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ORIGINAL PAPER

CONTENT OF SELENIUM IN SELECTED FOOD PRODUCTS ON THE MARKETS OF NORTH-WESTERN POLAND*

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Abstract

Depending on one's age and physiological status, the demand for selenium ranges between 50 and 100 μg but should not exceed 200 μg. Consumption of over 1 mg kg^{-1} Se (b.w.) may be lethal. The volume of selenium intake is affected mostly by the type and amount of consumed food, and the concentration of Se in food to some extent reflects the content of this element in the environment. The aim of this study was: (1) to evaluate the content of selenium in selected food products offered in the markets of north-western Poland, and (2) to assess to a what extent the selected food products cover the daily selenium demand in humans. The examination of the Se level was performed in meat, sliced meats, dairy products, fish and vegetables. Among the meat products, pork, beef, veal, chicken and pork and chicken liver were examined. Additionally, the meat, liver, stomach, heart and lungs of duck and the meat, heart and liver of wild boar were examined. Fish samples included sprat, mackerel, herring, carp and coalfish. The tested dairy products comprised different types of cheese, yoghurts and cottage cheese. The content of selenium was measured spectrofluorometrically with 2,3-diaminonapthalene (DAN). Among the examined products, the highest selenium level was found in meat products, including the duck liver (0.747 μg g^{-1}), whereas the lowest concentration was observed in vegetables, at 0.003 μg g^{-1}. The validity of the method was assessed with the BCR–185R, bovine liver reference material (European Commission Joint Research Centre, Institute for Reference Materials and Measurements – LGC Standards GmbH, Wesel, Germany). The recovery factor ranged from 91% to 95% of the reference value.

Keywords: selenium and human health, food, daily intake, selenium demand, groceries.

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INTRODUCTION

Selenium (Se) is a non-metallic trace element, crucial for the proper performance of metabolic processes in a body (Rayman 2012). Both Se excess or deficiency can cause a distinctly negative effect on a body and may lead to a number of afflictions. The borderline between an an excess and deficiency of selenium is very slim. Depening on one's age and physiological status, the demand for this element ranges between 50 and 100 μg but should not exceed 200 μg. Consumption of over 1 mg kg^{-1} Se (b.w.) may be lethal (B'Hymer, Caruso 2006). The volume of selenium intake is affected mostly by the type and amount of consumed food, and the concentration of Se in food partly reflects the content of this element in the environment (Valdés et al. 2017). The level of selenium in food products mostly depends on the content of this element in the soil, as the plants are the main recipients of selenium from soil and at the same time they are the source of this element for humans and animals (Dębski et al. 2001). The natural concentration of selenium in soils ranges from 0.1 to 2.0 μg g^{-1} d.w. (dry weight), while worldwide the mean Se concentration in surface layers of soil is below 0.5 μg g^{-1} d.w. (Combs 2001, Rodriguez et al. 2005, Borowska et al. 2007). However, selenium is not equally distributed in the Earth's crust. Particularly low concentrations of this element are observed in some regions of China, Finland, New Zealand and in a large part of Europe. Selenium-rich soils in turn are present in Canada, the USA, Australia, Ireland and Israel. In Poland, the level of selenium is low. Studies by Dębski et al. (2001) have indicated that a deficiency of Se is characteristic for more than 70% of the territory of Poland.

Deficiency of selenium in humans is one of the reasons of cardiovascular diseases, some tumors, diabetes and strokes (Alissa et al. 2003, Abdulah et al. 2005). The Keshan disease (heart muscle damage) is a classic example of disturbances in the circulatory system related to the deficiency of selenium (Rayman 2012, Fryer 2002). Its low level negatively also affects the nervous system. In these cases, symptoms of depression, fear, anxiety or mitigation were often observed (Rayman 2012). The deficiency of selenium also causes such disorders as vision problems, nail fragility, pale skin, anaemia, emaciation and fertility dysfunctions. Moreover, it has been noted that the deficiency of selenium affects the immune system, as it contributes to many changes in the functions of this system in human. The most significant ones include the suppression of immunological response to viral and bacterial infection, inhibition of synthesis of prostaglandins and immunoglobulins, decreased activity of T lymphocytes, NK cells and macrophages, reduced potential to counteract tumor development and increased aggregation of platelets (Saini et al. 2015). Many studies reported that Se deficiencies caused disorders of procreation processes. Selenium deficiencies may lead to gestational complications, miscarriages and damage to the nervous and immune systems of the fetus. Infertility in men due to an inferior quality of semen and worse sperm motility was also observed (Paszkowski et al. 1995, Boitani, Puglisi 2008, Pieczyńska, Grajeta 2015, D'Oria et al. 2018).

The concentration of Se in the serum depends not only on the consumed food but also on the age of a person. In infants, the concentration of this element is the lowest. The minimal values are observed during the first 6 months after birth, whereas the highest levels occur during adulthood. In people above 60 years old, the content of selenium decreases gradually (Kipp et al. 2015). As about 2/3 of the region of Poland is exposed to selenium deficient, the content of this element in the serum of the country's inhabitants is low, about 50 - 55 μg l^{-1} (Wąsowicz et al. 2003). A daily demand for Se depends on one's age and physiological status, and usually ranges from 20 μg (children) to 75 μg (adults) (Rayman 2012).

Selenium is present in most of food products, but its content is diversified (Wang et al. 1994). Selenium is characterized by a good potential to be incorporated into proteins, hence meat, fish and seafood and other food products with a high content of proteins are a good source of this element (Rayman 2012). Also, grain products are found to be a good source of Se, as they cover about 50% of selenium demand, whereas meat, poultry and fish are responsible for covering about 35% of the demand. Most drinking water contains low concentrations of Se and are generally considered to be a negligible source of Se, but in some areas the Se intake from drinks was 10-20% of total Se intake (Wang et al. 1994, Barron et al. 2009).

The contribution of fruit to daily selenium supplies is small, less than 10% of the demand for this element (Klapec et al. 2004).

The daily intake of Se in different countries varies. The highest intake is noted in Japan: 118 μg (Miyazaki et al. 2004), Switzerland: 70 μg and Netherlands: 67 μg (Esmaeili, Khosravi-Darani 2014). Interestingly, the estimated daily intake (EDI) in Slovakia (Kadrabova et al 2012), Sweden (Esmaeili, Khosravi-Darani 2014) and Poland (Pilarczyk et al. 2010b) ranges from 30 to 40 μg per day, which is only about half of the daily demand for this microelement in adults (Wąsowicz et al. 2003).

The aims of this study included (1) an evaluation of selenium content in the selected food products from markets of north-western Poland and (2) the assessment to what extent the selected food products cover the daily selenium demand in humans.

MATERIALS AND METHODS

Reagents

All the chemicals we used in the study were of analytical reagent grade. Most of the chemicals were obtained from Chempur®, except 2,3-diaminonaphtalene (DAN), which was obtained from Sigma Aldrich, and the Certified reference material BCR – 185R (bovine liver) (European Commission Joint Research Centre Institute for Reference Materials and Measurements) obtained from LGC Standards GmbH, Germany.

Samples

The study material was obtained in 2014 in NW Poland Poland. The examination of Se levels was performed in meat, sliced meats, dairy products, fish and vegetables. Among the meat products we have examined, there were pork, beef, veal, poultry and pork and chicken liver. Additionally, the meat, liver, stomach, heart and lungs of duck and meat, heart and liver of wild boar were examined. Fish samples included sprat, mackerel, herring, carp and coalfish. The dairy products we have examined consisted of different types of cheese, yoghurts and cottage cheese.

The samples were homogenized to obtain uniform material and frozen in -20°C until the time of analyses for selenium determination.

Chemical analysis

The content of selenium in the samples was measured with the spectrofluorimetric method on a Shimadzu RF-5001 PC device, using 2,3-diaminonapthalene applied after the previous wet mineralization of the samples in a concentrated mixture of HNO_3 and $HClO_4$. The mineralization process was carried according to the method described by Pilarczyk et al. (2010*a*). To reduce selenates (Se VI) to selenites (Se IV), 9% HCl was added to the samples. Next, selenites were complexed with 2,3-diaminonapthalene (Sigma), and the complex thus obtained was extracted with cyclohexane (Chempur). Fluorescence of the organic (cyclohexane) layer was measured using an emission wavelength at 518 nm and an excitation wavelength at 378 nm.

The validity of the method was assessed with the BCR–185R, bovine liver reference material (European Commission Joint Research Centre, Institute for Reference Materials and Measurements – LGC Standards GmbH, Wesel, Germany). The recovery factor ranged from 91% to 95% of the reference value, and the linearity passed the criteria of acceptance and reached r^2 = 0.998. Precision and reproducibility of analysis were 2.6% and 3.2%, respectively. The detection limit (DL) was 0.003 μg ml^{-1}. The analysis was performed in triplicate.

Statistical data analyses

The results were analyzed with Statistica 9.0 PL software. Statistical data such as arithmetic means ($\bar{X}$), standard error of the mean (SEM), and minimal and maximal values (range) are shown in the following tables.

RESULTS AND DISCUSSION

The data on the concentration of Se in the particular groups of food products are shown in the Table 1. The content of Se in products of animal origin depends mostly on the way of animal feeding and the quality of fodder used in diet (Niwińska, Andrzejewski 2014).

According to the results, the highest concentration of Se is noted in fish, representing the mean of 0.172 μg g^{-1}, than in meat, sliced meats and dairy products. The lowest concentration was noted in vegetables (Figure 1).

Table 1

The concentration of selenium in the examined food products

Products	*n*	Mean	SD	Range
Meat (μg g^{-1} ww)				
beef	3	0.101	0.010	0.091-0.111
pork	6	0.082	0.018	0.061-0.106
chicken	10	0.187	0.054	0.078-0.248
game - wild boar	2	0.085	0.011	0.083-0.099
Sliced meats (μg g^{-1} ww)	39	0.065	0.021	0.032-0.152
Dairy (μg g^{-1} ww)				
yoghurt	8	0.020	0.009	0.012-0.027
cottage cheese	2	0.022	0.01	0.022-0.037
cheese	11	0.070	0.014	0.051-0.094
Fish				
smoked sprat	3	0.230	0.01	0.22-0.24
smoked mackerel	3	0.269	0.019	0.250-0.288
herring	3	0.115	0.014	0.101-0.129
carp	3	0.047	0.007	0.040-0.054
coalfish	3	0.199	0.018	0.181-0.217
Offal - liver				
duck	3	0.747	0.041	0.700-0.774
chicken	3	0.151	0.011	0.140-0.162
pork	3	0.172	0.011	0.161-0.183
wild boar	3	0.074	0.014	0.060-0.088
Vegetables				
potatoes	3	0.003	0.001	0.001-0.003
tomato	3	0.003	0.002	0.0-0.003
cucumber	3	0.005	0.002	0.001-0.005
onion	3	0.003	0.002	0.0-0.003
pepper	3	0.003	0.001	0.001-0.003

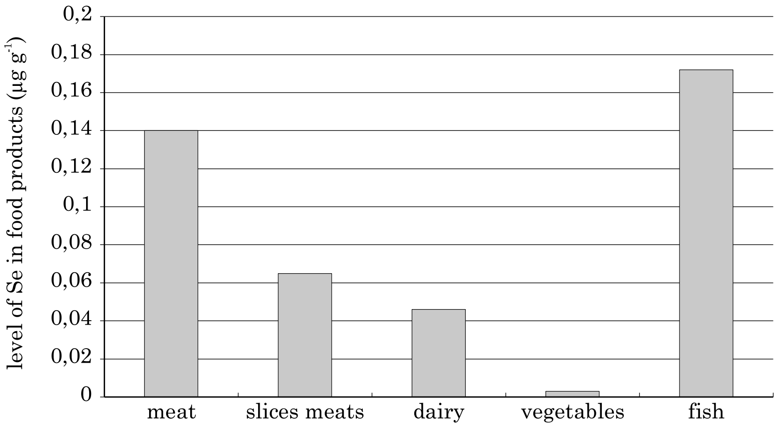

Fig. 1. The mean concentration of selenium in selected food products

The content of Se in fish is highly diversified and depends mostly on the origin and species of fish. Marine fish contain much more selenium than the freshwater species (Bayen 2012). The selenium concentration in fish varies according to species, site of occurrence and trophic level. Yamashita et al. (2013) reported that high levels of Se were found in predatory fish species. In addition, the season also affects the Se content in fish. Tomza-Marciniak et al. (2016) and Satovic et al. (2003) observed the highest Se concentrations in fish in the spring and the lowest in the winter, likely due to the seasonal changes in food availability. Generally, blue whiting and swordfish could contain >0.5 µg Se g^{-1}, whereas salmon, sola, mackerel, anchovy and sardines have 0.1 - 0.3 µg Se g^{-1} and (Pilarczyk et al. 2010, Calatayud et al. 2012). The examples of Se content in fish from different fisheries are shown in Table 2. The mean level of selenium in fish in our study reached 0.172 µg g^{-1}. The highest Se concentration was noted in smoked mackerel: 0.269 µg g^{-1}, and the lowest in carp: 0.047 µg g^{-1}. According to the study by Kuczyńska, Biziuk (2007), the mean content of selenium in smoked mackerel was 0.320 µg g^{-1}, and in herring 0.300 µg g^{-1}. In our study, the concentration of Se in smoked mackerel was similar but slightly lower, i.e. 0.269 µg g^{-1}, whereas the content of selenium in a fresh herring was much lower and reached 0.115 µg g^{-1}.

The studies performed by Pilarczyk et al. (2010*b*) in West Pomerania (Poland) have shown that the mean content of selenium in meat ranged between 0.064 and 0.094 µg g^{-1}. In our study, these concentrations ranged from 0.061 to 0.248 µg g^{-1}, and the highest concentration was characteristic for chicken. This may be caused by the use of mineral, Se-containing supplements in the farm diet of these animals. Table 3 shows the content of Se in meat from beef, pork and chicken in different countries reported by other authors.

The study has shown that apart from meat, offal can also be treated as

Table 2

The content of Se (μg g^{-1} w.w.) in fish in different countries

Species	Country	Mean	Range	Reference
Cod	Ireland	0.265	0.233-0.299	MURPHY, CASHMAN (2001)
Mackerel	Poland	0.320	n/d	KUCZYŃSKA, BIZIUK (2007)
Flounder	Poland	0.136	0.095-0.154	PILARCZYK et al. (2010*b*)
Sprat	Poland	0.175	0.144-0.310	
Salmon	Poland	0.171	0.068-0.244	
Herring	Sweden	0.347	n/d	ÖNNING (2000)
Mackerel	Sweden	0.117	n/d	
Flounder	Sweden	0.101	n/d	
Salmon	Norway	0.195	n/d	PLESSI et al. (2001)
Cod	Norway	0.188	n/d	
Sardine	Italy	0.678	n/d	PLESSI et al. (2001)
Perch	Italy	0.073	n/d	
Mackerel	Italy	0.356	n/d	
Seabass	Turkey	0.294	n/d	ERKAN et al. (2009)
Sea bream	Turkey	0.240	n/d	
Common dentex	Turkey	0.285	n/d	
Seabass[A]	Croatia	0.397	n/d	SATOVIČ, BEKER (2004)
Sardine	Croatia	0.580	n/d	
Salmon	Taiwan	2.01	n/d	CHIEN et al. (2003)
Bonneville whitefish	USA/Idaho	1.01	n/d	ESSIG, KOSTERMAN (2008)
Rainbow trout	USA/Idaho	n/d	0.06-0.71	
Carp	USA/Idaho	0.49	n/d	
Yellow perch	USA/Idaho	n/d	0.05-0.53	

n/d – no data, [A] farmed fish

a valuable source of selenium in human diet, as the concentrations of this element in offal may reach even up to 0.152 μg g^{-1} (Table 1). In general, the content of selenium in offal may be a few times higher than in meat from the same species of animals. Livers of most animals contain about four times more selenium than their skeletal muscles (COMBS 2001). This is due to the fact that the liver plays a very important role in the metabolism of this element. The liver is the central organ for Se regulation and produces excretory selenium forms to regulate selenium homeostasis. This organ responds to Se deficiency by curtailing excretion and secreting Se into the plasma at the expense of its intracellular selenoproteins (BURK, HILL 2015).

Despite the fact that meat and offal contain large amounts of Se, the process of thermal treatment of meat and other products contributes to a loss

Table 3

The content of Se ($\mu g\ g^{-1}$ w.w.) in meat in different countries

	Country	Mean	Range	Reference
Beef	Italy	0.034	n/d	Zagrodzki (2000)
	Croatia	0.131	n/d	Klapec et al. (2004)
	Ireland	0.081	0.061-0.105	Murphy, Cashman (2001)
	Poland	0.064	0.030-0.087	Pilarczyk et al. (2010b)
	Germany	0.214	n/d	Zagrodzki (2000)
	Scotland	0.056-0.489	n/d	Zagrodzki (2000)
	Australia	0.072-0.121	n/d	McNaughton, Marks (2002)
Pork	Germany	0.502	n/d	Zagrodzki (2000)
	Scotland	0.033-0.489	n/d	Zagrodzki (2000)
	Ireland	0.104	0.082-0.129	Murphy, Cashman (2001)
	Italy	0.062	n/d	Zagrodzki (2000)
	Poland	0.078	0.067-0.089	Pilarczyk et al. (2010b)
	Poland	0.180	n/d	Markiewicz et al. (2007)
Chicken	Germany	0.573	n/d	Zagrodzki (2000)
	Scotland	0.072-0.455	n/d	Zagrodzki (2000)
	Ireland	0.115	0.086-0.147	Murphy, Cashman (2001)
	Poland	0.094	0.076-0.139	Pilarczyk et al. (2010b)
	Australia	n/d	0.116-0.280	McNaughton, Marks (2002)
	Italy	0.029	n/d	Zagrodzki (2000)

n/d no data

in the selenium content, even up to 40%. The smallest loss of selenium is observed by cooking and the highest by frying and baking. This is due to the lability of some Se forms that occur in food. Relatively unstable selenium compounds can be easily lost during thermal processes. For example, volatile dimethyl selenide can be formed from the selenium salt of Se-methylselenomethionine (Erkan 2015).

In this study, the mean concentration of selenium in dairy products was 0.046 $\mu g\ g^{-1}$. Kuczyńska, Biziuk (2007) in their study detected the mean selenium level reaching 0.065 $\mu g\ g^{-1}$ in different types of cheese and about 0.025 $\mu g\ g^{-1}$ in yoghurts, which means that our results are similar to the data presented by the cited authors.

The lowest concentration of selenium was found in vegetables, with a mean level at 0.003 $\mu g\ g^{-1}$, thus their contribution to satisfying the selenium demand in humans is low. As reported by Kadrabova et al. (2012), this element in plants is mostly present in the protein fraction, and therefore the plants with a low content of proteins do not represent a rich source of selenium.

Table 4
Recommended dietetic standards of selenium for humans in Poland (JAROSZ 2017)

Group Sex/age	Estimated Average Requirement (μg per day)	Recommended Dietary Allowance (μg per day)
Babies		
0-0,5	15 (Adequate lntake)	
0,5-1	20 (Adequate lntake)	
Children		
1-3	17	20
4-6	23	30
7-9	23	30
Boys		
10-12	35	40
13-15	45	55
16-18	45	55
Men		
19-30	45	55
31-50	45	55
51-65	45	55
66-75	45	55
>75	45	55
Girls		
10-12	35	40
13-15	45	55
16-18	45	55
Women		
19-30	45	55
31-50	45	55
51-65	45	55
66-75	45	55
>75	45	55
Pregnat		
<19	50	60
>19	50	60
Lactating women		
<19	60	70
>19	60	70

For humans, food is the most important source of selenium. As reported by RAYMAN (2012), the daily selenium demand depends on one's age and physiological status, and ranges from 20 μg (children) to 75 μg (adults). Recommended dietetic standards of selenium for humans in Poland are presented in Table 4.

In the European countries, the share of animal origin food products in the general coverage of Se demand is large and usually varies from 50% to 60% (Table 5). The results obtained in this study show that the analyzed food provides 29 μg of the daily selenium requirement, which covers 58% of the selenium demand (Table 6).

Table 5

The content of Se (μg g^{-1} w.w.) in offal in different countries

	Country	Mean	Range	Reference
Chicken liver	Croatia	0.298	n/d	Klapec et al. (2004)
	Poland	0.401	0.309-0.643	Pilarczyk et al. (2010*b*)
Cow liver	Slovakia	0.096	0.058-0.154	Kadrabova et al. (2012)
Swine liver	Croatia	0.285	n/d	Klapec et al. (2004)
	Slovakia	0.230	n/d	Kadrabova et al. (2012)
	Spain	n/d	0.256-0.800	López-Bellido, López Bellido (2013)
	Poland	0.307	0.020- 0.413	Pilarczyk et al. (2010*b*)
Wild boar liver	Poland	0.230	0.036-0.626	Pilarczyk et al. (2010)

n/d-no data

Table 6

Daily Se intake (μg per day)

Products	Product consumption (g per day)	Mean concentration (μg g^{-1} ww)	Estimated daily intake of Se (μg per day)
Meat	109.0	0.140	15.26
Sliced meats	66.7	0.065	4.33
Dairy	161.0	0.046	7.41
Fish	11.0	0.172	1.89
Vegetables	28.9	0.003	0.09
Total			28.98

SUMMARY

The results obtained in this study indicate that the content of selenium in different food products is highly diversified. Fish and poultry seem to be an important source of selenium. While poultry is a popular type of meat in Poland, fish still do not perform a significant role in supplementing the selenium demand in the Polish population's diets. In turn, the potential role of vegetables to cover the selenium demand is marginal, as they contain even up to two orders of magnitude less selenium than meat products.

Regarding the fact that the share of the analyzed groups of products in the diet of a statistical person in Poland is about 40-45%, the daily selenium intake is at the level of 29 μg.

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