental degradation processes such as deforestation and erosion.

The deep roots of trees that grow on highly weathered soil can scavenge nutrient elements from deep soil layers where chemical weathering is not complete. Consequently, biophile elements that have been deposited from rainwater (*e.g.* sulphur, selenium, iodine and bromine) are recycled and prevented from being removed by leaching processes because of their active uptake into plant roots and mycorrhiza. But when the forest is cut down or burnt, the vertical transport of nutrient elements upwards from deep soil layers will cease, and the system becomes more open than before, with enhancement of the rate of nutrient element removal by leaching and topsoil erosion. The only viable solution for the future is to try to replace these open agricultural ecosystems with new ones that in a geochemical sense are similar to the natural forest ecosystems that they have replaced (Christophersen et al 2012).

Medical consequences of biophile element depletion

Selenium and sulphur are strongly biophile elements. Selenium (as selenate) and sulphur (as sulphate) are very leachable under humid climatic conditions, and can also be lost to the atmosphere in the form of SeO_2 and SO2 , respectively, as a consequence of anthropogenic fires, especially on the savannah (Christophersen et al 2012). Sulphur is necessary, similarly to nitrogen, for protein synthesis in plants, with the synthesis of more sulphur-rich protein molecules being even more strongly inhibited than total protein synthesis when the soil is sulphur-deficient. In the more humid parts of Sub-Saharan Africa, there are large areas where the human diet is deficient in sulphur amino acids, which is in part explained by a low protein intake, but which may also be due to sulphur deficiency in the soil (Christophersen et al 2012; Gondwe et al, unpublished). For example, a survey of Zambian maize grain conducted in 2012 revealed a median sulphur concentration of only 1030 mg/kg and nitrogen: sulphur ratios of 13-15 (Gondwe et al, unpublished). Critical deficiency levels for sulphur in maize grain are around 1700 mg/kg and 8-9, respectively (Reuter and Robinson 1997). Likewise, plant-available selenium is very low in many soils in Zambia, Malawi, Rwanda, Burundi and other sub-Saharan African countries, with levels of less than 20 µg /kg selenium in maize grain common (Chilimba et al, 2011; Gondwe et al, unpublished; Hurst et al, 2013; Vanderpas et al, 1990).

Protein deficiency is likely to be associated with deficiencies in vitamins (e.g. vitamin A, vitamin B12) and minerals (e.g. zinc, iron, selenium and iodine). Medical consequences include brain damage in foetuses and children (because of iodine and zinc deficiencies), kwashiorkor, general impairment of immunological defence *i.a.* as a consequence of reduced growth rate in leukocytes, more rapid growth of tubercle bacilli, and more rapid replication and population dispersal of the HIV virus (*i.a.* because glutathione and selenium depletion leads to enhanced activation of oxidatively activated transcription factors such as NF-*kappa*B and Sp1 that enhance the transcription of the HIV provirus gene in infected leukocytes) (Christophersen et al 2012). A marked decline in selenium associated with progression of HIV disease was observed in rural Malawi (van Lettow et al 2004).

Drumming up a village-level solution: the promise of the Drumstick tree (*Moringa oleifera*) for Africa

The “drumstick tree” or “miracle tree” (*Moringa oleifera*) is already well known for its high nutritional value. It grows well in tropical and sub-tropical regions, even on poor soils and produces abundant leaves high in protein (with a favourable amino acid balance), vitamins, minerals and a range of beneficial phytochemicals, including anticancer glucosinolates (Anwar et al 2007; Mbikay 2012). Moringa leaves had the highest beta-carotene level (427 mg/kg) of all leaf samples collected by our group in South Pacific countries and Northern Australia in 2012 (Table 1), and bioconversion of beta-carotene in Moringa leaves to vitamin A is efficient (Ejoh et al 2010). Moringa leaves are low in antinutrients, hence the bioavailability of nutrients and micronutrients in the leaves is high (Anwar et al 2007; Mbikay 2012).

Table 1: Drumstick tree (*Moringa oleifera*) and Aibika (*Abelmoschus manihot*) grown together at Burns Creek, Honiara, Solomon Islands in 2012 and English cabbage (*Brassica sp.*, average of samples bought from Honiara market, Solomon Islands and Nukualofa market, Tonga in 2012) (concentration in mg/kg dry weight, except N: % dry weight). Aibika data: average of 3 varieties (Goebel et al, 2013).

	Cu	*Zn*	*Ca*	*Mg*	*S*	*N %*	*Se*	*Lutein*	*Beta-carotene*	*Alpha-carotene*
Drumstick	**7**	**31**	**20000**	**3700**	**12300**	**5.1**	**2.0**	**773**	**427**	**0**
Aibika	8	44	23600	7100	4500	4.9	0.17	1006	338	31
Cabbage	2	20	5700	1450	5900	2.8	na	5	2	0

Furthermore, Moringa is drought-resistant and its new leaves appear at the end of the dry season when other greens are scarce (Anwar et al, 2007). The use of local resources like Moringa is critical to reduce the dependence of developing countries on imported goods and to improve nutrition in low-income households. Moringa leaves can be produced intensively in a small garden, with just two or three trees being sufficient for a family.

Perhaps the most exciting feature of this plant, in view of the widespread deficiency of plant-available selenium and sulphur in Sub-Saharan Africa (and the relevance of these nutrients to HIV disease), is its exceptional ability to take up and accumulate both of these elements, even when grown on soils where they are poorly available to most other plants. We have found that Moringa leaves commonly accumulate around four times the concentration of sulphur and 12 times the concentration of selenium compared to a range of other plants growing on the same soil (Lyons et al, 2014). Our most recent data are included in Table 2.

Selenium speciation was performed by USDA Parlier, California, using HPLC after water/methanol/protease XIV extraction. Four *Moringa* leaf powder samples were analysed, from Western Samoa, California, Solomon Islands and the Torres Strait Islands, Australia. Results: selenomethionine was found to be the dominant Se form: mean 67% (SD 18%); selenodiglutathione 23 (20); selenocysteine/selenocystine 4 (0.7); unknown 4 (3); selenite 1 (0.6); methylselenocysteine 1 (0.3).

Table 2: Drumstick: an efficient accumulator of selenium and sulphur. Comparison of levels of Se and S in leaves of *Moringa oleifera* and other food crops grown at the same location on the same soil

Location	*Selenium micrograms/kg*		*Sulphur milligrams/kg*	
	Drumstick	Others	Drumstick	Others
Adelaide	785	70	9300	2550
Torres Strait	970	86	8400	2140
Solomon Islands	2000	170	12300	3130
Samoa	540	28	12400	3460
Rwanda	455	40	8500	2070
Tuvalu	510	52	11300	3400
Mean	**877**	**74**	**10367**	**2792**
-fold increase	**11.8**		**3.7**	

The Adelaide samples were grown in a growth chamber at the University of Adelaide. The Torres Strait Islands lie between Australia and Papua New Guinea. Other samples include leaves of cassava, sweetpotato, Ceylon spinach, sandpaper fig, aibika, pawpaw, noni, chaya, chilli and barley.

Programs which encourage villagers in Sub-Saharan Africa (and other parts of the world where the climate is suitable and nutrition problematic) to grow Drumstick trees deserve support.

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