SELENIUM CONTENT IN FOODSTUFFS AND ITS NUTRITIONAL REQUIREMENT FOR HUMANS

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Abstract

Selenium is an essential microelement; it acts as an antioxidant and immunomodulator and it is involved in the regulation of certain endocrine pathways. Selenium content in foodstuffs from different countries is given by categories: a) fruit, vegetables, mushrooms and spices; b) legumes, nuts, cereals and derivatives; c) meat, poultry meat, eggs and seafood; d) milk and dairy products and e) beverages and oils. Overall selenium content varies significantly between different categories of foodstuffs. Fruits and vegetables generally contain low levels of selenium, with some exceptions. Selenium content in meat, poultry, eggs and seafood is generally high. Legumes, cereals and derivatives are the main contributors to the dietary selenium intake for most countries. For estimating selenium nutritional requirements, different criterias have been used. The first values regarding selenium requirements were established in 1989 in USA, followed by the 1996 WHO basal and normative requirements and the 2000 RDI from USA. For most countries, the daily selenium dietary intake exceeds the 1996 WHO requirements, with a few exceptions, such as Burundi, China (Shanxi province and other areas), Croatia, Greece, Poland, Turkey, United Kingdom. At present, in the case of some countries, there are no studies regarding selenium content in foodstuffs.

Keywords: selenium, foodstuffs, nutritional requirement, dietary intake.

CONŢINUTUL DE SELENIU DIN PRODUSELE ALIMENTARE ŞI NECESARUL NUTRIŢIONAL DE SELENIU PENTRU OAMENI

Rezumat

Seleniul este un microelement esenţial; are rol antioxidant şi imunomodulator şi este implicat în reglarea anumitor activităţi endocrine. Conţinutul de seleniu din produse alimentare provenind din mai multe ţări este prezentat pe categorii: a) fructe, legume, ciuperci şi condimente; b) leguminoase, nuci, cereale şi produse derivate; c) carne, carne de pasăre, ouă şi organisme marine; d) lapte şi produse lactate şi e) băuturi şi uleiuri. În ansamblu, conţinutul de seleniu variază semnificativ între diferitele categorii de alimente. Fructele şi legumele au în general un conţinut redus de seleniu, cu anumite excepţii. Conţinutul de seleniu în carne, carne de pasăre, ouă şi organisme marine este în general ridicat. Leguminoasele, cerealele şi produsele derivate reprezintă principalii contributori la aportul alimentar de seleniu, în cazul celor mai multe ţări. Pentru estimarea necesarului nutriţional de seleniu au fost folosite diferite criterii. Primele valori privind necesarul de seleniu au fost stabilite în 1989 în SUA, urmând valorile privind necesarul bazal şi normal stabilite în 1996 de OMS şi valorile privind aportul recomandat, stabilite în 2000 în SUA. În cazul celor mai multe ţări, aportul alimentar zilnic de seleniu este mai mare decât necesarul stabilit în 1996 de OMS, cu unele excepţii precum Burundi, China (provincia Shanxi şi alte zone), Croaţia, Grecia, Polonia, Turcia, Regatul Unit. În cazul anumitor ţări nu există în prezent studii privind conţinutul de seleniu în produsele alimentare.

Cuvinte cheie: seleniu, produse alimentare, necesar nutriţional, aport alimentar.

Introduction

Selenium is an essential microelement, which is incorporated by specific mechanisms in the structure of some proteins and enzymes with multiple physiological roles [1]. At present, a number of at least 25 protein compounds containing selenium in their structure have been discovered, most of them being enzymes and known under the generic designation of selenoproteins [2]. Physiologically, the most important selenoproteins are the glutathione-peroxidases, the deiodinases of the thyroid hormones and the thioredoxin reductases [1-5]. Among its numerous implications in the human body, selenium has an antioxidant role [6], modulates the immune response [7] and regulates certain endocrine pathways, including the biosynthesis and metabolism of the thyroid hormones [2,8,9]. Selenium also acts as an insulin-mimetic [8,9].

Selenium deficiency can lead to cardiovascular diseases, cancer [10], a weakened immune system and hypothyroidism [1]. Keshan disease and Kashin-Beck disease are endemic to some areas of Asia, mainly China, where the selenium content of soils is very low [1,11]. In high amounts, selenium has toxic effects [1]. Long time exposure to selenium, in high, but sub-toxic doses results in increased mortality due to malignant neoplasms [12]. There are areas in the world where selenium content in soils is very high. In these areas chronic selenosis occurs, which manifests itself by hair loss, nail brittleness, gastrointestinal and neurological disfunctions, skin rash and "garlic-breath" odor [1,13]. Depending on the dose, acute intoxication leads to acute tubular necrosis and/or severe gastritis or gastric ulcer [14,15].

The dietary intake of selenium for humans depends mainly on its concentration in food and the amount of food consumed [1,16]. As a result, it is important to know its content in foodstuffs. A multitude of analytical methods have been developed for the determination of selenium in foodstuffs, with various sensitivities and range of products to which are applicable to. The methods based on fluorimetry and hydride generation atomic absorption spectrometry (HGAAS) possess certain advantages [17]. Selenium dietary intake also depends on its bioavailability [1,16].

Factors influencing selenium content in foodstuffs

Selenium content in foodstuffs varies geographically within and between countries. The selenium levels from soil and its bioavailability is directly reflected into its content in the plants that are grown on that soil [18,19]. The bioavailability for plants depends mainly on the chemical forms of selenium that exist in the soil, but is also influenced by some physicochemical parameters of the soil. The absorption of Se+6 is generally higher than that of Se+4 [18-20]. The selenium content in animal products depends on its content in the diet consumed by the animals [18,21].

Another factor influencing selenium levels is the content of proteins in foodstuffs, because sulphur-containing amino acids can be replaced by selenium-containing amino acids – selenomethionine (Se-Met), selenocysteine (Se-Cys) or selenocystathionine, due to their physicochemical similarity. In plants, selenium compounds are used mainly for the biosynthesis of Se-Met and Se-Cys, which are incorporated into vegetable proteins. The selenium forms contained within the vegetable proteins from animal feed would be used for the biosynthesis of animal proteins, facilitating their accumulation in livestock [1,18]. Se-Met is incorporated into proteins non-specifically, in place of methionine [1,22].

Agricultural activities can influence selenium levels in foodstuffs. In some areas of the world selenium has been added to fertilizers, in order to increase selenium levels in cultivated plants and indirectly improve selenium status in humans [20,23]. A contaminated aquatic environment, due to various industrial activities can lead to selenium accumulation in fish and other marine animals [18,24].

Processing of foodstuffs or intermediary products can decrease selenium content by various mechanisms. Cooking (boiling, baking, grilling) could reduce selenium content by volatilization, in specific situations [25].

Selenium content in different categories of foodstuffs

Overall selenium levels vary significantly between different categories of foodstuffs.

Fruits contain low levels of selenium, primarily because of their high water and low protein content. The majority of fresh vegetables have also low selenium contents [16,18,26-31]. As a result, selenium intake of vegetarians and lacto-vegetarians is decreased. This could contribute to a nutritional selenium deficiency [18,35]. Some vegetables, such as those from the *Brassica* genus (cabbage, broccoli, mustard and others) and *Allium* genus (onion, garlic) tend to accumulate and have higher selenium concentrations, probably because of their greater fraction of sulphur-containing amino acids [18,25,32]. Some species of mushrooms, such as *Agaricus bisporus* and *Boletus edulis* also accumulate selenium [25]. Selenium content of several fruits, vegetables, mushrooms and spices from different countries are shown in Table I.

Selenium content in legumes, nuts, cereals and derivates is given in Table II. Selenium content in legumes varies on a very broad range. In legumes from Greece it ranged from 24,4 to 443,9 ng/g [16,18]. Legumes and cereals and derivatives represent the main contributor to the total selenium intake of the general population in most

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Table I. Selenium content in fruits, vegetables, mushrooms and spices.

Type of sample	Origin (purchased or grown)	Se content (ng/g)	Ref.	Type of sample	Origin (purchased or grown)	Se content (ng/g)	Ref.
Apple	Australia	4,5	[32]	Cabbage	S Arabia	9,0±0,2	[26]
	Greece	1,4±0,2	[16]		Croatia	66,1±5,6	[31]
	S Arabia	11,0±4,4	[26]		Thailand	2-14	[29]
	Portugal	0,7	[27]	Broccoli	Korea	6	[28]
	Croatia	8,8±1,6	[31]		Thailand	6	[29]
Pear	Greece	6,3±1,6	[16]		Portugal	11,5±7,0	[27]
Kiwi	Greece	3,9±0,5	[16]	Spinach	Korea	24	[28]
	Croatia	11,4±0,1	[31]		S Arabia	7,0±0,2	[26]
Orange	Greece	4,3±0,8	[16]	Tomato	Croatia	7,9±3,2	[31]
	Croatia	7,6±1,5	[31]		Greece	2,3±0,1	[16]
	S Arabia	28±1,7	[26]		Portugal	0,3	[27]
	Portugal	0,6	[27]	Eggplant	S Arabia	67,0±2,4	[26]
	Korea	28	[28]		Thailand	3-13	[29]
Mandarin	Greece	3,6±1,5	[16]	Potato	S Arabia	1,0±0,3	[26]
Lemon	Greece	1,7±0,5	[16]		Croatia	9,5±1,3	[31]
Mango	S Arabia	5,0±0,2	[26]		Portugal	3,9±3,2	[27]
	Thailand	6-11	[29]		Slovenia	1,5±0,3	[30]
Grapes	S Arabia	23,0±2,6	[26]	Cucumber	S Arabia	21,0±0,7	[26]
	Croatia	12,9±3,6	[31]		Korea	4	[28]
Bananas	S Arabia	24,0±1,9	[26]	Onion	S Arabia	43,0±2,2	[26]
	Croatia	20,3±0,6	[31]		Greece	7,3±0,05	[16]
	Greece	5,0±0,7	[16]		Korea	52	[28]
Sharon fruit	Greece	2,6±0,6	[16]		Croatia	15,3±1,8	[31]
Peach	Croatia	11,0±3,5	[31]	Garlic	Greece	13,7±0,9	[16]
Plum	Croatia	8,7±0,9	[31]		Korea	21	[28]
Pineapple	Thailand	2	[29]	Green peas	India	180	[18]
Melon	Thailand	1	[29]		S Arabia	37,0±9,1	[26]
	S Arabia	4,0±0,8	[26]	Parsley	Greece	7,2±0,2	[16]
Carrot	Croatia	19,6±0,2	[31]		S Arabia	7,0±0,5	[26]
	Portugal	2,9	[27]	Mint	S Arabia	14,0±2,7	[26]
	S Arabia	2,0±0,4	[26]	Pepper	India	150	[18]
	Thailand	39	[29]		Greece	4,2±0,3	[16]
Lettuce	S Arabia	10,0±4,2	[26]	Sweet basil	S Arabia	11,0±1,9	[26]
	Greece	2,4±1,5	[16]	Mustard	India	248±15	[18]
	Korea	6	[28]	*A. bisporus*	Korea	83	[28]
Cardamon	India	80±4	[18]	Pine mushr	Korea	139	[28]

Table II. Selenium content in legumes, nuts, cereals and derivatives.

Type of sample	Origin (purchased or grown)	Se content (ng/g)	Ref.	Type of sample	Origin (purchased or grown)	Se content (ng/g)	Ref.
Beans	Greece	24,4±3,7	[16]	Rice	Greece	19,1±1,4	[16]
	Slovenia	52,6±21,3	[30]		S Arabia	72,0±0,4	[26]
Lentils	Greece	443,9±29,3	[16]		Thailand	50±11	[29]
	S Arabia	76,0±4,3	[26]	Wh. flour	Korea	123	[28]
Peanuts	S Arabia	145,0±6,3	[26]	Bread	S Arabia	52,0±4,1	[26]
	Korea	146	[28]		Greece	70,0-131,8	[16]
Brazil nuts	Brazil	38000	[34]	Macaroni	S Arabia	43,0±1,3	[26]
Chestnuts	Korea	2	[28]	Cornflakes	Greece	19,7±0,6	[16]
Coconut	S Arabia	93,0±2,1	[26]	Cookies	S Arabia	124±24	[26]
Wheat	S Arabia	165,0±1,2	[26]	Snacks	Korea	43	[28]

countries [1,18]. Brazil nuts contain very high amounts of selenium and could reach as much as 38000 ng/g [18,34]. One single nut can exceed the recommended dietary allowance (RDA) [25].

Data on selenium content of meat, poultry meat, eggs, fish and other types of seafood, from several countries, is presented in Table III. These food categories are rich in proteins and also contain high levels of selenium [18,31].

Meat, fish and eggs represent the major contributor to the total daily selenium intake of the general population in Greece, Portugal and Japan [16,18,27].

Selenium concentrations in milk from different species decreases in the following order: human>sheep>goat>cow [18]. Selenium concentrations in milk are negatively correlated with its fat content [16]. This fact is also obvious in the case of cheese [21]. Milk and its derivatives products contribute significantly to the total selenium dietary intake, particularly for infants [16,18,33]. In Table IV selenium content in milk and dairy products from different countries is presented.

In Table V the selenium content of some beverages and oils is presented. Selenium content in beverages and potable water is generally low, compared to its content in food. Oils usually have low selenium contents [18].

Table III. Selenium content in meat, poultry meat, eggs and seafood.

Type of sample	Origin (purchased or grown)	Se content (ng/g)	Ref.	Type of sample	Origin (purchased or grown)	Se content (ng/g)	Ref.
Pork	Greece	94,1±4,1	[16]	Turkey	Slovenia	99-116	[30]
	Croatia	129,9-158,1	[31]	Eggs	Korea	267	[28]
	Thailand	172-187	[29]		Greece	90,4-181,1	[16]
Rabbit	Spain	74-106	[36]		S Arabia	226,0±3,5	[26]
Beef	Greece	48,8±8,6	[16]	Sardine	Greece	297,2±35,6	[16]
	Korea	324	[28]		Croatia	571±22	[31]
	S Arabia	390,0±8,1	[26]	Tuna (oil)	Croatia	859,2±101,6	[31]
Lamp	S Arabia	425,0±5,3	[26]		Korea	453	[28]
Sausage	Croatia	116,1-198,7	[31]	Mackerel	Korea	733	[28]
Salami	Croatia	118,4±8,8	[31]	Shrimp	Korea	251	[28]
Pate	Croatia	94,4±16,9	[31]	Cod	Korea	360	[28]
Chicken	Greece	79,4±3,1	[16]	Trout	Greece	62,7±34,2	[16]
	Korea	147	[28]	Bogue	Greece	506,7±13,2	[16]
	Slovenia	97-153	[30]	Squid	Korea	448	[28]

Table IV. Selenium content in milk and dairy products.

Type of sample	Origin (purchased or grown)	Se content (ng/g)	Ref.	Type of sample	Origin (purchased or grown)	Se content (ng/g)	Ref.
Cow milk	Greece	10,7-17,7	[16]	Gouda cheese	Greece	85,4±10,0	[16]
	Croatia	16,9-28,7	[31]	Feta	Greece	51,8±5,4	[16]
	Slovenia	12,5±0,9	[30]	Sheep cheese	Greece	43,5±15,7	[16]
Yogurt	Croatia	29,9±10,4	[31]	Goat cheese	Greece	43,3±16,3	[16]
	Slovenia	12,4±0,5	[30]	Cream	Greece	6,9-13,8	[16]
	Korea	11	[28]		Slovenia	15,3±1,4	[30]
Butter	Greece	4,4	[16]		S Arabia	24,0±4,3	[26]
	Slovenia	24,0±6,3	[30]	Ice cream	Korea	47	[28]

Table V. Selenium content in beverages and oils.

Type of sample	Origin (purchased or grown)	Se content (ng/g)	Ref.	Type of sample	Origin (purchased or grown)	Se content (ng/g)	Ref.
Beer	Korea	18	[28]	Olive oil	S Arabia	2,0±0,3	[26]
Apple juice	Australia	0,7-5,1	[18]		Greece	1,1±0,6	[16]
Tap water	Greece	0,06	[16]	Soybean oil	Korea	8	[28]

Selenium nutritional requirement

The first criteria used for estimating the selenium nutritional requirement for the human body was the prevention of Keshan disease, the only proven selenium-responsive disease. An 17 µg/day intake prevents this disease [2,37,38]. More recently, the maximization (or optimization) of plasma glutathione peroxidase activity was used by official institutions as a criteria for assessing the selenium requirement [39-41]. Based on the adapted results of a clinical trial conducted in a Keshan disease area, in which the glutathione peroxidase activity was monitored after administration of Se-Met over a period of several months [2], the Recommended Dietary Allowance (RDA) was established for the first time: 70 µg/day for males and 55 µg/day for females [2,39].

In 1996, The World Health Organization (WHO) published its dietary standards for a series of trace elements, including selenium. Unlike the 1989 RDA Committee from USA, the WHO Committee decided that full expression of glutathione peroxidase activity was unnecessary for maintaining human health and two-thirds full activity offers sufficient protection against oxidative stress. The basal requirement (BR) and normative requirement (NR) for selenium were defined. The BR was considered to be the quantity needed to protect against Keshan disease. A maximal daily safe dietary intake was also established – 400 µg/day [2,40]. In Table VI the BR and NR for selenium are given.

Table VI. The 1996 WHO Basal and Normative Requirements for selenium (µg/day) [40].

Life stage	Age (years)	BR µg/day	NR µg/day
Infants	0-0,25	3	6
	0,25-0,5	5	9
	0,5-1,0	6	12
Children	1-3	10	20
	3-6	12	24
	6-10	14	25
Males	10-12	16	30
	12-15	19	36
	15-18	21	40
	> 18	21	40
Females	> 10	16	30
Pregnancy		18	39
Lactation (months)	0-3	21	42
	3-6	25	46
	6-12	26	52

BR = Basal requirement
NR = Normative requirement

Based on the results of the trials carried out in China and on those obtained from a trial carried out in New Zeeland [42], the 2000 RDI Committee from USA has established new values regarding selenium nutritional requirement. The term „Dietary reference intake" was used to describe four different terms: RDA, Adequate intake (AI), Tolerable upper intake level (UL) and Estimated Average requirement (EAR). For infants under one year of age the RDA could not been defined and were substituted by AI [41]. The RDA/AI for selenium established by the 2000 Committe from USA are shown in Table VII.

Table VII. The 2000 Dietary Reference Intakes for selenium (µg/day) [41].

Life stage group	Age	RDA/AI (µg/day)
Infants	0-6 months	15*
	7-12 months	20*
Children	1-3 years	20
	4-8 years	30
Men	9-13 years	40
	14-70 years	55
	> 70 years	55
Women	9-13 years	40
	14-70 years	55
	> 70 years	55
Pregnancy		60
Lactation		70

RDA = Recommended dietary allowance
AI = Adequate intake
* - values with asterisk are AI

A more recent trial conducted in China has utilized selenoprotein P (SelP) as a biomarker for evaluating selenium requirement. SelP did not become optimized in this trial, even at doses of 61 µg/day, administered as Se-Met, while glutathione peroxidase activity reached a plateau at a dose of 37 µg/day. It was suggested that an upward of the current values regarding selenium nutritional requirements will be required [43].

Selenium dietary intakes

It is difficult to obtain unbiased estimates of dietary trace elements intakes, no matter the epidemiological method used [44]. Due to high variability in selenium content of different foodstuffs and in inter-individual diets, the procedure for estimating selenium dietary intake is questionable [45]. Measurement of serum or plasma levels of selenium in healthy individuals can also be a way of indirectly assessing dietary selenium intake [1].

In Table VIII the estimated selenium intakes for adults from various countries are presented. The estimates for daily intakes vary widely between different countries. Based on the data available in the scientific literature and excluding the values corresponding to selenosis and Keshan areas, it can be estimated that the normal intake for an adult ranges from about 17 to 224 µg/day.

The selenium nutritional requirements established by WHO in 1996 are still the most used reference values for the majority of the countries of the world [2]. Taking these values as reference, it can be assumed that for most countries the nutritional requirements are met. The NR values established by WHO are different for males and females and also for different age groups, but most studies which have been conducted in order to assess selenium intake in different countries considered the population as a whole and were not generally focused on population groups. Thus certain problems can occur in estimating in which countries the selenium nutritional requirements are met.

According to the data from the studies mentioned in Table VIII and considering a NR for selenium of 40 µg/day (according to the WHO dietary standards), in certain countries the selenium nutritional requirement is not met: Burundi, China (Shanxi province and other areas), Croatia, Greece, Poland, Turkey, United Kingdom.

Conclusions

Selenium content in foodstuffs varies on a broad range between countries, depending mainly on selenium content in soils and its availability (bioavailability) for plants. In most countries, legumes and cereals, including derivatives represent the main source for selenium intake, due to their predominance in the diet. In few cases, meat, poultry and seafood are the main contributing food categories to selenium intake. Due to the more recent achievements in understanding selenium involvement in

Table VIII. Estimated selenium intake in various countries.

Country	Selenium intake (µg/day)	Ref.	Country	Selenium intake (µg/day)	Ref.
Australia	55-87	[47]	Korea	60	[55]
Austria	48	[26]	Mexico	61-73	[56]
Burundi	17	[48]	Netherlands	72	[57]
Canada	98-224	[46]	Poland	30-40	[10]
China-Shanxi prov.	15	[44]	Russia	54-80	[1]
China -Eastern areas	53-80	[49]	Saudi Arabia	75-122	[26]
China-Keshan areas	7-11	[1]	Slovenia	87	[30]
China-selenosis areas	750-4990	[1]	Spain	44,6-50,4	[58]
Croatia	27,3	[50]	Sweden	44	[59]
Croatia	33,9	[51]	Switzerland	70	[10]
Egypt	49	[52]	Switzerland	66	[60]
Greece	39,3	[16]	Turkey	30	[10]
Italy	51	[53]	UK	34	[21]
Japan	129	[54]	USA	60-220	[1]

human physiology and health, the values regarding selenium nutritional requirements established by WHO and The RDI Committee from USA should be revised. The selenium nutritional requirements according to WHO are met in the case of most countries, with a few exceptions. There are still many countries for which there are no available studies regarding selenium content in foodstuffs.

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