Selenium biofortification and human health

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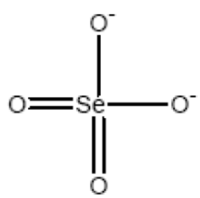
Selenium

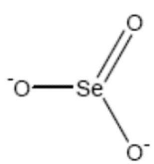
- discovered in Sweden by Jöns Jacob Berzelius (1817)
- impurity contaminating sulfuric acid (H_2SO_4) – sulphur analogue
- semiconductor – used in electronics
- speciation!

Selenium speciation

In environment and human health:

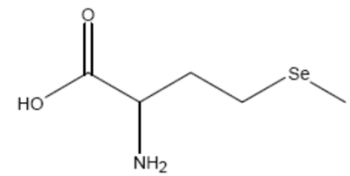


selenaat (+VI)

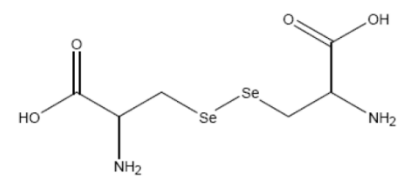


seleniet (+IV)

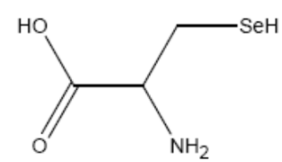
H_2Se selenide (-II)



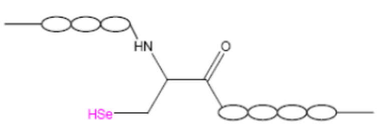
selenocysteïne



selenocystine



selenomethionine

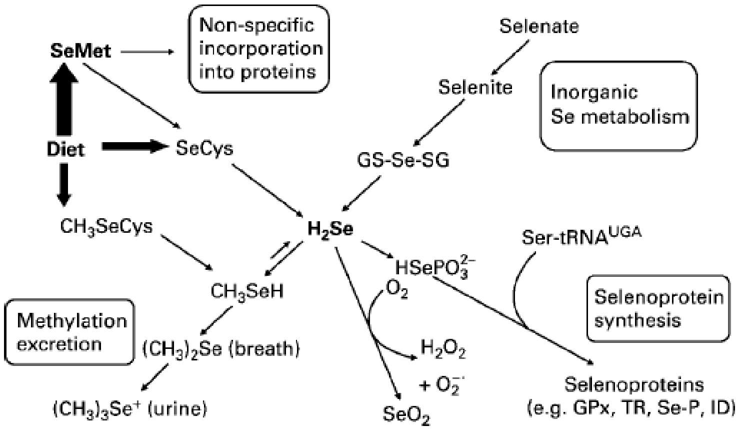


selenoproteïnen

Different fate in environment, availability to crops, humans and animals, accumulation risks, toxicity

Importance of selenium

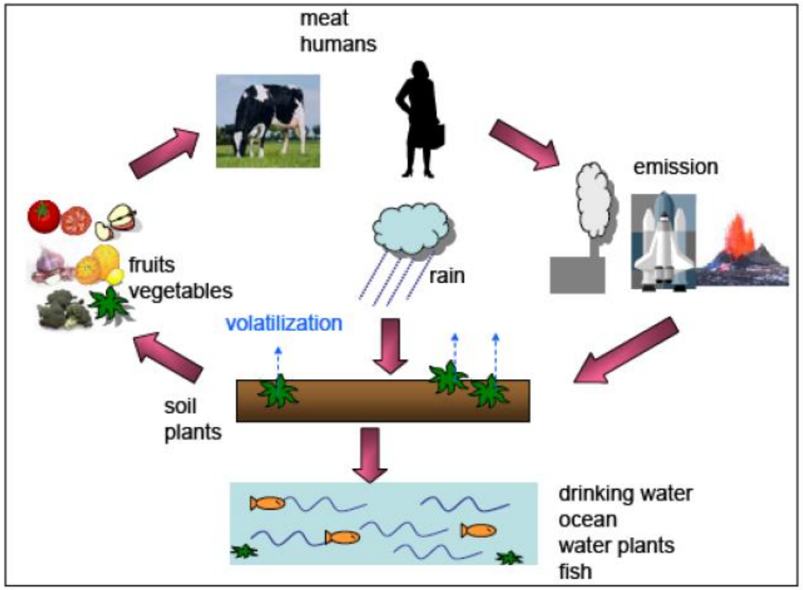
- Selenocysteine incorporated in selenoproteins (>25)
  - glutathione peroxidases (GPx) → antioxidant
  - thyroid hormone deiodinases (DIO) → functioning thyroid gland
- Synergy with vitamin E



Source: Rayman, 2004

Selenium in environment

- Europe: generally low Se contents in soil



Land	Se-concentratie (mg Se/kg DS)
China (Keshan area)	0.17
België	**0.11***
Turkije	0.03
Zweden	0.39
Verenigd Koninkrijk	0.18-29.70
Frankrijk	0.18
Spanje	0.07-0.39
USA	0.11-18.36
Finland	0.15-0.72
Japan	0.70-1.00
China (Enshi provincie)	10-40
Duitsland	6.6

Source: Dumont, 2006; Robberecht et al., 1982

Selenium in food crops

- Decrease due to exhaustion of soil + altered food consumption pattern

	Content (µg Se/g)
Cereals	0,01-0,55
Meat, fish, eggs	0,01-0,36
Milk and dairy products	<0,001-0,17
Fruit and vegetables	0,001-0,022
Se-accumulating crops	>1000

Selenium in food crops

Wheat imports to the UK

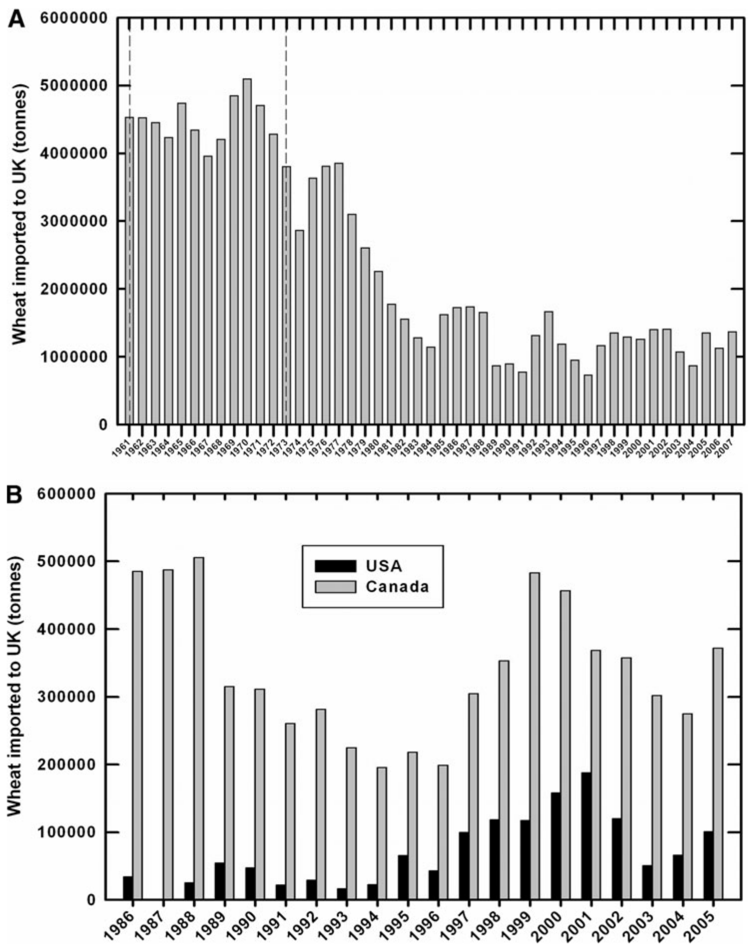
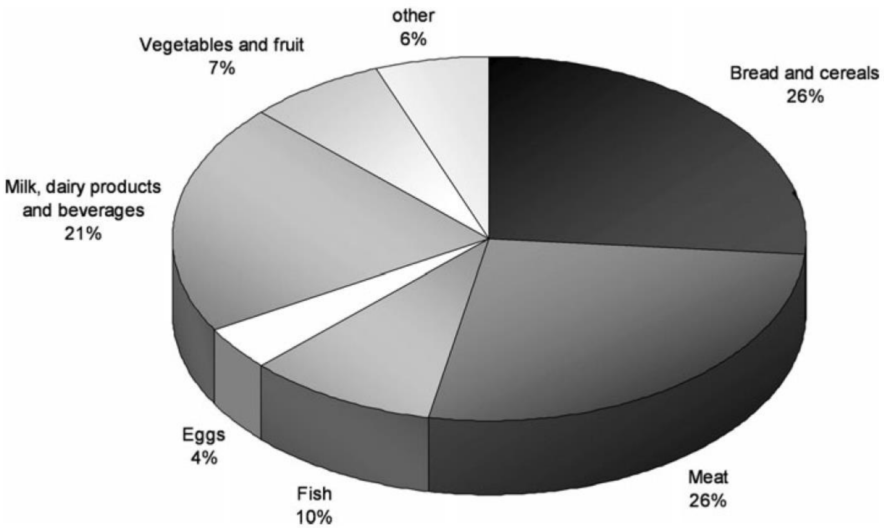


FIG. 5. Wheat imports to UK. (A) Wheat imports to UK from all sources 1961–2007. Wheat imports to UK from all sources 1961–2007 data obtained from reference (120). The introduction of the Chorleywood Bread Process in 1961 is highlighted with a dashed line; this process enabled use of UK and EU wheat in bread making instead of North American wheat. The second dashed line represents the year when the UK became a member of the European Economic Community in 1973. **(B)** Wheat imports to UK from United States and Canada 1986–2005. Wheat imports to UK from United States and Canada 1986–2005 data obtained from reference (120).

Fairweather-Tait et al. (2011). Antioxidants and redox signaling, 14, 1337-1383

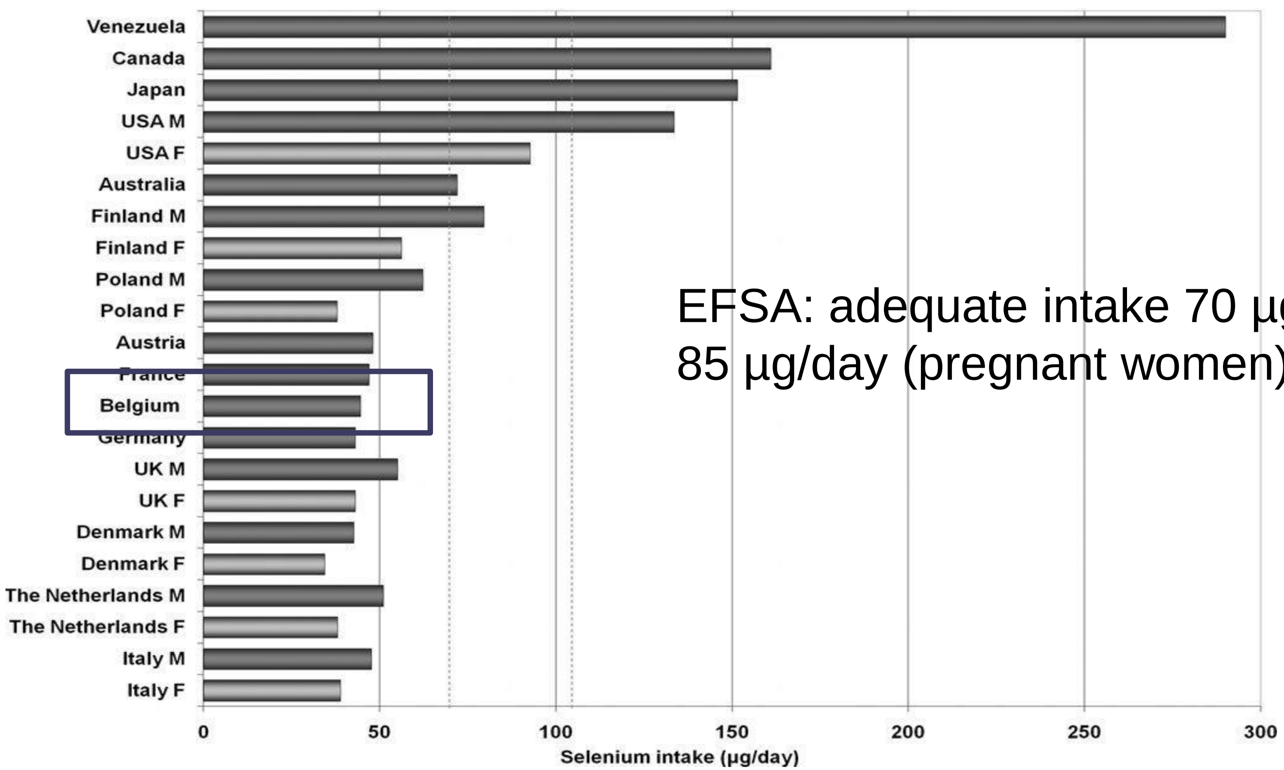
Dietary selenium intake

FIG. 1. Contribution of each food group to total population dietary exposure in the UK. Adapted from data presented in the UK Food Standards Agency document (136).



Fairweather-Tait et al. (2011). Antioxidants and redox signaling, 14, 1337-1383

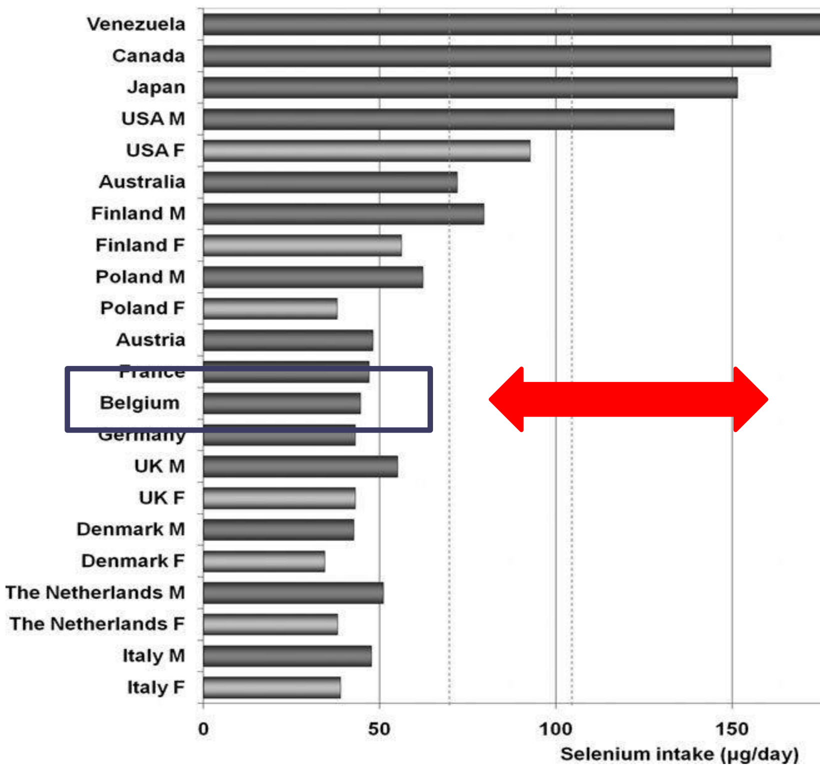
Dietary selenium intake



EFSA: adequate intake 70 µg/day (adults); 85 µg/day (pregnant women)

males (M) and females (F); obtained from Fairweather-Tait et al., 2011

Dietary selenium intake

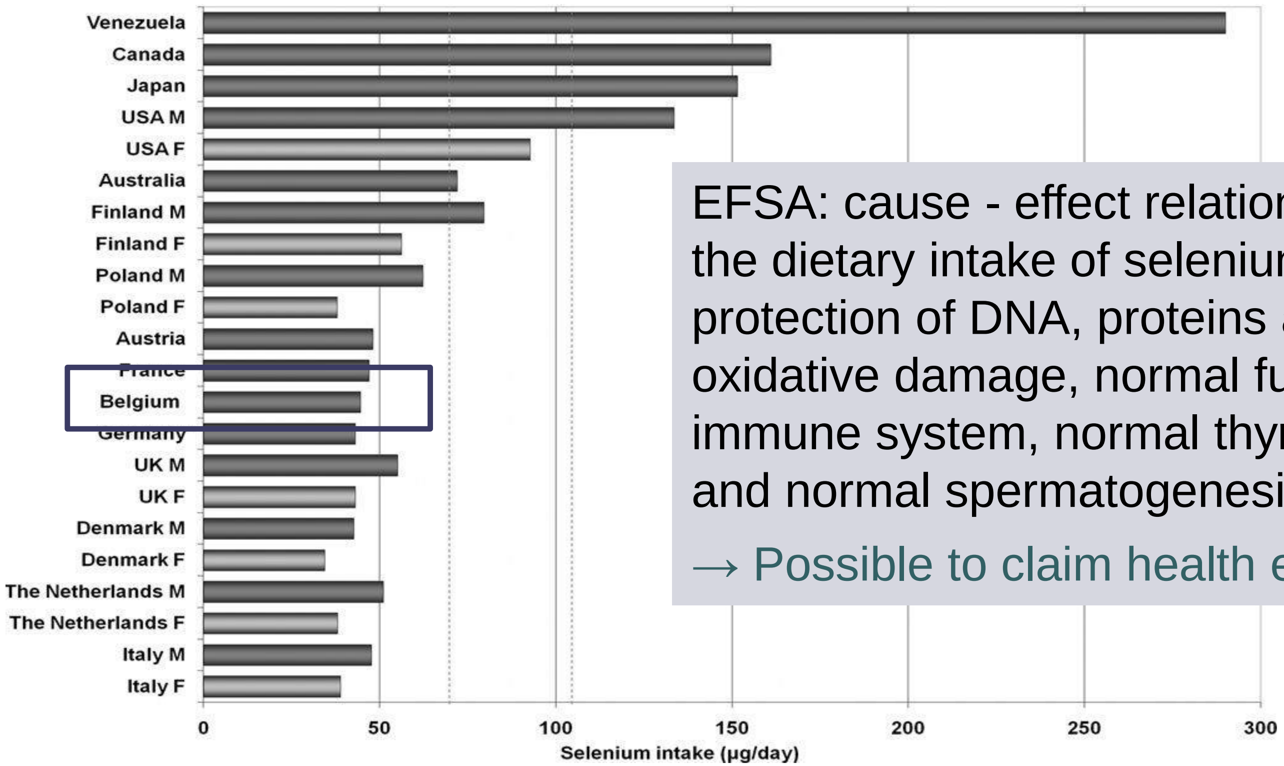


males (M) and females (F); obtained fro[illegible]

FIFA World Ranking

Rank	Team	Total Points	Previous Points	+/- Positions		2016 (100 %) Avg.	2016 (100 %) AVG WGT	2015 (50 %) Avg.	2015 (50 %) AVG WGT	2014 (30 %) Avg.	2014 (30 %) AVG WGT	2013 (20 %) Avg.	2013 (20 %) AVG WGT
1	Argentina	1634 (1634.02)	1621	0		903.24	903.24	662.66	331.33	937.59	281.28	590.90	118.18
2	Brazil	1544 (1544.05)	1410	1	▲	879.22	879.22	584.70	292.35	796.05	238.81	668.33	133.67
3	Germany	1433 (1432.54)	1465	-1	▼	752.68	752.68	478.66	239.33	1090.54	327.16	566.83	113.37
4	Chile	1404 (1403.96)	1273	2	▲	739.73	739.73	763.35	381.68	523.75	157.12	627.18	125.44
5	Belgium	1368 (1367.77)	1382	-1	▼	600.01	600.01	764.94	382.47	849.03	254.71	652.93	130.59
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	▼	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	France	1305 (1305.41)	1271	0		862.90	862.90	290.76	145.38	700.29	210.09	435.22	87.04
8	Portugal	1229 (1229.12)	1231	0		617.85	617.85	635.88	317.94	570.26	171.08	611.29	122.26
9	Uruguay	1187 (1187.31)	1175	0		620.21	620.21	532.30	266.15	585.86	175.76	625.97	125.19
10	Spain	1166 (1165.66)	1168	0		507.92	507.92	783.37	391.69	420.42	126.12	699.69	139.94
11	Switzerland	1129 (1128.75)	1071	3	▲	602.17	602.17	490.21	245.11	523.66	157.10	621.89	124.38
12	Wales	1121 (1120.86)	1113	-1	▼	610.14	610.14	622.99	311.50	433.23	129.97	346.28	69.26
13	England	1114 (1114.45)	1090	-1	▼	568.56	568.56	595.78	297.89	523.32	156.99	455.04	91.01
14	Croatia	1103 (1103.27)	1027	2	▲	632.53	632.53	493.37	246.69	459.98	137.99	430.28	86.06
15	Poland	1089 (1089.36)	1029	0		702.26	702.26	435.41	217.71	436.18	130.85	192.69	38.54

Dietary selenium intake



EFSA: cause - effect relationship between the dietary intake of selenium and protection of DNA, proteins and lipids from oxidative damage, normal function of the immune system, normal thyroid function and normal spermatogenesis

→ Possible to claim health effects!

males (M) and females (F); obtained from Fairweather-Tait et al., 2011

Selenium in Africa

Physiologia Plantarum 151: 208–229. 2014 ISSN 0031-9317

Dietary mineral supplies in Africa

Edward J. M. Joy[a,b,†], E. Louise Ander[b,†], Scott D. Young[a], Colin R. Black[a], Michael J. Watts[b], Allan D. C. Chilimba[c], Benson Chilima[d], Edwin W. P. Siyame[e], Alexander A. Kalimbira[e], Rachel Hurst[f], Susan J. Fairweather-Tait[f], Alexander J. Stein[g], Rosalind S. Gibson[h], Philip J. White[i] and Martin R. Broadley[a,*]

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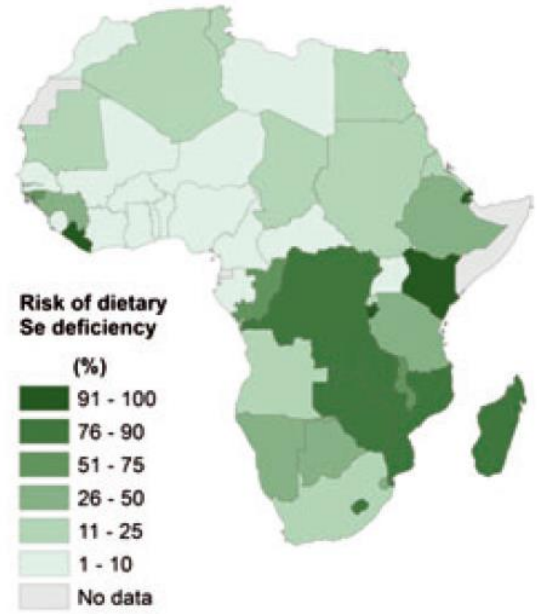
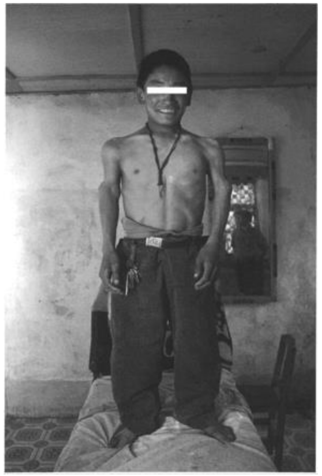


Selenium deficiency



Kashin-Beck

White muscle disease

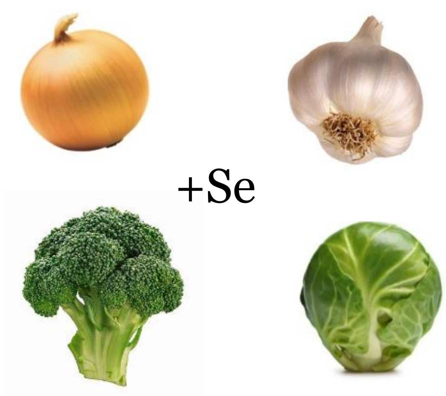
Mastitis

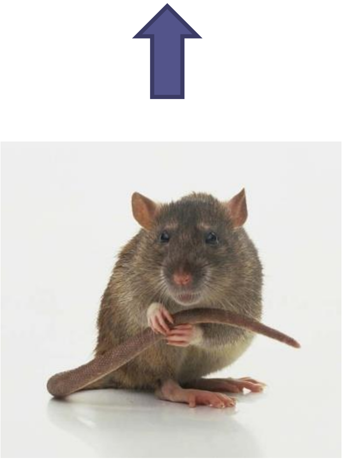
Selenium toxicity: selenosis

Positive impact of supplementation

- Indications
  - Anti-inflammatory, antiviral
  - Cardiac diseases, arthritis, HIV/AIDS
  - Cancer

- Rat trials
  - Allium
  - Brassica





Selenium requirements

Toxic

Cancer protection

Adequate

Deficiency diseases

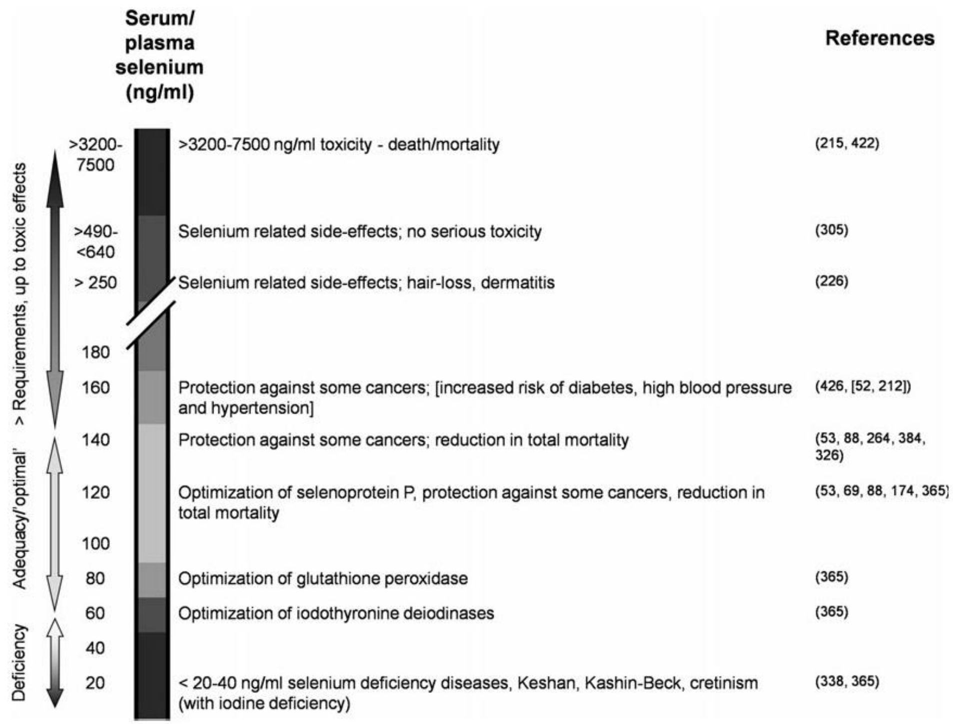


FIG. 14. Range of blood selenium concentrations with possible related health effects from deficiency to toxicity. Various parameters associated with selenium function or health have been assessed in relation to a range of selenium intakes and blood selenium concentrations. The plasma/serum selenium concentration ranges and associated health effects were compiled from published literature (refer to references displayed in the figure) to give some indication of how these parameters are affected by selenium status. Precise relationships between selenium intake/status and health effects remain to be defined.

Fairweather-Tait et al. (2011). Antioxidants and redox signaling, 14, 1337-1383

Cancer protection

Clark's experiment (NPC)

- 1996
- 1300 men
- Se-containing yeast, 200 µg Se/day, mainly selenomethionine
- Significant decrease of cancer incidence

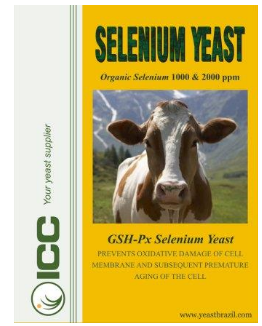
SELECT clinical trial

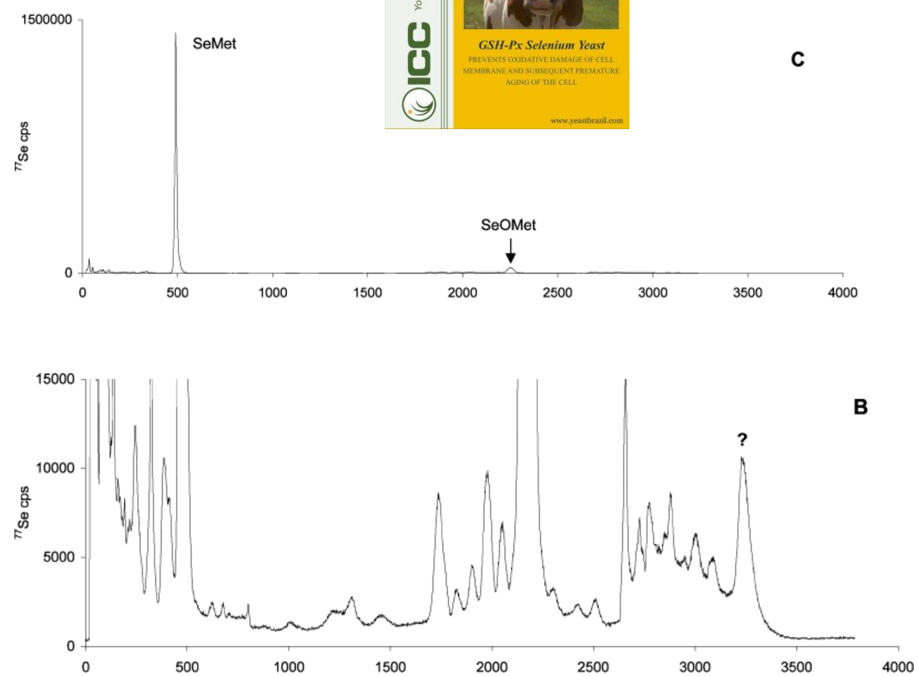
- 2001
- 35000 men
- pure L-selenomethionine, 200 µg Se/day
- No effect (on prostate cancer)

- Participants NPC trial more Se deficient compared to SELECT
- Se yeast does not only contain L-selenomethionine

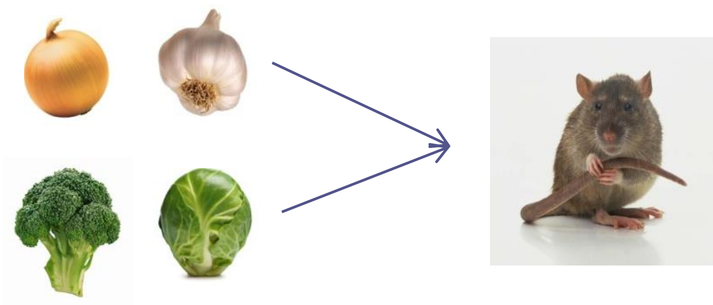
Composition Se yeast

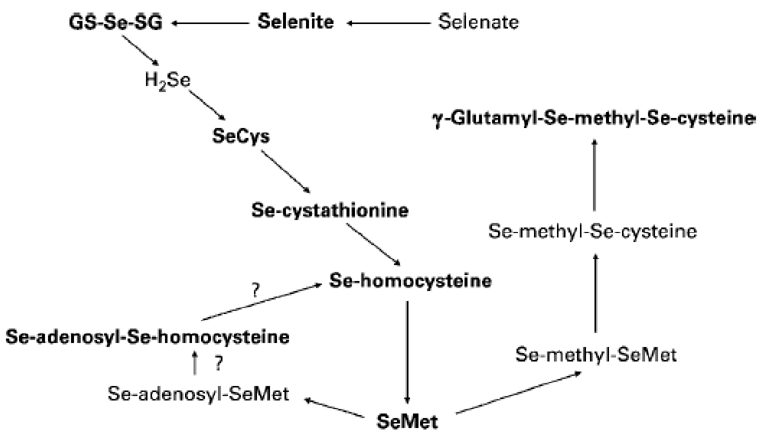
- selenomethionine (70%)
- selenocysteine
- Se-methylselenocysteine
- selenoethionine
- selenoglutathione
- selenodiglutathione
- γ-Glutamyl-Se-methylselenocysteine
- selenite





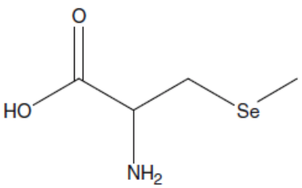
Role of Se speciation



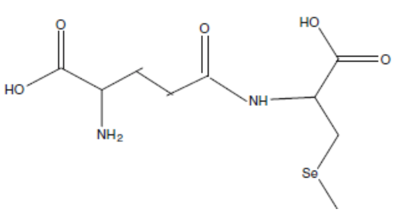


Bron: Rayman, 2004

Se-methylselenocysteine



γ-Glutamyl-Se-methylselenocysteine



anticarcinogenic effects?

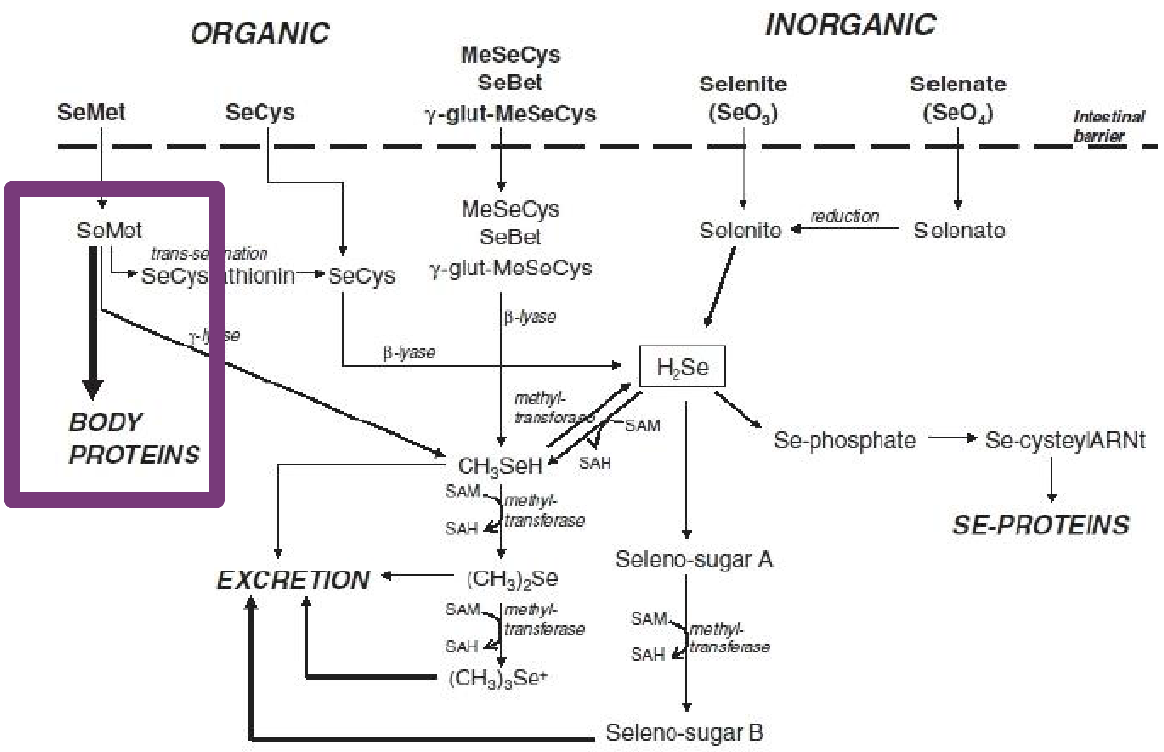


Figure 4. Proposed schematic representation of Se metabolism in humans (adapted fromSuzuki et al., 2006a, Suzuki et al., 2006b, Suzuki et al., 2008). CH_3SeH: methylselenol; $(CH_3)_2Se$: dimethylselenide; $(CH_3)_3Se^+$: trimethylselenonium; γ-glut-methylselenocysteine: gamma glutamyl methylselenocysteine; GSH: glutathione; H_2Se: hydrogen selenide; MeSeCys: methylselenocysteine; SAH: S-adenosylhomocysteine; SAM: S-adenosylmethionine; SeBet: selenobetaine; SeCys: selenocysteine; SeMet: selenomethionine

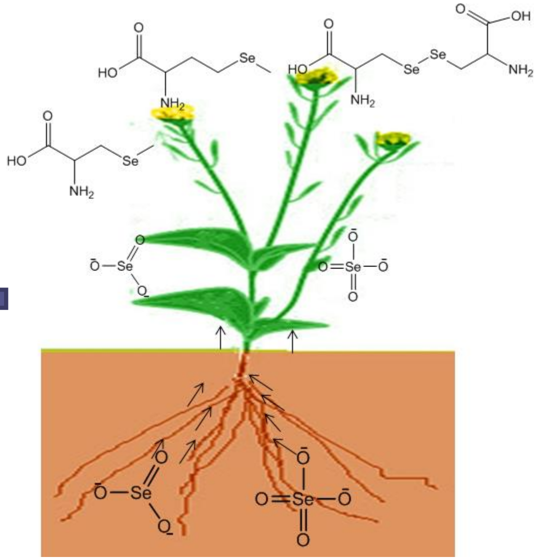
Differences in uptake and metabolism

Organic Se – mainly SeMet - considered to have higher absorption and retention

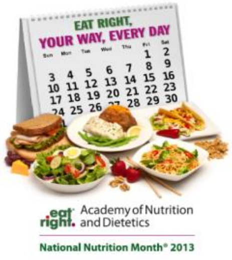
Source: RVS Lavu, PhD thesis, 2013

Strategies to increase Se intake

➢ Biofortification (biofortified food crops)



➢ Food/feed supplements, dietary diversification, addition during food/feed processing



Benefits of biofortification

Organic species!

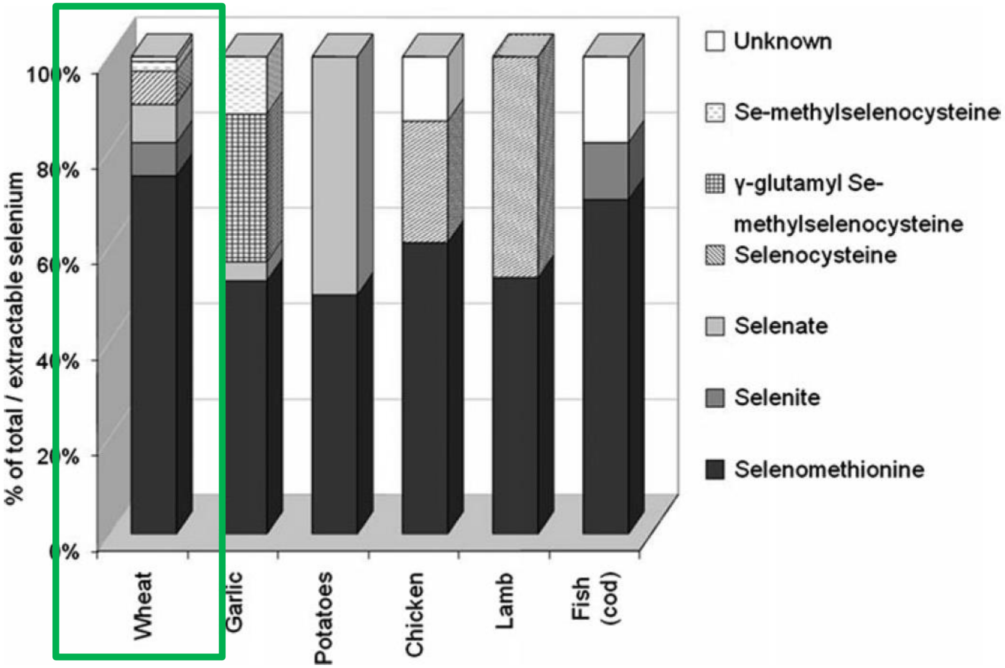


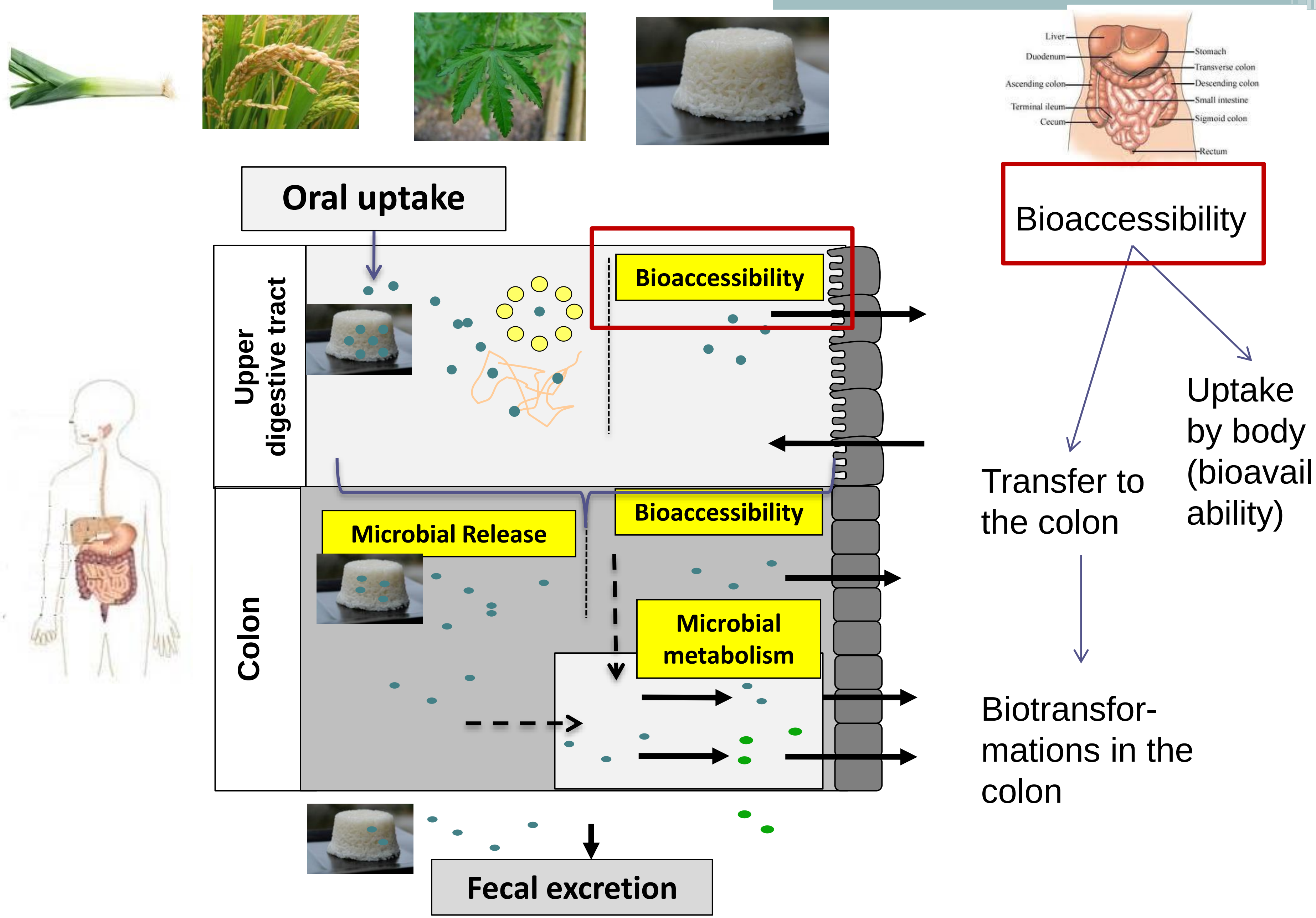
FIG. 2. Species of selenium in natural un-enriched foods, % contribution of each type of selenium to total/extractable selenium. This figure was produced from data presented in references (47, 117, 207, 302, 400, 405) with the percentage of total/extractable selenium species presented for natural un-enriched foods with typical selenium contents (fresh weight) for wheat, 0.1–30 mg/kg; garlic, <0.5 mg/kg; potatoes, 0.12 mg/kg; chicken, 0.5 mg/kg; lamb, 0.4 mg/kg; fish (cod), 1.5 mg/kg.

Fairweather-Tait et al. (2011). Antioxidants and redox signaling, 14, 1337-1383

Effectiveness of supplementation strategies

Bioaccessibility and bioavailability to be taken into account!

Role of food matrix and speciation

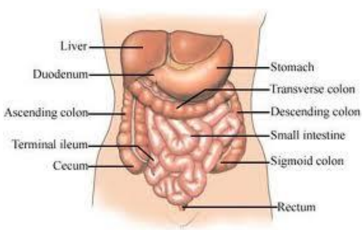


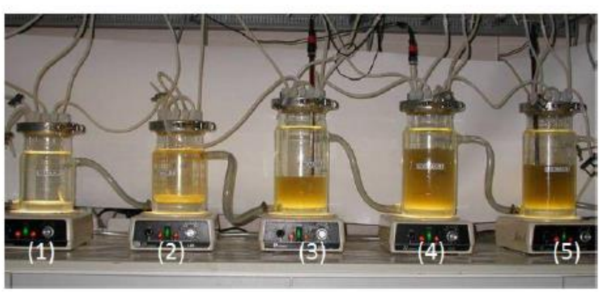
Liver
Duodenum
Ascending colon
Terminal ileum
Cecum
Stomach
Transverse colon
Descending colon
Small intestine
Sigmoid colon
Rectum
Oral uptake
Upper digestive tract
Bioaccessibility
Colon
Bioaccessibility
Microbial Release
Microbial metabolism
Fecal excretion
Bioaccessibility
Transfer to the colon
Uptake by body (bioavail ability)
Biotransfor-mations in the colon

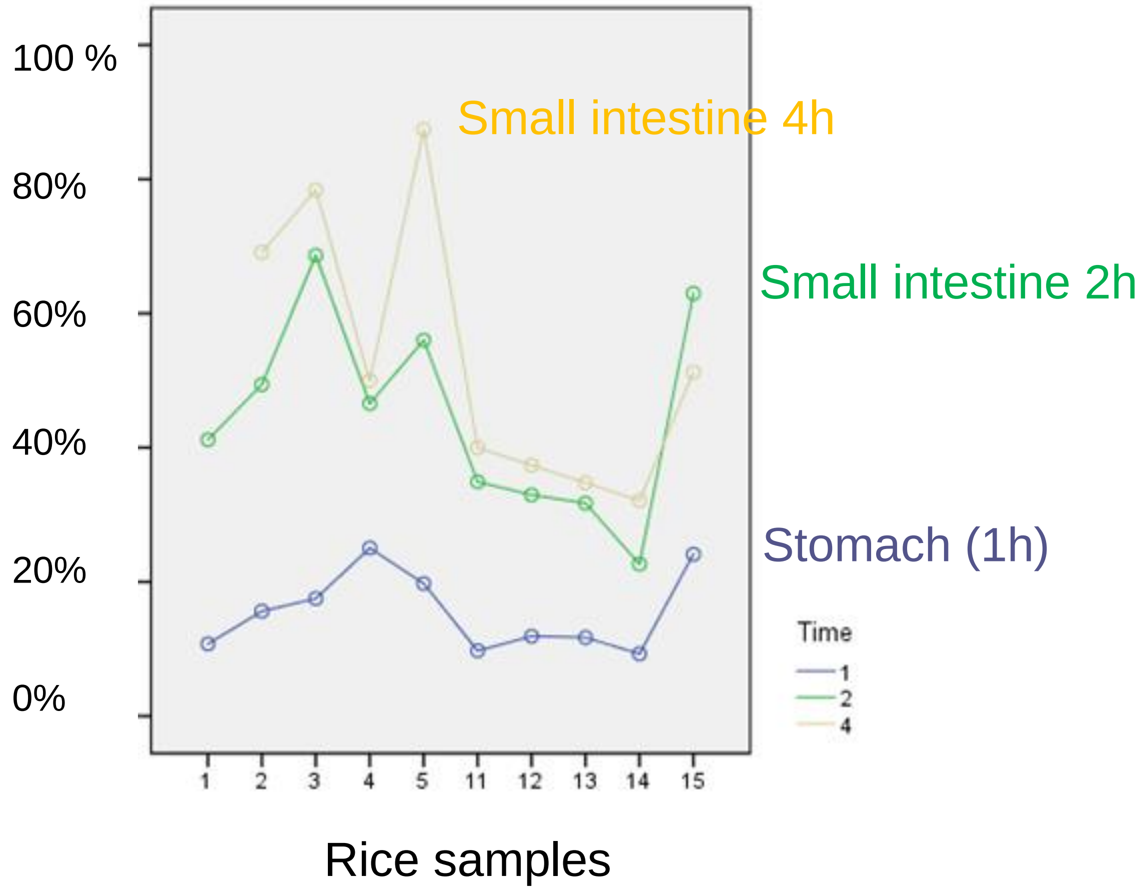
Selenium bioaccessibility

In vitro Se bioaccessibility in different Se-enriched rice crop samples (unpublished data)

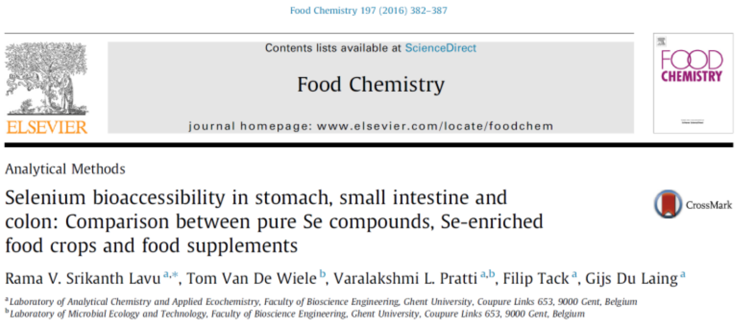
SHIME system:







Selenium bioaccessibility


Food Chemistry 197 (2016) 382–387

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journal homepage: www.elsevier.com/locate/foodchem

Analytical Methods

Selenium bioaccessibility in stomach, small intestine and colon: Comparison between pure Se compounds, Se-enriched food crops and food supplements

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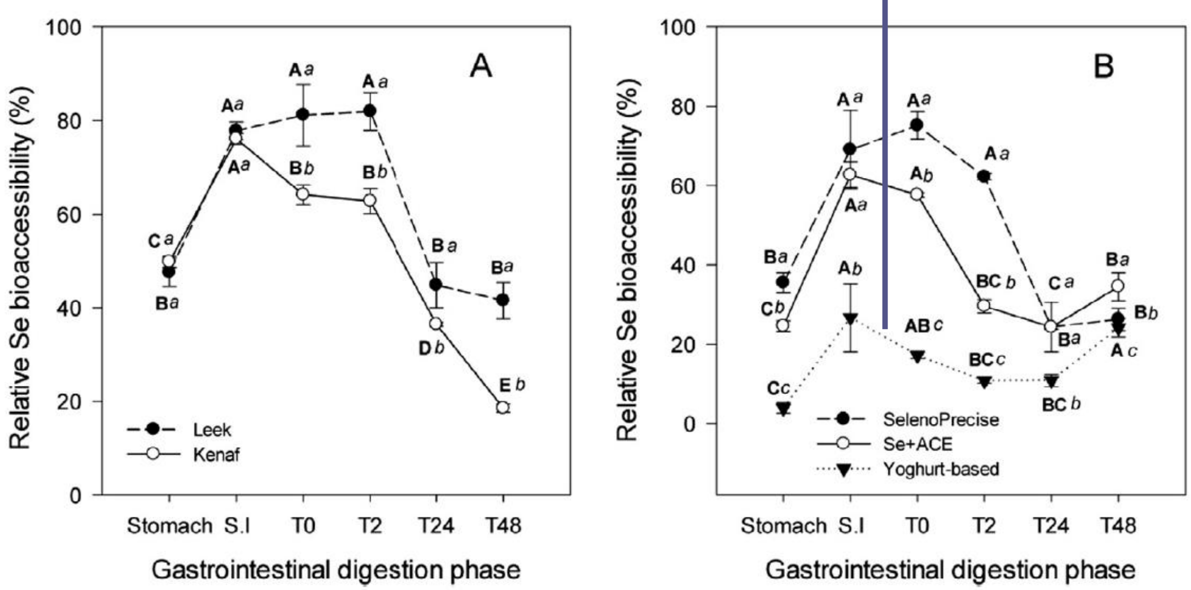
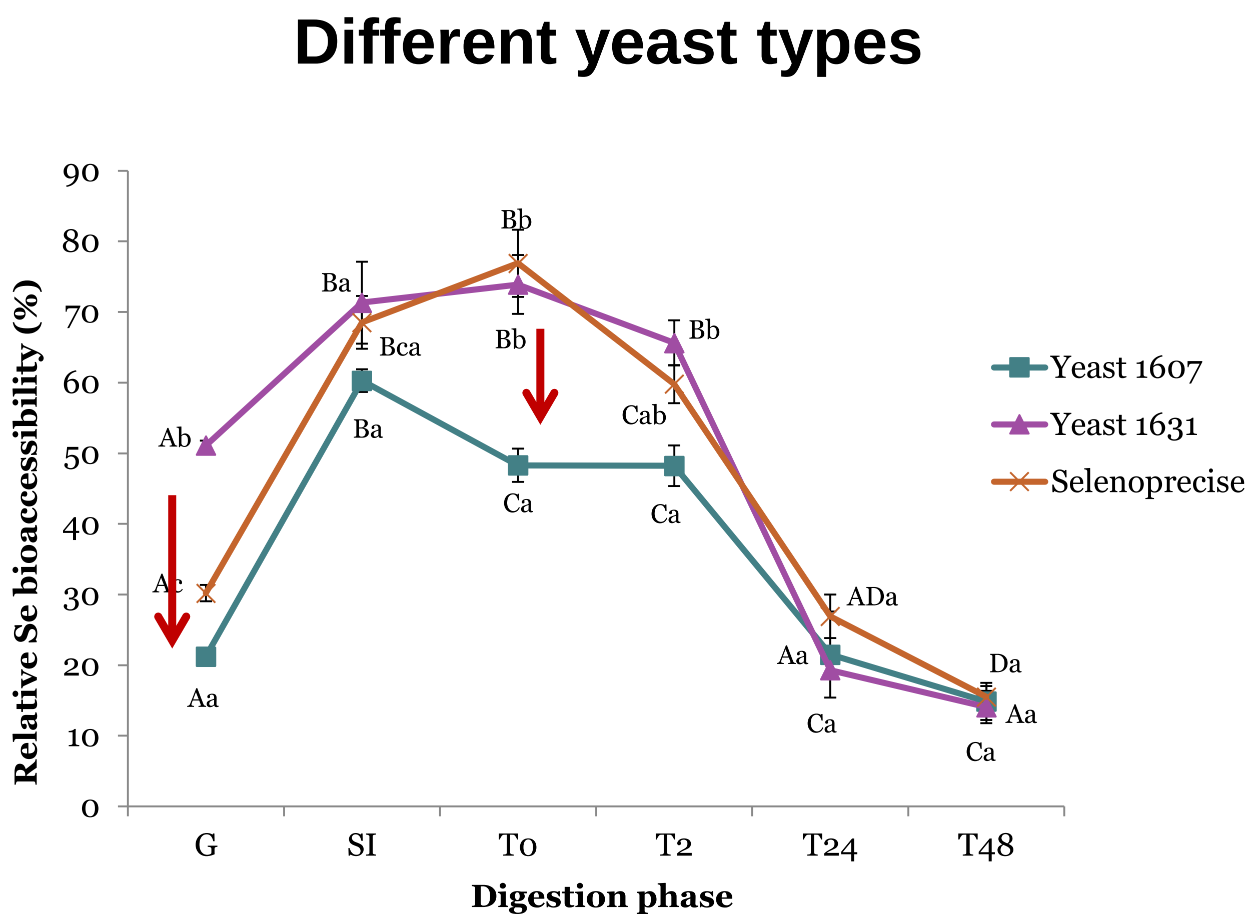
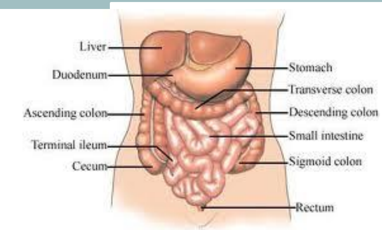
Low bioavailability: relation with formation of elemental selenium (microparticles)?



Selenium bioaccessibility




Liver
Duodenum
Ascending colon
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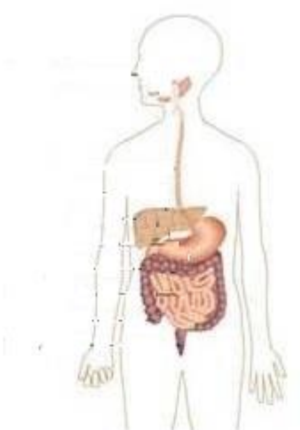
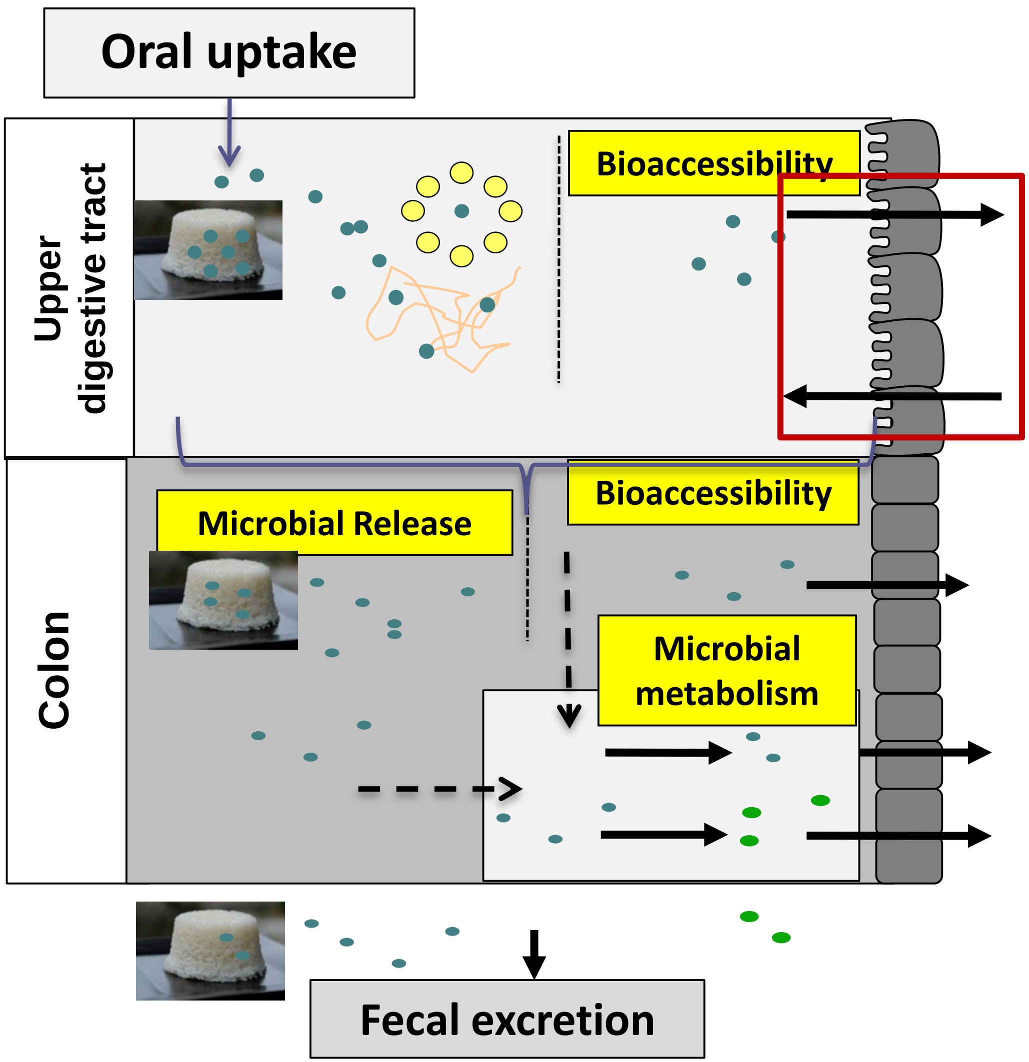
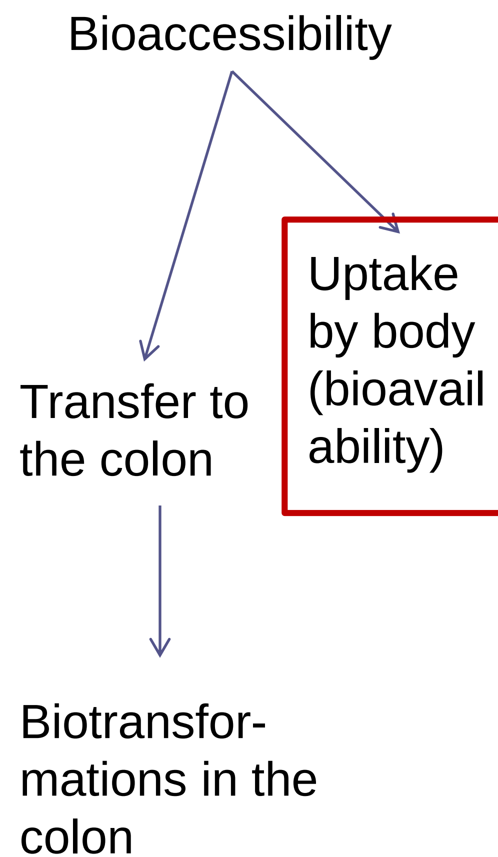
Cecum
Stomach
Transverse colon
Descending colon
Small intestine
Sigmoid colon
Rectum




Oral uptake
Upper digestive tract
Bioaccessibility
Colon
Microbial Release
Bioaccessibility
Microbial metabolism
Fecal excretion


Bioaccessibility
Transfer to the colon
Uptake by body (bioavail ability)
Biotransfor-mations in the colon

Selenium bioavailability

British Journal of Nutrition (2013), **109**, 2126–2134 doi:10.1017/S0007114512004412

An *in vitro* investigation of species-dependent intestinal transport of selenium and the impact of this process on selenium bioavailability

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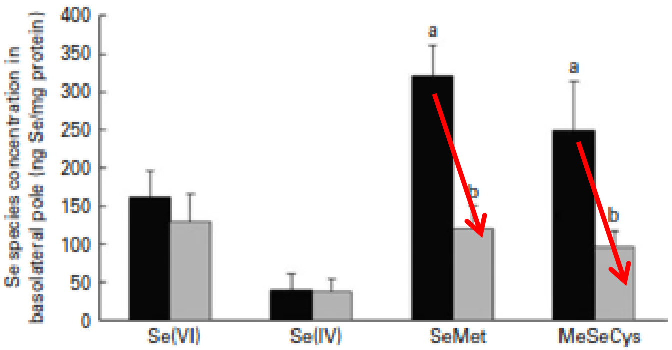

Fig. 6. Concentrations of selenate (Se(VI)), selenite (Se(IV)), methylselenocysteine (MeSeCys) and selenomethionine (SeMet), per mg of protein, in the basolateral compartment at 3 h after having been added to the apical compartment (100 ng selenium/ml) in the presence or absence of their sulphur analogue (10 μg selenium/ml). Values are means, with standard deviations represented by vertical bars. [a,b] Mean values with unlike letters are significantly different from each other for a given species ($P \leq 0.05$). ■, Selenium; ▪, selenium + sulphur.

- Organic Se: higher transfer
- Selenate: unclear transport mechanism
- Selenite: paracellular transport
- Organic species: combined paracellular and transcellular transport, transport system shared with S-analogue

Conclusion

- Selenium supplementation may be beneficial also for those having already an “adequate” uptake
- Narrow range between deficiency and toxicity
- Role of speciation: organic species preferred
- Bioaccessibility and bioavailability of Se in enriched products is variable, depending on speciation and growth conditions

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