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Abstract

Selenium is an important essential trace micronutrient for living systems. Selenium in trace concentrations are essential for the growth and reproduction of plants, animals and microorganisms; however, this essential trace micronutrient element easily become toxic at concentrations higher than the physiological level. Selenium deficiency is regarded as a major health problem for 0.5–1 billion people worldwide. Oxyanions of selenium, *viz.* selenite and selenate, are bioavailable; selenium in the form of selenate ion (SeO_4^{2-}) is more toxic to most organisms than selenite (SeO_3^{2-}). Contrarily, elemental selenium (Se^0) is insoluble, less toxic compared to other selenium forms. Nano-Se (Se^0) in the range of 100–500 nm has similar bioavailability to other selenium forms into plants, animals, humans and microorganisms. Microbial nano-selenium biosynthesis is an eco-friendly and potentially economically viable ‘green synthesis’ route towards synthesis of red elemental selenium and contributes to the application of selenium for human health. In the soil, applied selenium is rapidly reduced to insoluble forms, and usually the crop nutrient use efficiency was less than 10 % only. Selenium addition in commercial fertilizers may be a larger programme method that is too wasteful, as much of the Se used thereby will be lost for future utilization. Direct addition of selenium compounds to food (process fortification) can be undertaken by the food industry for judicial use of this essential trace micronutrient. Selenium is a non-renewable resource. So it should be a concern of the all stakeholders that the extracted selenium should be judiciously used and to be stockpiled for use as an essential nutrient over generations.

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22.1 Introduction

Selenium is an important essential trace micro-nutrient for living systems. Selenium has special value to industrial element having the unique properties as a semiconductor, but it is also an essential nutrient for humans and animals and may promote plant growth and quality. About 0.5–1 billion people worldwide have major health problem related to selenium deficiency; even larger number may consume less selenium than required for optimal protection against cancer, cardiovascular diseases and severe infectious diseases like HIV disease. Selenium in trace concentrations are essential for the growth and reproduction of plants, animals and microorganisms; however, this element easily become toxic at concentrations higher than the physiological level.

22.2 Status of Selenium

In geosphere the natural elemental selenium that is worth to exploit with economic benefit is not enough; there are no deposits that can be mined for selenium alone. Usually, we can find relatively large amount of elemental selenium in ores, few carbon layers of the soil and the soils of volcanic areas. Selenium is extracted as a by-product of copper mining, and the world reserves of selenium at 93,000 tonnes only cover the estimated contents of economic copper deposits. Substantial resources also exist in association with other metals, coal deposits and uneconomic copper deposits (Table 22.1). The average world production of selenium is estimated at 3000–3500 tonnes per year. In 2010, the production of selenium metal in respect of chief producers was estimated to be 1924 tonnes (Table 22.2).

Selenium occurs in the environment at concentrations of 0.01–2.0 $\mu\text{g} \cdot \text{g}^{-1}$ of surface soil as selenate, Se(VI); selenite, Se(IV); selenide, Se(II); and elemental selenium, Se⁰ (James et al. 1989; Wang and Gao 2001; Stolz et al. 2006). From a global perspective, a selenium cycle occurs as the oxidation states of selenium are changed in response to geochemical (Myneni et al. 1997) and biological processes (Frankenberger and Engberg 1998; Dhanjal and Cameotra 2010). The most common selenium forms in the soil environment are the inorganic selenium salts. These salts leach easily from the soil and become available for the plants (Cooke and Bruland 1987).

22.3 Selenium: An Essential Trace Element

Selenium is as an essential trace element for many biological systems from bacteria to mammals (Shamberger 1983). In plants selenate is much more easily transported than selenite or organic Se (Zayed et al. 1998). The principal form of Se in cereals and other plants are the Se proteins as Se-*Met* are common in Brazil nuts and onion, garlic, species of *Brassica* genus and

Table 22.1 World reserves of Selenium (by principal countries)

Country	Reserves ^a (Tonnes of metal content)
Canada	6000
Chile	20,000
Peru	13,000
Philippines	500
Russia	20,000
USA	10,000
Other countries	23,000
World total (rounded)	93,000

^aReserve based on identified copper deposits only (IBM 2012)

Table 22.2 World production of selenium metal (by principal countries)

Country	2008	2009	2010
Belgium	200	200	200
Canada	191	193	79
China	65	65	65
Finland	65	66	66
Germany	250	230	250
Japan	754	709	754
Kazakhstan	130	120	130
Poland	82	80	80
Russia	170	160	170
Sweden	139	129	130
Average world production (estimated)			3000

Source: IBM (2012)

Table 22.3 Recommended dietary allowances of selenium

Group		Intake ($\mu\text{g Se/day}$)
Infants	(0–0.5 years)	10–40
	(0.5–1 year)	20–60
Children	(1–3 years)	20–80
	(4–6 years)	30–120
Adolescents	(7–10 year)	50–200
	(+11 year)	50–200
Adults	(18 years and above)	50–200

Source: NAS (1980)

mushrooms. Plant species, developmental phase, physiological condition, form, concentration of the Se available and the presence of other substances, especially sulphates, determine the selenium distribution over several plant parts or compartments. *Se-Met* and its S-analogue *Met* cannot be distinguished by animal systems. So both amino acids are incorporated in proteins *via* the same enzymatic pathway (Dumont et al. 2006). The yeast, *Saccharomyces cerevisiae*, has the ability to accumulate and transform high concentration of selenium. Due to its low cost and its ability to synthesize selenoproteins, yeasts can be well utilized for nutritional supplementation.

The breakthrough discovery between supra-nutritional doses of Se and possible cancer protection came from Clark et al. (1996) and has resulted in considerable research to elucidate fully its mode of action and rapidly becoming recognized as one of the more promising cancer chemopreventative agents (Meuillet et al. 2004).

The level at which Se is considered likely to be most effective in chemoprevention exceeds that in daily recommended allowances of 50–70 μg per day (approximately 70 μg in men and 50 μg in women) (Table 22.3). About 100–200 μg Se per day has been shown to inhibit cancer development in humans, with 400 μg Se per day being considered the upper limit (El-Bayoumy et al. 2002); at intake doses above 350 μg per day, it starts to exert toxic (Rayman 2000) or even mutagenic effects (Shamberger 1985). Nevertheless, the behaviour of selenium with particular respect to the health of humans and animals is dichotomous.

22.4 Global Selenium Budget

In selenium budget, the selenium production can be derived by the addition of the world's production of Se from mining and agricultural products and fisheries. A demand estimate of how much

Se is needed annually to cover the Se requirements for the world's human and live-stock population is calculated by multiplying world population with the recommended Se intake using both the recommended amount of about 50 mg Se per day and the daily amount that may be recommended to prevent certain types of cancer, 250 mg Se per day (Table 22.4). This amount of Se if evenly distributed is enough to supply nutritional demand per day for each person and each head of livestock in the world, but it is not enough to supply the higher rate that may protect against cancer. The annual Se production via agriculture and fisheries may be too small to cover the human requirement and livestock needs, and supplementation of Se would be likely to be needed in many areas of the world.

22.5 Selenium Toxicity

Many elements in trace concentrations are essential for the life; however, these elements easily become toxic at concentrations higher than the physiological level. Nevertheless, the behaviour of selenium with particular respect to the health of humans and animals is dichotomous. The toxicity of selenium is related to its chemical form. Both oxyanions selenite and selenate are soluble and bioavailable; selenium in the form of Se IV, selenate ion (SeO_4^{2-}), is more toxic to most organisms than Se VI, selenite (SeO_3^{2-}). Selenates have better soluble but worse absorption properties than selenites. Contrarily, elemental selenium (Se^0) is insoluble and cannot be absorbed by the biological systems (Barceloux 1999), but elemental selenium is

Table 22.4 Estimated annual selenium budget – Se production, demand and scarcity

Particulars	Se production (tonnes)	Se consumption (tonnes)	Se scarcity (tonnes)
<i>Se production</i>			
Mining industries (IBM 2012)	3500		
Se produced from agriculture and fisheries (Haug et al. 2007)	400		
Total Se production	3900		
<i>Se demand</i>			
Human requirement, prevention of Se deficiency (0.05 mg/day/person for 7.0 billion people) (Combs 2001)		130	
If human requirement is higher for prevention of several diseases, 0.25 mg/day/person for 0.7 billion people (one tenth of population) (Combs 2001)		65	
#Domestic animal requirement (for 3.42×10^9 heads @0.1 mg/day) (FAO 2006)		125	
#Fertilizing one third of arable land of 1.40×10^8 ha @20 g Se/ha/year (FAO 2006)		935	
#Fertilizing one third of pasture land of 3.43×10^8 ha @20 g Se/ha/year (FAO 2006)		2290	
<i>Industrial demand* (IBM 2012)</i>			
Metallurgy (30 % of Se produced)		900	
Glass (30 % of Se produced)		900	
Chemical and pigments (10 % of Se produced)		300	
Electronics (10 % of Se produced)		300	
Other industries (10 % of Se produced)		300	
Total Se consumption		6245	
Net Se demand scarcity			-2345

less toxic compared to other selenium forms, and the inorganic forms of Se are accepted to be more acutely toxic than organic forms. However, a number of human studies show that up to 800 mg Se/day administered as Se yeast gave no symptoms of toxicity (Rayman 2004), and about 400 mg Se/day is considered a safe upper limit (Whanger 2004). Presently, researchers proved that elemental nano-Se has similar bioavailability to other selenium forms. Nano-size, in the range of 100–500 nm, also helps the better absorption of selenium into plants, animals, humans and microorganisms.

22.6 Soil Selenium Bioavailability for Crop Uptake

Soil Se deficiency is the most common cause of severe Se deficiency in poor countries, such as in parts of sub-Saharan Africa. Low Se concentration in the soil and poor availability of soil Se for uptake into the plant roots (or a combination of both factors) lead the agricultural crops as Se deficient. Poor uptake seems often to be the principal cause of Se deficiency in plants grown on cultivated lands in industrial countries (where there are large regions with medium to high soil Se concentrations). The low bioavailability of soil Se is likely to become even more prevalent in the future, as a consequence of population and economic growth.

22.7 Factors Influencing Se Bioavailability

22.7.1 Forms of Selenium

The most common selenium forms in the soil environment are the inorganic selenium salts as selenate, selenite, selenide and elemental selenium. Selenate is less strongly adsorbed to minerals in the soil and more readily taken up by plants than selenite. Selenate ion (SeO_4^{2-}) is thermodynamically stable form of selenium and is in the alkaline environment. Selenates have better soluble but worse absorption properties

than selenites. Selenite (SeO_3^{2-}) occurs in neutral pH environment, and it is less soluble compared to selenate. Selenite can be reduced to elemental selenium (Se^0) by chemical or biological ways. Selenides (Se^{2-}) and the selenium-enriched sulphides occur in reductive or acidic environment, have weak soluble and oxidating properties and have limited bioavailability to plants and animals. Many factors such as dry climate, low organic matter concentration in the soil, high temperature, high pH and no water logging may give a high ratio between selenate and selenite in the soil. However, in the Nordic countries with high concentrations of organic matter, the selenite is the dominant form of inorganic Se in soils (because of low soil temperatures causing much slower degradation of soil organic matter than in tropical countries) and most likely also in waterlogged soils (during rice cultivation).

22.7.2 Selenium Fortification in Commercial Fertilizers

Fortification of commercial fertilizers used in the food production chain was chosen to ensure an increased Se intake for the whole population in Finland. The Finnish supplementation programme to add sodium selenate to multinutrient (NPK) fertilizers for all the field and horticultural crops at rates of 6 mg/kg fertilizer for grasses and 16 mg/kg fertilizer for cereal and horticultural crops (Aro et al. 1995; Aspila 2005) has provided experience with this approach to increase Se concentration in the diet, and it has been shown to be an effective and safe approach to raise Se levels in a human population.

In acid soil conditions, Se from sodium selenate was more readily taken up by the plants than Se from sodium selenite. Selenium supplementation to plants may also enhance the production and quality of edible plant products, by increasing antioxidant activity in tea leaves (Xu et al. 2003) and in rice (Xu and Hu 2004), alter glucosinolate and sulphoraphane content (Robbins et al. 2005) as well as increase plant

growth and fertility (Graham et al. 2005). Therefore, Se fertilization may not only be beneficial for nutritive value in the food chain but also for crop quality and, under certain circumstances, yield.

22.7.3 Agronomic Selenium Use Efficiency by Fertilization

In the soil, Se is rapidly reduced to insoluble forms; usually less than 10 % of the applied Se was taken up by the crop. The Se not taken up by plants readily after application was apparently unavailable for crops growing later in the season or the next year (Yli-Halla 2005), and better recovery of Se applied in fertilizers to grain (18 %) was reported by Lyons et al. (2004). Se fertilization to spring season crops at when the crop is beginning to grow rapidly recorded higher efficiency (Curtin et al. 2006).

The foliar application of Se either as sodium selenate or sodium selenite has shown to be several times more efficient than application in fertilizers (Aspila 2005) but riskier as Se uptake by the crop depends on spraying conditions Curtin et al. (2006). The sodium selenate which is commonly used in foliar application is highly toxic. Health and safety precautions must therefore be taken during its on-farm use. However, Lyons et al. (2004) found foliar application to be less efficient than application to soil at planting (at application rates of 40 and 120 g Se/ha) in Australian trials.

Seed can be treated by applying sodium selenate directly on the seed surface (Gissel-Nielsen 1998). However, it has not been shown to give efficient recovery of Se (Curtin et al. 2006; Gissel-Nielsen 1998).

22.7.4 Selenium Interaction with Other Fertilizers

In soil environment that phosphorus renders much of the Se unavailable for uptake by plants (Hopper and Parker 1999; Dhillon and Dhillon 2000; Liu et al. 2004) may be due to

co-precipitation of selenite ions with phosphate. When new phosphate fertilizers are added to the soil and new precipitation of phosphate minerals takes place, Se remains fixed in the precipitate and unavailable for uptake. Conversely, phosphate may also lead to desorption of selenite ions bound to minerals in the soil, as phosphate is bound more strongly to trivalent iron and aluminium than is selenite (Liu et al. 2004; Nakamaru et al. 2006).

In the prairie lands of USA and Canada where the soil has been so fertile, that application of large amounts of phosphate fertilizers has been unnecessary. Cereals grown on these lands have enriched with Se at high concentrations that can be explained by a combination of high natural Se concentration in the soil and excellent bioavailability of soil Se for uptake by the plant roots, due to lack of commercial P fertilizer application.

Sulphate fertilization further reduced the selenium concentrations in plants as a result of competition between sulphate and selenate for transporters in plant roots (Lyons et al. 2004). Selenium and sulphur (S) compete with each other in the biochemical pathways, leading to the synthesis of selenomethionine (*Se-Met*) and methionine in plant cells. So the concentration of *Se-Met* in plant seeds depends strongly on the ratio of Se uptake to S uptake in the roots.

The process that was used for the removal of arsenic from superphosphate fertilizers took away Se as well, and the colour of the fertilizer changed from pink (because of finely disseminated elemental Se) to white or grey that leads declined selenium status in plants and livestock in New Zealand.

22.7.5 Microbe-Selenium Plant Interactions

Plant-microbe interactions in Se hyper accumulators can range from pathogenic to symbiotic (Rogerson 1957; Wangeline and Reeves 2007), and such interactions appear to be strongly influenced by the distribution and

accumulation of Se across the plant tissues (de Souza et al. 1999; Di Gregorio et al. 2006).

Microbes assimilate, accumulate and detoxify selenium through elemental reduction or volatilization (Hassoun et al. 1995; Chasteen and Bentley 2003; Vallini et al. 2005; Stolz et al. 2006) and that levels of tolerance varied among them and by above processes. Microbes assimilate selenium into seleno-enzymes using the similar pathways for sulphur (Bradfield et al. 1970; Cypionka 1987; Stolz et al. 2006; Lechenne et al. 2007). When exposed to 30 mg/kg NaSeO₄ or NaSeO₃, selenium-sensitive fungi can initially reduce most of the selenium and accumulate 90 % of it as organic Se and selenite. Selenium-tolerant fungi will accumulate between 60 and 70 % of the Se as organic selenium, 15–30 % as elemental selenium and 5–10 % as selenite. Selenium reduction and greater volatilization are among the many mechanisms that selenium-tolerant fungi use differently compared to selenium-sensitive fungi.

Based on their metabolic capacities, microbes may affect plant uptake of selenium by changing the concentration and chemical speciation of Se in the soil. For instance, microbial-mediated Se volatilization and break down or accumulation of organic Se by microbes in the rhizosphere can reduce plant Se availability. Rhizosphere microbes may also induce plant root hair formation and enhance plant sulphate/selenate uptake as a result of increased serine/O-acetylserine concentrations in the rhizosphere (de Souza et al. 1998).

22.7.6 Mycorrhiza and Selenium Bioavailability

An important unresolved question concerns the mechanism of selenite uptake into mycorrhiza and plant roots, whether there is a specific membrane transporter for the selenite ions or if selenite and some other more abundant anion, such as phosphate, may share a common membrane transporter. If the latter should be the case, it must be expected that phosphate will function as a competitive inhibitor of selenite ion

transport into the plant roots (Munier-Lamy et al. 2007). The same question could also be raised regarding the mechanism of active transport of selenite ions into other types of organism, e.g. into various groups of planktonic algae or into mammalian cells such as erythrocytes.

22.8 Nano-selenium Biosynthesis and Its Bioavailability

Selenium element is well known for its photoelectric, semiconductor, free radical scavenging, anti-oxidative and anticancer properties (Zhang et al. 2004). Among the various forms of selenium, the red amorphous selenium have the biological activity similar to that of sodium selenite (Wang et al. 2007; Zhang et al. 2007), and it was considered the most potent chemical form to the artificial selenium enrichment. It was generally considered that elemental selenium is to be biologically inert, but researchers proved that nano-Se has similar bioavailability to other selenium forms. Therefore, the red amorphous selenium has attracted much attention (Mishra et al. 2011; Hunter and Kuykendall 2007; Dwivedi et al. 2013; Hunter and Manter 2009). The production of nano-selenium can be achieved through chemical and biological methods. Chemical detoxification of metals is proven to be very expensive and often results in secondary effects on the environment.

In natural environments, the bacteria, fungi, yeasts and plants are known to be capable of converting selenate and selenite to Se⁰ (Oremland et al. 1989; Hunter and Manter 2009). Among these, bacteria are preferred for biosynthesis due to their extracellular particle production ability, short generation time, ease of culturing, downstream processing and manipulation (Ramanathan et al. 2013). Microorganisms have been shown to be particularly resistant to SeO₃²⁺ (Kessi et al. 1999; Kessi 2006). This resistance is attributed to the capacity of the organisms to reduce Se oxyanions to their elemental ground state. In recent years, several different bacteria have been reported for the biological synthesis of Se⁰ (Fig. 22.1), such

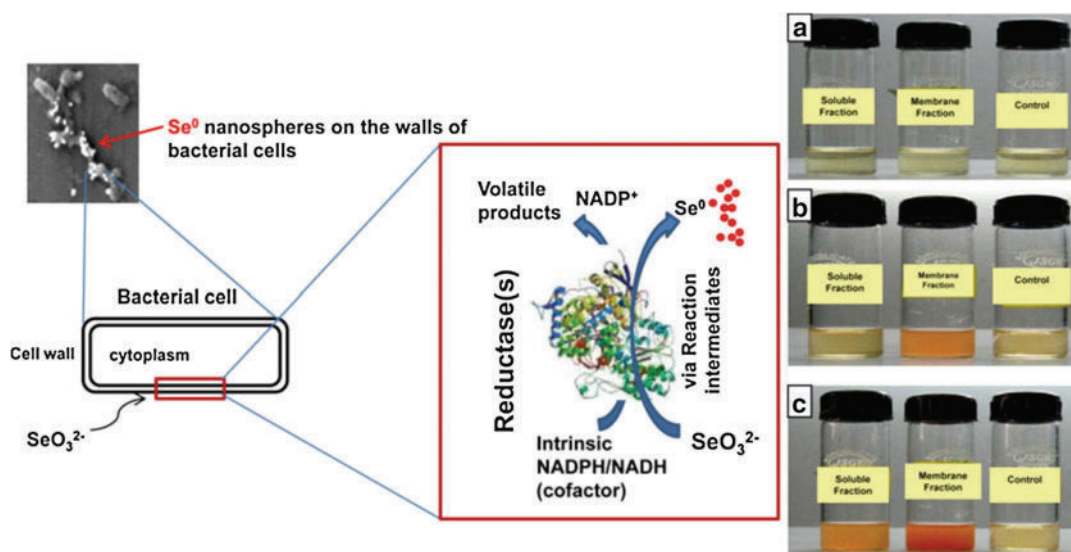


Fig. 22.1 Schematic representation biogenesis of selenium (Se^0) nanospheres. (a) Selenite reduction at 0 h. (b) Formation of red elemental selenium in membrane

fraction after 3–4 h of incubation. (c) Prolonged incubation of 12 h resulted in the formation of red elemental selenium in soluble fraction (Dhanjal and Cameotra 2010)

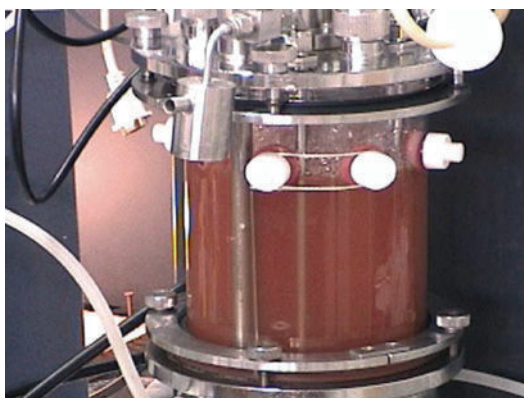


Fig. 22.2 Bioreactor after 72 h anaerobic growth of *P. fluorescens* K27 at 30 °C following 1.0 mM sodium selenite amendment. Brick-red coloration is due to elemental selenium in the well-mixed solution (Hapuarachchi et al. 2004)

as *Thauera selenatis* (Bledsoe et al. 1999), *Rhizobium selenitireducens* strain B1 (Hunter and Manter 2009; Euzéby 2008; Hunter et al. 2007), *Escherichia coli* (Avazeri et al. 1997), *Clostridium pasteurianum* (Yanke et al. 1995), *Pseudomonas fluorescens* K27 (Hapuarachchi et al. 2004) (Fig. 22.2), *Bacillus cereus* (Dhanjal

and Cameotra 2010) and *Bacillus selenitireducens* (Afkar et al. 2003). Debieux et al. (2011) reported that the production of volatile selenium compounds occurred during the stationary phases (Fig. 22.3). It means that the reduction is independent of strain growth. Moreover, this result suggests that reduction reaction is controlled by the stationary phase of the cultures.

Nano-Se and selenite have large difference in acute toxicity (Zhang et al. 2004). Nano-Se was less toxic than selenite in terms of suppressing growth, liver toxicity and antioxidant status but has similar bioavailability. Wang et al. (2007) concluded that based on animal tests, nano-selenium (nano-Se) is a very effective antioxidant, without high toxicity properties which is typical for other selenium forms. Nano-selenium has at least the same effect on activating glutathione peroxidase and thioredoxin reductase enzymes as selenoproteins have, but according to the LD50, this form is less toxic; it does not trigger acute liver injury and short-term toxications. Furthermore, nano-selenium accumulates less in the treated mice and activates glutathione S-transferase more effectively than

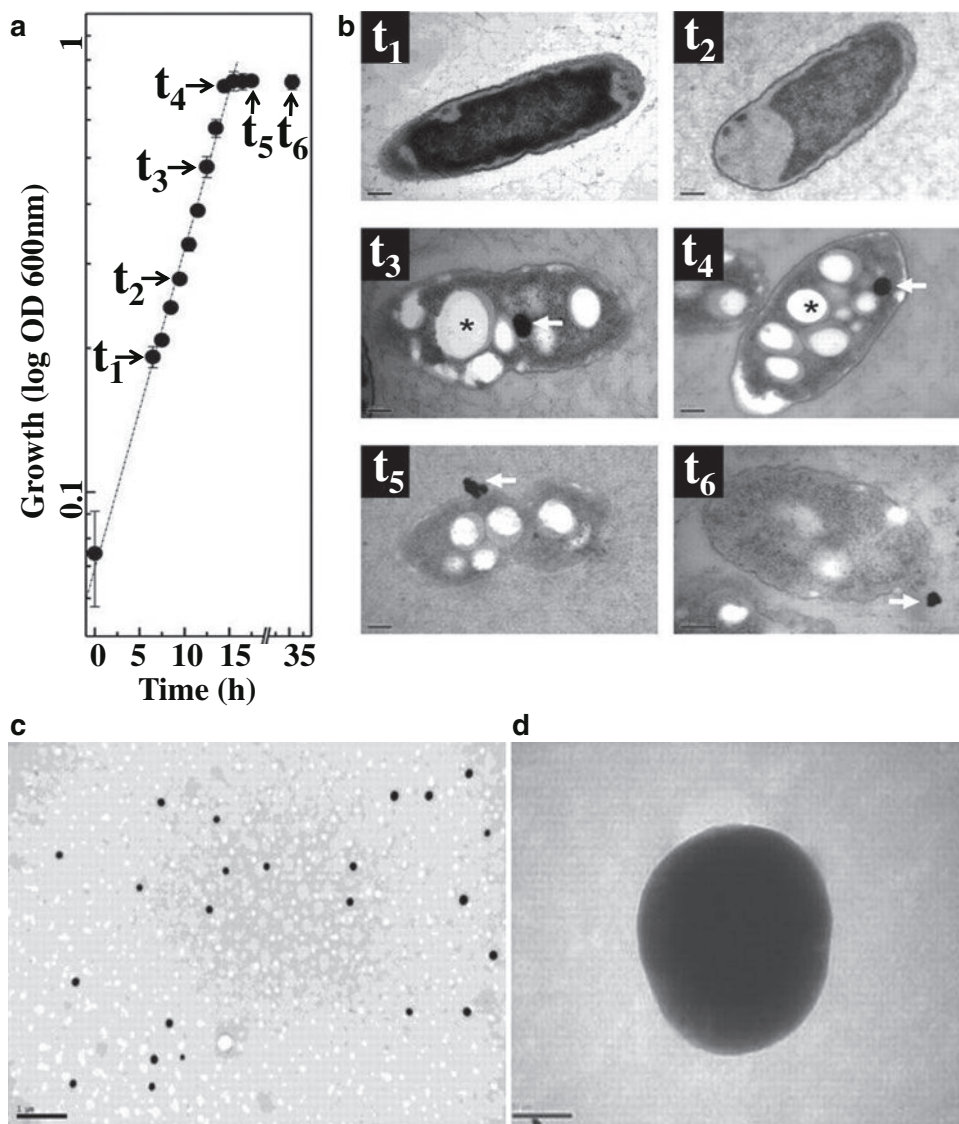


Fig. 22.3 Physiological analysis of Se-nanosphere production. (a) Growth curve of *T. selenatis* grown on acetate using selenate (10 mM) as the sole electron acceptor (Error bars are SEM: $n + 10$ cultures). Time points $t_1 - t_6$ indicate the samples used for EM analysis. (b) Transmission electron micrographs of time points from (a). Micrographs t_1 and t_2 show mid-exponential phase,

t_3 and t_4 show late exponential phase, and t_5 and t_6 show stationary phase. Scale bar, 200 nm. Selenium deposits are indicated by an asterisk. (c, d) Transmission electron micrographs of purified Se nanospheres. (c) Scale bar, 500 nm. (d) Scale bar 50 nm (Debieux et al. 2011, Source: <http://www.pnas.org/cgi/doi/10.1073/pnas.1105959108>. Accessed 12 Jan 2015)

selenoproteins, independently from the level of toxication.

Certain lactic acid bacteria and other probiotic bacteria species are able to reduce the selenite in toxic concentration into nano-sized elemental selenium spheres (Patented) (Prokisch et al. 2010), and these bacterial strains produce

uniform-sized, high-purity selenium spheres in different size ranges from 50 to 500 nm (Figs. 22.4 and 22.5) (Eszenyi et al. 2011). Advantageously, when used as a food additive, the nanospheres produced according to the processes of the technology need not be fully purified or purified at all because the medium

Fig. 22.4 Electron microscopic view of 250 nm-sized selenium nanosphere

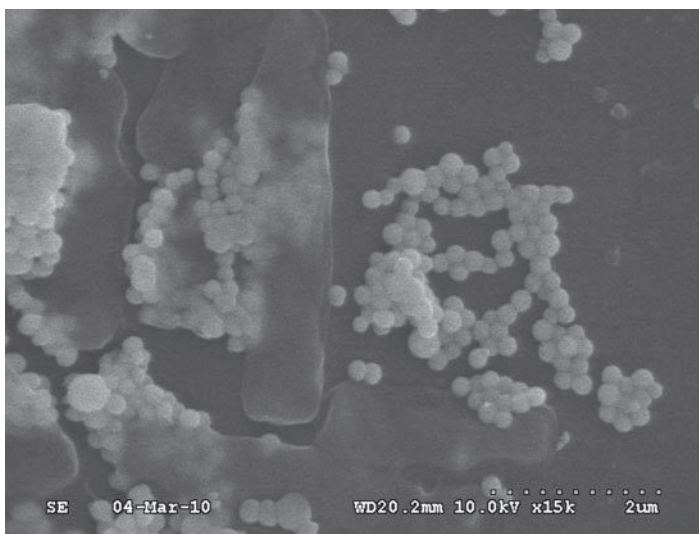


Fig. 22.5 Lactomicrosel^R nano-selenium-rich yoghurt (dried and powdered)

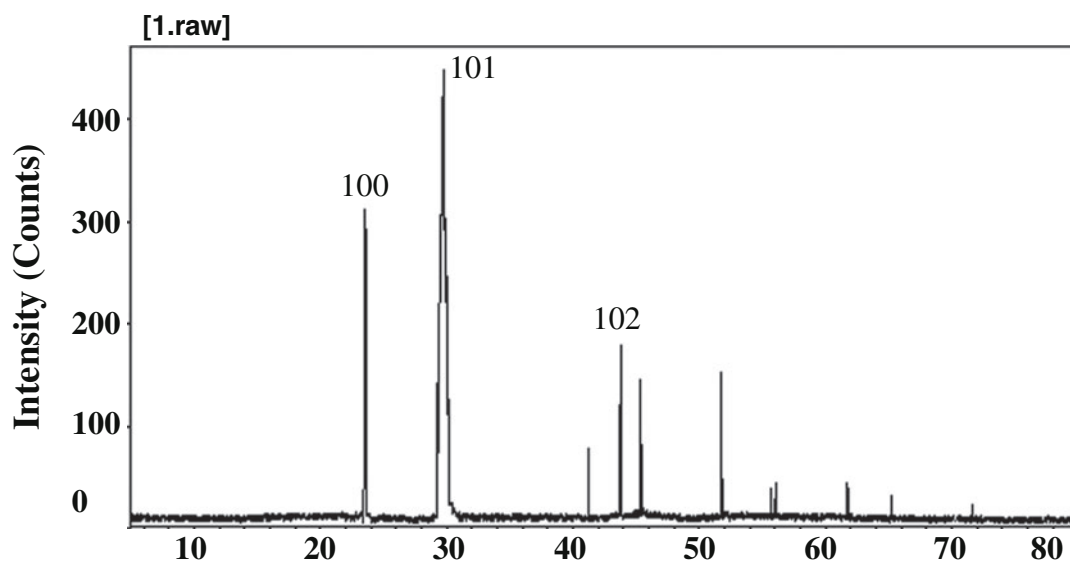


Fig. 22.6 XRD pattern of selenium-containing particles formed by *Rhodopseudomonas palustris* strain N. The characteristic strong diffraction peak located at 29.777u is ascribed to the (101) facets of the face-centred cubic elemental Se⁰ structure (Li et al. 2014) (Source: DOI:10.1371/journal.pone.0095955.g005)

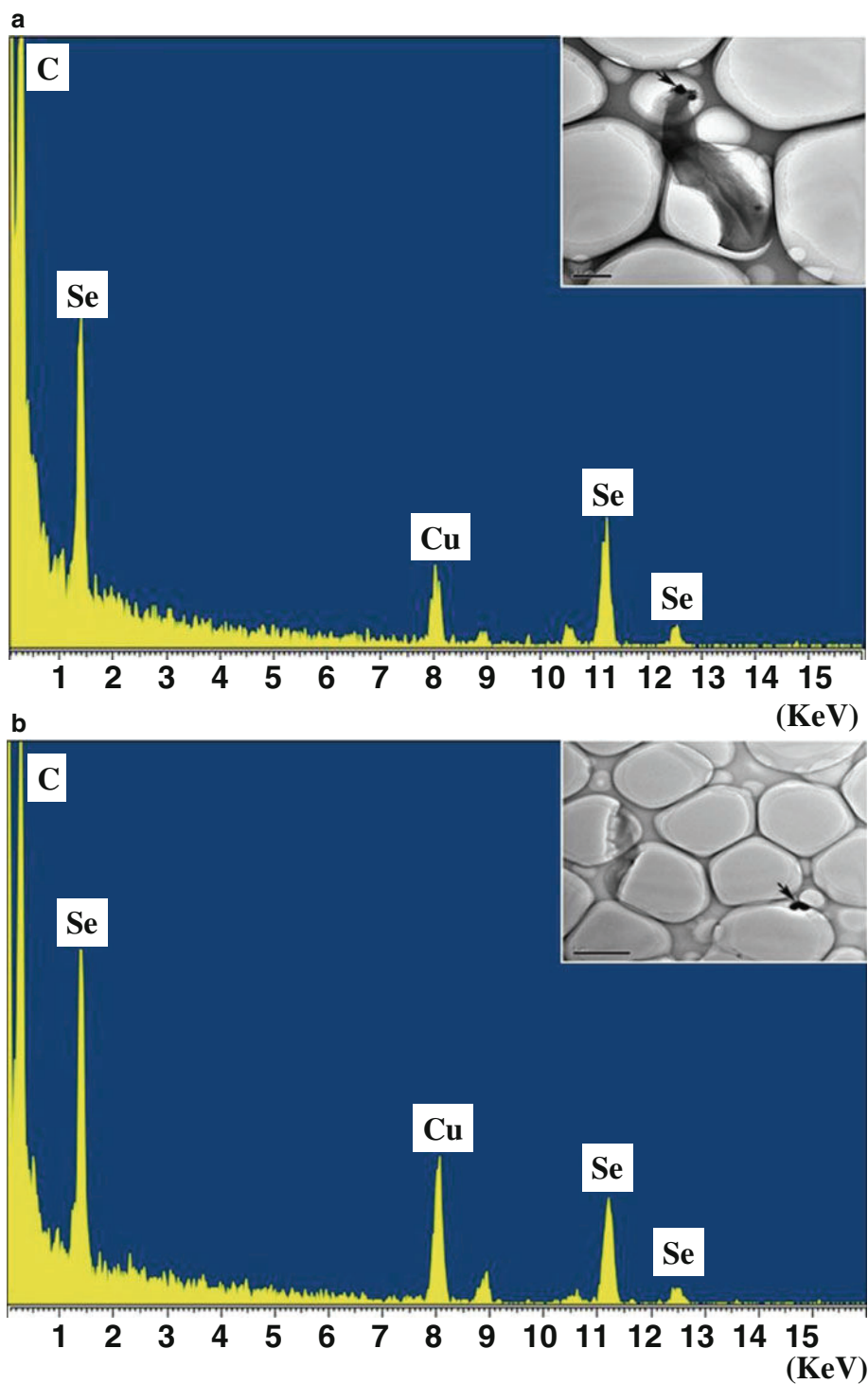


Fig. 22.7 (a) Particles on the cell membrane. Energy levels (in kiloelectron volts) are indicated on the x axis. The emission lines for selenium are at 1.37 keV (peak SeLa), 11.22 keV (peak SeKa) and 12.49 keV (peak SeKb). (b) Particles in the culture medium. Energy levels (in kiloelectron volts) are indicated on the x axis. The emission lines for selenium are at 1.37 keV (peak SeLa), 11.22 keV (peak SeKa) and 12.49 keV (peak SeKb) (Li et al. 2014) (Source: DOI:10.1371/journal.pone.0095955.g004)

and the bacteria applied in the production process may be fully suitable for human or animal consumption.

The photosynthetic bacteria, *Rhodospseudomonas palustris* strain N, has more digestible bacterial cell wall and are rich in protein, carotenoids, biological cofactors and vitamins (Kobayashi and Kurata 1978). They were already shown to be suitable amendments to health foods for humans and animals. Therefore, the reduction of SeO_3^{2+} to Se^0 by *Rhodospseudomonas palustris* strain N (Li et al. 2014) (Figs. 22.6 and 22.7) provides a potential application to artificially enrich food with selenium for human health. It will provide an eco-friendly and potentially economically viable 'green' synthesis route towards synthesis of red elemental selenium and contribute to the application of selenium for human health (Li et al. 2014).

22.9 Conclusion

Selenium is an important essential trace micro-nutrient for living systems. There are no deposits that can be mined for selenium alone, only as by-product of copper mining as resource. Direct addition of selenium compounds to food (process fortification) is to be undertaken by the food industry, which is fruitful rather than the wasteful agronomic selenium fortification. New ways to bio-fortify food products are needed, and it is generally observed that there is less wastage if selenium is added late in the production chain rather than early. Bacterial nano-selenium will provide an eco-friendly and potentially economically viable 'green' synthesis route towards synthesis of red elemental selenium with enhanced bioavailability. Selenium is a non-renewable resource. So it should be the concern of all stakeholders that the extracted selenium should be judiciously used and to be stockpiled for use as an essential nutrient by future generations.

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