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Review

Developmental selenium exposure and health risk in daily foodstuffs: A systematic review and meta-analysis

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A R T I C L E I N F O

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A B S T R A C T

Selenium (Se) is a trace mineral and an essential nutrient of vital importance to human health in trace amounts. It acts as an antioxidant in both humans and animals, immunomodulator and also involved in the control of specific endocrine pathways. The aim of this work is to provide a brief knowledge on selenium content in daily used various foodstuffs, nutritional requirement and its various health consequences. In general, fruits and vegetables contain low content of selenium, with some exceptions. Selenium level in meat, eggs, poultry and seafood is usually high. For most countries, cereals, legumes, and derivatives are the major donors to the dietary selenium intake. Low level of selenium has been related with higher mortality risk, dysfunction of an immune system, and mental failure. Selenium supplementation or higher selenium content has antiviral outcomes and is necessary for effective reproduction of male and female, also decreases the threat of chronic disease (autoimmune thyroid). Generally, some advantages of higher content of selenium have been shown in various potential studies regarding lung, colorectal, prostate and bladder cancers risk, nevertheless results depicted from different trials have been diverse, which perhaps indicates the evidence that supplementation will merely grant advantage if the intakes of a nutrient is deficient. In conclusion, the over-all people should be advised against the usage of Se supplements for prevention of cardiovascular, hepatopathies, or cancer diseases, as advantages of Se supplements are still ambiguous, and their haphazard usage could result in an increased Se toxicity risk. The associations among Se intake/status and health, or disease risk, are complicated and need exposition to notify medical practice, to improve dietary recommendations, and to develop adequate communal health guidelines.

1. Introduction

Selenium [Se] is a trace mineral and an indispensable micronutrient for all humans. Diet is the most important source of this trace mineral to all living organism. The intake of Se mainly depends on its food contents and the total amount of food consumption. The biochemical nature plays an important role in its bioavailability, which is being found considerably higher for organic chemical forms (Dumont et al., 2006; Sigrist et al., 2012). Increased Se emissions and other trace elements has produced a thorough counterpunch for both the environment as well as human health (Ullah et al., 2017; Yousaf et al., 2017a, 2017b). The role of Se in human health is antioxidant, as it shows a kind of enzymatic redox action by means of vital enzymes named glutathione peroxidase. Glutathione peroxidase enzyme and vitamin E, both collectively activates the process of hydrogen peroxide reduction and further by virtue of cell protecting practices reduces hydro peroxides from oxidative deterioration. Moreover, the role of Se is crucial in many metabolic processes and also among endocrine and immune systems (Williams and Harrison, 2010; Sigrist et al., 2012). The intake of Se become toxic when taken at high levels and can cause poisoning in human beings and animals (Al-Ahmary, 2009). For the production of selenoproteins, Se is assimilated into proteins. The oxidative pressure is protected by a number of selenoproteins (Al-Ahmary, 2009).

Deficiency of Se can cause cancer, some cardiovascular diseases (Foster and Sumar, 1997) destabilized immune scheme and hypothyroidism (Ellis and Salt, 2003). Kashin-Beck and Keshan disease found mostly in China and in some regions of Asia, where very low levels of Se were found (Reilly, 2006; Saxena and Jaiswal, 2007). High contents of

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Se has toxic and harmful effects (Reilly, 2006; Pappa et al., 2006). Chronic selenosis happened in several regions of the world due to the presence of extremely high levels of Se in soils, which has resulted in different disorders such as, nail brittleness, hair loss, gastrointestinal dysfunctions, skin rash, "garlic-breath" smell and neurological disorder (Yang and Zhou, 1994; Reilly, 2006; Al-Ahmary, 2009). Severe intoxication can cause critical tubular necrosis and gastric ulcer or acute gastritis, mainly relying on the intake amount (Kise et al., 2004; Kample et al., 2009). Both excessive and deficient ingestion of Se has malignant effects on the organism. The gap among high and low undesirable intakes is very narrow, presenting unpredictable situation for optimal intake of Se, which requires a comprehensive information to be known (Rayman, 2008). Therefore, it is of great importance in recent days to know the Se deficiency and abundance in different foodstuffs in order to estimate its real intakes of people.

Globally, about 15% people of the total estimated 7000 million population, are selenium-deficient (White et al., 2012). Some of the Se-deficient reported areas in the world are China, Russia, Poland, and some volcanic areas of previous Yugoslavia country. Various research studies have concluded a protective effect of Se in resistance against some kinds of cancer disease (Brozmanová et al., 2010), controls molecules released by immune cells during respiratory disorder (asthma) and also reduce heart disease casualty (Brown and Arthur, 2007). It also strengthens the bone balance and acts as guard against bone injury and damage (Zhang et al., 2014). Se-deficient soils in many geographic areas are considered to cause bone disorders and cardiovascular diseases, which may be sorted out by ingestion of food Se (Lemly, 1997; Tan et al., 2016).

The status of Se in food is generally reflected by its availability and contents in the soils of a region, where it is produced. Globally, an extensive variations exists in the soils Se content (Cuvardic, 2003). High contents of Se (> 5 mg/kg) in soils were calculated in countries like Canada, Germany, France and some areas of western USA, whereas, very low Se levels (< 0.05 mg/kg) were found in soils from some regions of China, New Zealand and Finland. Therefore, the concentration of Se is variable among the same foodstuff, depending mostly on cultivated arena of producing or cultivating. Hence for this reason, the local or regional information for nutrients can imitate this type of variations and may be more applicable than those who account the data related to average dietary intake (Smrkolj et al., 2005; Fordyce, 2005; Tan et al., 2016). However, insufficient or even no data about the Se concentration in food and soils is still an issue of great concern in several regions of Southern Asia, Africa and South America, (Samman and Portela, 2010; Sigrist et al., 2012). Many authors described some schemes, through which we can improve Se contents in food of the people living in areas of Se-deficient soils which are, (i) application of Se- enriched fertilizers (Dumont et al., 2006), (ii) augmentation/supplementation of Se to the field or farmland animal food (Tinggi, 2003; Muniz-Naveiro et al., 2006; Pappa et al., 2006; Lyons et al., 2007) and (iii) the undeviating or direct intakes of Se food additions (Dumont et al., 2006). Nevertheless, the people should be advised regarding the Se intakes additions aimed for diseases control, because advantages of Se supplementations are still ambiguous and their haphazard application might produce some risks of increased Se toxicity (Stoedter et al., 2010).

For humans, the food Se intake mainly depends on its contents present in foodstuff and quantity of food utilized (Reilly, 2006; Al-Ahmary, 2009; Slencu et al., 2012). The concentration of Se in different foodstuffs significantly varies depending mainly on level of the element exist in the soil, where growth of the plant species or animals takes place (Barclay et al., 1995; IOM, 1998; Uden et al., 2004). Humans get Se mainly through the dietary intakes/food ingestion. Specifically, seafood and meat are considered the key sources for Se, as most of the animals need Se, while in case of plants, not as necessary as animals (Sirichakwal et al., 2005; Klapec et al., 2004). Globally, the ingestion of dietary Se differs significantly among people due to the presence of huge variation in the Se levels of foodstuffs in different regions (McNaughton and Marks, 2002). For that reason, in every country of the world, the monitoring of Se concentration in typical and most extensively used food is indispensable and important.

The physicochemical properties of Se is highly similar to sulfur, hence replace it in the amino acids, therefore high Se contents are found in protein-rich foods, e.g. meat, eggs, fish, chicken, and cereals, particularly in the form of organic mixtures (Sager, 2006; Klapec et al., 2004; Ventura et al., 2007a, 2007b). The role of these food groups for dietary Se intake is most important. Fish is reported to be the highest in foodstuff list in terms of Se content, with huge fluctuation among its diverse classes. Nevertheless, fish is typically considered a deprived home of available Se, due to the presence of undue contents of heavy metals and Hg element, fix to Se developing inorganic compounds, which are insoluble. By this way, the toxic effects of many trace elements and metals are reduced by Se (Pappa et al., 2006). Some sulfur compounds-enriched vegetables like broccoli, cauliflowers, cabbage, Brussel sprouts, garlic, onion and chives could be converted into a decent nutritional source of selenium relying on its consumed amount. Vegetables and fruits generally contains low Se contents with a value of about 10–20 μg/kg, most probably because of small amount of protein (Klapec et al., 2004; Ventura et al., 2009; Sigrist et al., 2012), thus, their contribution to the Se dietary intake is very small. Among the foodstuffs, the highest levels of Se were reported to be 3800 μg/kg, in Brazilian nuts (Manjusha et al., 2007). The significant addition of cow's milk to that of total dietary intake, largely for children is of great concern (Zand et al., 2011; Pappa et al., 2006).

It is absolutely significant to perform an accurate calculation of content of Se in various foodstuffs since the gap among the low and high levels is quite narrowing for safety. The currently available different procedures for the analysis of trace element selenium (Foster and Sumar, 1995) are, (i) analysis of neutron mobilization (Slejkovec et al., 2000), (ii) AFS (atomic fluorescence spectrometry) (Semenova et al., 2003; Pappa et al., 2006), (iii) AAS (atomic absorption spectrometry) by means of both electro-thermal reduction to atoms/atomization (Hussein and Bruggeman, 1999) and method for production of hydride (Mindak and Dolan, 1999), and (iv) ICP MS, or inductively coupled plasma spectrometry (Park and Kim, 2001; Featherstone et al., 2004).

2. Selenium content in different foods

Food safety for public health has prime importance worldwide and oral ingestion of food has been reflected as a most significant exposure path of selenium and other PTEs to humans. Human diet may contain a range of essential as well as toxic elements (Abbas et al., 2017). Most of the people get the total Se nearly from the foods which they consume. In plant and animal tissue, Se is located usually bound with proteins. Hence, the utmost important food sources of Se reported are seafood and meats (based on their higher protein contents), and cereals, as they likely to be taken in massive amounts (Fig. 1). On contrary, foods with comparatively low protein contents, such as fruits and vegetables, have relatively low contents of Se. In all cases, food Se contents reveals the available soil Se content utilized for the production of these foods (Lichtfouse et al., 2015). Different sources and ranges of selenium concentration are depicted in Fig. 2, still the amounts may differ extensively according to the soil Se content in different regions (Mahalingam et al., 1997).

The Upper Level (UL) of tolerable intake for an adult is fixed at 400 μg/day, which is built on an adverse effect known as selenosis (Food and Nutrition Board, USA Institute of Medicine, 2000). For adults a so-called population reference Intake of 55 μg Se/day, however based on other criteria more levels of intakes were also set by the Scientific Committee for Food of the European Commission (1993). A combined IAEA /FAO /WHO skilled discussion (WHO, 2004) provided numerous ways for the requirements calculation of an individual and entire populations. The daily Se dose set by World health organization, for an

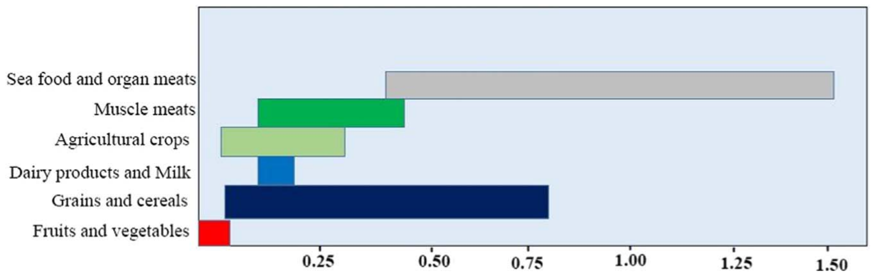

Fig. 1. Typical selenium concentration (mg/kg) of food sources.

adult person is 30–40 µg/day, highlighted the safe Se doses value of 400 µg/day. For women, at the time of lactation and pregnancy, an intake level 60–70 µg Se/day should be established (Slencu et al., 2012). A recommended intake of 50 µg Se/day for men was established by the Nordic Nutrition Recommendations (1996), with an average requisite of 35 µg/day and a lower limit of required intake of 20 µg/day, while for women the corresponding figures being 40, 30 and 20 µg/day, respectively. Nevertheless, when the World Health Organization (WHO) and the Nordic Nutrition Council restructured their recommendations in 2004 (Nordic Council of Ministers, 2004; WHO, 2004), they decided that there was no significant innovative indication to include into their conclusions and the reference standards were remained unchanged, regardless of almost ten years passing since the preceding reports. Two among the most updated published recommendations, Australia and New Zealand (AU/NZ) (National Health and Medical Research Council, 2005), and WHO (WHO, 2004) are relatively dissimilar, regarding the Recommended Dietary Intake (RDI, RDA equivalent) of AU/NZ more as double the value of the corresponding Recommended Nutrient Intake (RNI) established by WHO. In fact, the AU/NZ recommendations are more in harmony with those previously published in 1991 by UK.

2.1. Selenium content in meat (chicken, fish, beef pork) and eggs

Meat, fish, chicken and eggs are protein-rich foods in which high Se contents are present (Sirichakwal et al., 2005). Levels of Se present in these groups of foodstuffs are given in Table 1. Ventura et al. (2007a, 2007b) determined Se contents in various foodstuffs ranging from 87.6 to 737 µg/kg. Highest contents of Se were found in fish and eggs (Haratake et al., 2007). In many countries like Japan, Portugal and Greece, the main source of food Se, were meat, eggs and fish (Ventura et al., 2007a, 2007b; Haratake et al., 2007). Fish was the major supplier of Se in Japan, for the total intake/day (60%), as compared to daily used necessary food like vegetables and rice (Haratake et al., 2007). Data regarding Se concentration in fish across various countries ranged from 120.0 to 632.0 µg/kg in Australia (McNaughton and Marks, 2002), in Greece 62.7–506.7 (Pappa et al., 2006), in Slovenia 153–686 (Smrkolj et al., 2005) in New Zealand 195–512 (NZ-ICFRL, 2000) and in the USA from 126 to 502 µg/kg (USDA, 1999).

Gbadebo et al. (2010) reported a much higher Se content of 3020 µg/kg in chicken from Nigeria. Larsen et al. (2002) calculated Se levels in eggs from Denmark having an average content of 242 ranging from 171 to 326 µg/kg, in Portugal 240.1 µg/kg (Ventura et al., 2007a, 2007b), Lemire et al. (2010) determined Se content in both egg yolk and white from Brazil having 560 and 210 µg/kg respectively; while Tinggi (1999) determined levels of Se in boiled eggs in Australia, with 90 µg/kg in white and 260 µg/kg in yolk. Selenium contents found in meat derivatives were in the range of 55.0–329 µg/kg, which were higher as compared to other dietary groups (Marzec et al., 2002). In terms of Se contents in meat, it revealed great deviation, speculating changes exist in Se levels of the feedstuff exhausted by different animal species (Pappa et al., 2006). Pappa et al. (2006), determined mean Se content in meat from Greece, with a value of 48.8–94.1 µg/kg, with pork calculating considerably much higher meat. In Spain for pork meat Se concentration reported was 849–1543 µg/kg (Díaz-Alarcon et al., 1996); in China 109.5–177.7 (Gao et al., 2011) and in UK 120–150 µg/kg (Barclay et al., 1995).

2.2. Selenium concentration in vegetables and fruits

Generally, low contents of Se are present in fruits (as shown in Table 2) and this case could be better understood mainly due to the presence of low protein and high water level. Most of the fresh vegetables were also found to be the poor sources of Se (Sirichakwal et al., 2005; Pappa et al., 2006; Al-Ahmary, 2009). Therefore, the number of Lacto-vegetarians and vegetarians in terms of Se intake is reduced, which could lead to deficiency of Se in food (Navarro-Alarcon and Cabrera-Vique, 2008; Slencu et al., 2012). Some of the vegetables, which are well-known for having a trend to accumulate high Se contents are *B. juncea*, some known species from the *Brassica* genus

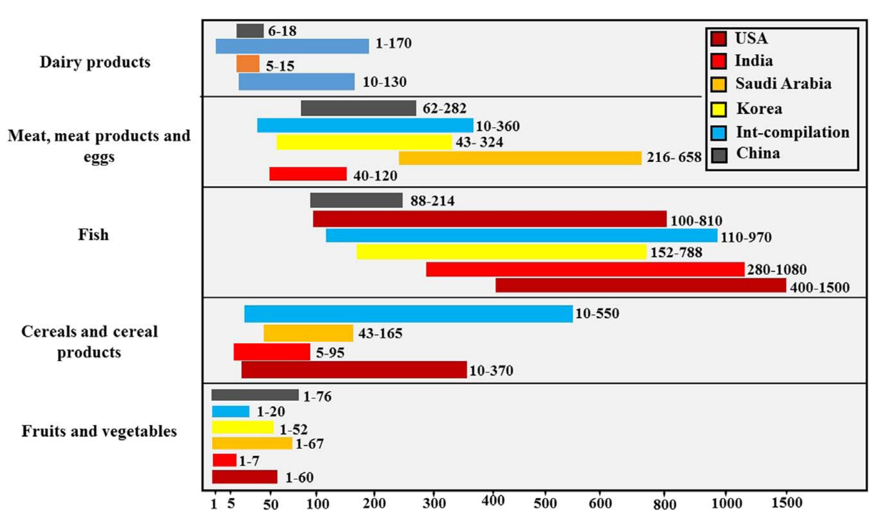

Fig. 2. Various sources and selenium levels (ranges of Se concentrations in µg/kg fresh weight).

Table 1
Selenium content in meat (chicken, fish, beef, pork) and eggs across different countries.

Type of food/ Sample	Country	Contents(μg/kg)	SD	Range	References
Meat					
Chicken	China	111.7	32.0	62.1–150.4	Gao et al. (2011)
	Saudi Arabia	353	0.0074	–	Al-Ahmary (2009)
	Argentina	120	–	62–205	Sigrist et al. (2012)
	Korea	147	–	–	Choi et al. (2009)
	Slovenia	–	–	97–153	Smrkolj et al. (2005)
	Greece	79.41	± 3.1	–	Pappa et al. (2006)
	Brazil	330	± 70	150–580	Lemire et al. (2010) and Santos et al. (2017)
	Russia	120	± 0.05	–	Gorbunov et al. (2015)
	Ireland	–	–	86–147	Murphy and Cashman (2001)
	Turkey	188	± 0.01	–	Demirel et al. (2008)
	Denmark	124	–	71–177	Larsen et al. (2002)
	Nigeria	3020	± 0.10	–	Gbadebo et al. (2010)
	Portugal	144.6	± 43.1	92.6–194	Ventura et al. (2007a, 2007b)
Fish	China	126.6	34.5	88.4–214.2	Gao et al. (2011)
	Saudi Arabia	658	0.0063	–	Al-Ahmary (2009)
	Argentina	243	–	94–314	Sigrist et al. (2012)
	Australia	–	–	120.0–632.0	McNaughton and Marks (2002)
	Russia[a]	550	± 0.48	–	Gorbunov et al. (2015)
	Russia[b]	590	± 0.32	–	Gorbunov et al. (2015)
	Korea	251	–	–	Choi et al. (2009)
	Slovenia	–	–	153–686	Smrkolj et al. (2005)
	Ireland	–	–	233–299	Murphy and Cashman (2001)
	France	–	–	20–761	Guerin et al. (2011)
	Greece	–	–	62.7–506.7	Pappa et al. (2006)
	Denmark[c]	187	–	117–285	Larsen et al. (2002)
	Portugal	616.8	± 128.2	457–737	Ventura et al. (2007a, 2007b)
	USA	–	–	126–502	USDA (1999)
Beef	China	89.6	14.9	66.8–116.1	Gao et al. (2011)
	Saudi Arabia	390	0.0081	–	Al-Ahmary (2009)
	Argentina	86	–	42–153	Sigrist et al. (2012)
	Brazil	380	± 0.09	300–470	Lemire et al. (2010) and Santos et al. (2017)
	Russia	27	± 0.009	–	Gorbunov et al. (2015)
	Korea	324	–	–	Choi et al. (2009)
	Slovenia	35	± 3	–	Smrkolj et al. (2005)
	Ireland	–	–	61–105	Murphy and Cashman (2001)
	Australia	–	–	80–200	Sigrist et al. (2012)
	USA	–	–	190–1000	Murphy and Cashman (2001)
	Greece	–	–	48.8–94.1	Pappa et al. (2006)
	UK	76	–	68–84	Barclay et al. (1995)
	Turkey	381	± 0.03	–	Ayar et al. (2009)
	Denmark	93	–	< 40–148	Larsen et al. (2002)
	Portugal	145.5	± 39.8	87.6–174	Ventura et al. (2007a, 2007b)
Pork	China	150.3	16.6	109.5–177.7	Gao et al. (2011)
	Russia	120	–	–	Gorbunov et al. (2015)
	Korea	174	± 0.04	–	Choi et al. (2009)
	USA	–	–	144–450	USDA (1999)
	Ireland	10.4	–	8.2–12.9	Murphy and Cashman (2001)
	Spain[d]	–	–	849–1543	Díaz-Alarcon et al. (1996)
	Denmark	115	–	63–210	Larsen et al. (2002)
	Nigeria	720	± 0.04	–	Gbadebo et al. (2010)
	UK	140	–	120–150	Barclay et al. (1995)
Duck	China	107.2	13.7	88.2–128.1	Gao et al. (2011)
Eggs	China	151.7	48.7	81.7–242.0	Gao et al. (2011)
	Australia	–	–	90–260	Tinggi (1999)
	Greece	172.8	–	–	Pappa et al. (2006)
	Saudi Arabia	226	0.0035	–	Al-Ahmary (2009)
	Argentina	178	–	134–217	Sigrist et al. (2012)
	Brazil[e]	560	± 0.19	190–830	Lemire et al. (2010) and Santos et al. (2017)
	Brazil[f]	210	± 0.14	40–530	
	Korea	267	–	–	Choi et al. (2009)
	Ireland[f]	–	–	56–81	Murphy and Cashman (2001)
	Ireland[e]	–	–	222–282	=
	Denmark	242	–	171–326	Larsen et al. (2002)
	Portugal	240.1	± 16.4	230–262	Ventura et al. (2007a, 2007b)

[a] River fish.
[b] Shrimps.
[c] Trout.
[d] Pork kidney.
[e] Egg yolk.
[f] White.

Table 2
Selenium concentration in vegetables and fruits reported by various authors across the globe.

Type of food	Sample	Country	Contents (µg/kg)	SD	Range	References
Vegetable and fruits	Apple	China	1.47	0.52	0.76–2.32	Gao et al. (2011)
		S Arabia	11	0.004	–	Al-Ahmary (2009)
		Greece	1.41	4	–	Pappa et al. (2006)
		Australia	4.5	± 0.2	–	Pyrzynska (2009)
		Portugal	0.7	–	–	Ventura et al. (2009)
		Croatia	8.8	–	–	Klapec et al. (2004)
	Brassica	China	2.80	1.75	0.49–4.32	Gao et al. (2011)
	Banana	China	3.21	1.43	0.99–6.81	Gao et al. (2011)
		S Arabia	4	0.0019	–	Al-Ahmary (2009)
		Greece	25.012	± 0.7	–	Pappa et al. (2006)
		Croatia	20.3	± 0.6	–	Klapec et al. (2004)
	Cabbage	China	2.96	2.51	0.52–7.74	Gao et al. (2011)
		S Arabia	9	± 0.0002	–	Al-Ahmary (2009)
		Russia	< 20	–	–	Gorbunov et al. (2015)
		Slovenia	–	–	1.1–76.7	Smrkolj et al. (2005)
	Potato	China	6.18	2.26	3.78–10.8	Gao et al. (2011)
		Brazil	110	± 0.14	10–230	Lemire et al. (2010)
		Russia	< 20	–	–	Gorbunov et al. (2015)
		Turkey	72	–	–	Sager (2006)
		Slovenia	1.5	± 0.3	–	Smrkolj et al. (2005)
		Sweden	–	–	9–34	Sager (2006)
		Germany	–	–	9–34	Kumpulainen (1993)
		S Arabia	1.0	± 0.3	–	Al-Ahmary (2009)
		Croatia	9.5	± 1.3	–	Klapec et al. (2004)
		Portugal	0.3	–	–	Ventura et al. (2009)
		Australia	–	–	30.0–70.0	Marro (1996)
		Scotland	–	–	9–34	Kumpulainen (1993)
		Norway	–	–	9–34	Sager (2006)
		Austria	–	–	20 – 40	Eurola et al. (2003)
	Carrot	China	1.86	1.17	0.82–4.28	Gao et al. (2011)
		Greece	6.12	± 2.4	–	Pappa et al. (2006)
		Croatia	19.6	± 0.2	–	Klapec et al. (2004)
		Portugal	2.9	–	–	Ventura et al. (2009)
		S Arabia	4.0	± 0.8	–	Al-Ahmary (2009)
		Russia	< 20	–	–	Gorbunov et al. (2015)
		Slovenia	–	–	0.1–11.6	Smrkolj et al. (2005)
	Orange	Greece	4.312	± 0.8	–	Pappa et al. (2006)
		S Arabia	28	± 1.7	–	Al-Ahmary (2009)
		Croatia	7.6	± 1.5	–	Klapec et al. (2004)
		Portugal	0.6	–	–	Ventura et al. (2009)
		Korea	28	–	–	Choi et al. (2009)
		Australia	5.00	–	–	Marro (1996)
	Mushroom	China	76.1	23.7	45.3–112	Gao et al. (2011)
		Ireland	3.3	–	2.5–3.8	Murphy and Cashman (2001)
		India	1340	± 13	–	Manjusha et al. (2007)
	Tomato	China	1.54	1.06	0.64–4.27	Gao et al. (2011)
		S Arabia	15	0.0006	–	Al-Ahmary (2009)
		Greece	2.32	± 0.1	–	Pappa et al. (2006)
		Russia [a]	801	± 0.06	–	Gorbunov et al. (2015)
		Turkey [a]	331	± 0.02	–	Karadas (2014)
		Slovenia	–	–	1.1–29.1	Smrkolj et al. (2005)
		Portugal	0.3	–	–	Ventura et al. (2009)
		Croatia	7.9	± 3. 2	–	Smrkolj et al. (2005)
		Nigeria	100	± 0.74	–	Gbadebo et al. (2010)
	Grapes	Greece	0.023	± 0.0026	–	Pappa et al. (2006)
	Dill	Greece	13.41	± 2.5	–	Pappa et al. (2006)
	Garlic	Slovakia	3.5	–	–	Kadrabova et al. (1997)
	Onion	Greece	7.312	± 0.05	–	Pappa et al. (2006)
		Brazil	70	± 0.11	< 10- 210	Lemire et al. (2010)
		S Arabia	43	± 0.0022	–	Al-Ahmary (2009)
		Korea	52	–	–	Choi et al. (2009)
		Slovenia	–	–	1.1–10.5	Smrkolj et al. (2005)
		Croatia	15.3	–	–	Klapec et al. (2004)
		India	127	–	–	Singh and Garg (2006)

[a] Tomato sauce;

(cauliflower, cabbage, kohlrabi, broccoli, mustard, collards,) onion, garlic and chives from *Allium* genus. These species accumulate high Se contents due to the presence of sulfur-riched amino acids in higher fragment in them (Kapolna and Fodor, 2007; Pyrzynska et al., 2009). Dumont et al. (2006), concluded onions and garlic not only as a good source of dietary Se, but they also had admirable anti-carcinogenic actions. In addition, intake dosage of both of them (even at excess levels) neither result in surplus Se aggregation in tissues nor could cause any disruption in Se enzymes activity.

High levels of Se (1340 µg/kg) in mushrooms were found by Manjusha et al. (2007), in India. According to Dumont et al. (2006), not the total species of mushrooms but few have a predisposition to get Se, since some other vegetable species which contains compounds having high levels of sulfur. One of the most frequently investigated mushrooms for the purpose of Se speciation is *Agaricus bisporus,* which is also most commonly exhausted in the USA and Europe. Some other species of mushrooms which can accumulate Se are *Braccica macrolepiota* and *Boletus edulis*.

2.3. Selenium content in milk and dairy products

High Se contents has been revealed in human's milk amongst various species of animals followed by sheep, goat and cow milk. The correlation between Se contents in milk with its fat concentration were known to be negative (Pappa et al., 2006). This fact was also found in UK by Barclay et al. (1995) in cheese. Milk and dairy products play a significant role, specifically for newborn children in total food Se intake (Pappa et al., 2006; Slencu et al., 2012). A study conducted on Se content in cow milk of Australia, showed a huge fluctuation with lower contents (20.7 ± 4.2 µg/kg) in winter milk than in summer with (23.8 ± 4.6 µg/l) higher levels (Navarro-Alarcon and Cabrera-Vique, 2008). Se concentration in dairy products was determined by Cabrera et al. (1996), they observed a great variation amongst the figures obtained, because of the different Se content found in milk, cereals, fruit, eggs and other different feedstuffs utilized for their production. Se contents in milk and dairy products are listed in Table 3, reported by various authors across different countries.

2.4. Cereals and its derivatives, nuts and legumes

Murphy and Cashman (2001), reported that the Se content in wheat grain from the USA ranged from 627 to 870 µg/kg, presenting the highest concentration (Table 4). The Se concentration of wheat flour and wheat grain samples from Germany, Sweden, Norway and Scotland, were only 9–34 µg/kg, which was less than reported in Turkish wheat, 72 µg/kg (Kumpulainen, 1993). A very high mean concentration of Se (3800 µg/kg) in Brazil nuts was reported by Manjusha et al. (2007). The Brazilian nuts are especially famous for their remarkable Se contents and the Recommended Dietary Allowance (RDA) for Se could be exceeded by a single Brazil nut (Dumont et al., 2006).

Al-Ahmary (2009) determined Se contents in bread (52 µg/kg), while Marro (1996), found Se concentration of 80–109 µg/kg in white bread with a mean of 92.6 µg/kg and 100–152 µg/kg in the total meal bread with a mean of 125 µg/kg. The mean Se levels for bread was from 70 to 131.8 µg/kg, reported by Pappa et al. (2006). In Australia, the most important source of Se was wheat derivatives like bread with 60–150 µg/kg and pasta 10–100 µg Se/kg, reported by Tinggi et al. (1992) and also by Díaz-Alarcon et al. (1996).

3. Agents controlling Se levels in different foodstuffs

Geographically, foodstuffs of each country of the world possess different levels of Se content. The type of soil directly reveals the content and bioavailability of Se into plants, on which the plants are grown (Moreno Rodriguez et al., 2005; Navarro-Alarcon and Cabrera-Vique, 2008). Some physicochemical factors generally influence the bioavailability of Se for plants, but the chemical mode of Se exist in soil is considered more significant. The Selenate is more vulnerable to be absorbed as compared to Selenite (Aro et al., 1995; Navarro-Alarcon and Cabrera-Vique, 2008). The Se content in diet, consumed by animals reflect the content of Se in different animal foodstuffs (Barclay et al., 1995; Slencu et al., 2012).

The protein contents present in food is another agent which influence the levels of Se in various foodstuffs. Amino acids containing Se, such as Se-Met (selenomethionine), selenocystathionine and Se-Cys

Table 3
Selenium content (µg/kg) in milk and dairy products, reported by various authors.

Type of food	Sample	Country	Contents(µg/kg)	SD	Range	References
Milk and dairy products	Milk	China	15.0	2.7	10.1–18.0	Gao et al. (2011)
		Turkey	230	± 0.12	–	Ayar et al. (2009)
		Korea	60	–	–	Choi et al. (2009)
		Slovenia	12.5	± 0.9	13.1–21.9	Smrkolj et al. (2005)
		Greece	–	–	16.9–28.7	Pappa et al. (2006)
		Croatia	–	–	14–22	Klapec et al. (2004)
		Ireland	–	–	–	Murphy and Cashman (2001)
		Egypt	53	–	8–12	Akl et al. (2006)
		UK [a]	1	–	7–34	Barclay et al. (1995)
		UK [b]	15	–	–	Barclay et al. (1995)
		India [b]	25.7	± 5.3	–	Sager (2006)
	Yoghourt	China	8.55	1.14	6.93–10.6	Gao et al. (2011)
		Korea	11	–	–	Choi et al. (2009)
		Slovenia	12.5	± 0.5	–	Smrkolj et al. (2005)
		Croatia	29.9	± 10.4	–	Klapec et al. (2004)
		UK [c]	14	–	9–21	Barclay et al. (1995)
		UK [d]	15	–	11–18	Barclay et al. (1995)
	Butter	Turkey	320	± 0.35	–	Ayar et al. (2009)
		Slovenia	24.0	± 6.3	–	Smrkolj et al. (2005)
		Greece	4.4	–	–	Pappa et al. (2006)
		Australia	–	–	0.7–14.2	Fardy et al. (1994)
		S Arabia	226	± .0035	–	Al-Ahmary (2009)
	Cream	S Arabia	24.0	± 4.3	–	Al-Ahmary (2009)
		Greece	–	–	6.9–13.8	Pappa et al. (2006)
		Slovenia	15.3	± 1.4	–	Smrkolj et al. (2005)
	Cheese	Slovenia	23.2	± 3.1	–	Smrkolj et al. (2005)
	Cheese [e]	Greece	43.5	± 15.7	–	Pappa et al. (2006)
	Cheese [f]	Greece	43.3	± 16,3	–	Pappa et al. (2006)

[a] Skimmed milk.
[b] Whole milk.
[c] Full fat.
[d] Low fat.
[e] Sheep cheese.
[f] Goat cheese.

Table 4
Selenium content (μg/kg) in cereals and its derivatives, nuts and legumes.

Type of food	Sample	Country	Contents(μg/kg)	SD	Range	References
Cereals and its derivatives	Flour	China	21.2	3.7	15.7–31.8	Gao et al. (2011)
	Rice	China	23.6	6.2	14.5–34.6	Gao et al. (2011)
		Thailand	50	± 11	–	Sirichakwal
		Greece	19.1	± 1.4	–	Pappa et al. (2006)
		Spain	67	± 2	–	Matos-Reyes et al. (2010)
		Italy	20.1	± 45.3	–	Smrkolj et al. (2005)
		Brazil	130	± 0.09	30–230	Lemire et al. (2010)
		Russia	230	± 0.12	–	Gorbunov et al. (2015)
		Turkey	92	± 0.01	–	Demirel et al. (2008)
		Korea	50	–	–	Choi et al. (2009)
		Nigeria	2010	–	–	Gbadebo et al. (2010)
	Wheat	S Arabia[a]	165	± 0.0012	–	Al-Ahmary (2009)
		Argentina[b]	28	–	22–42	Sigrist et al. (2012)
		Sweden [a]	–	–	9–34	Sager (2006)
		Germany [a]	–	–	9–34	Sager (2006)
		Korea[a]	123	–	–	Choi et al. (2009)
		Slovenia[a]	11	–	–	Smrkolj et al. (2005)
		Scotland [a]	–	–	9–34	Sager (2006)
		Norway [a]	–	–	9–34	Kumpulainen (1993)
		Ireland[a]	–	–	13–39	Murphy and Cashman (2001)
		USA[a]	–	–	627–870	Murphy and Cashman (2001)
		Sweden [b]	–	–	9–34	Kumpulainen (1993)
		Germany [b]	–	–	9–34	Sager (2006)
		Scotland [b]	–	–	9–34	Kumpulainen (1993)
		Norway [b]	–	–	9–34	Kumpulainen (1993)
		Turkey [a]	72	–	–	Sager (2006)
		Turkey [b]	72	–	–	Kumpulainen (1993)
	Maize	S Arabia	110	± 0.0085	–	Al-Ahmary (2009)
	Cakes	S Arabia	108	± 0.0512	–	Al-Ahmary (2009)
	Bread	S Arabia	52	0.0041	–	Al-Ahmary (2009)
		Greece	70.0–131	± 8	–	Pappa et al. (2006)
Nuts	Brazilian nut	Brazil	3800	–	–	Manjusha et al. (2007)
	Coconut	S Arabia	93	± 2.1	–	Al-Ahmary (2009)
	Chestnut	Korea	2	–	–	Choi et al. (2009)
	Peanuts	Korea	146	–	–	Choi et al. (2009)
		S Arabia	145.0	± 6.3	–	Al-Ahmary (2009)
		USA	75	–	–	USDA (1999)
	Beans	Slovenia	52.6	± 21.3	–	Smrkolj et al. (2005)
		Greece	24.4	± 3.7	–	Pappa et al. (2006)
	Lentils	USA	28.0	–	–	USDA (1999)
		S Arabia	76.0	± 4.3	–	Al-Ahmary (2009)
		Greece	443.9	± 29.3	–	Pappa et al. (2006)

[a] Wheat grain.
[b] Wheat flour.

(selenocysteine), can replace Sulfur in the amino acids because of their similar physicochemical properties. The biosynthesis of Se-Cys and Se-Met, is the main function of Se complexes in plants, later on, both are assimilated into proteins of vegetables. Forms of Se present in vegetable proteins derived from livestock feedstuff can be utilized for animal proteins production, in order to promote their aggregation in animals (Reilly, 2006; Navarro-Alarcon and Cabrera-Vique, 2008). Selenomethionine is generally integrated into proteins, instead of an essential amino acid in human, methionine (Thomson, 1998; Reilly, 2006).

Another factor which affects Se contents in various foodstuffs is different agricultural practices. To indirectly promote the Se status in humans, fertilizers supplemented with Se, have been used to increase Se contents in grown plants (Aro et al., 1995; Slencu et al., 2012). Fish and other aquatic species can accumulate high levels of Se, in a polluted aquatic ecosystem, as a result of several manufacturing and industrial actions (Navarro-Alarcon and Cabrera-Vique, 2008, Hamilton, 2004). The intermediary and transforming events of different foodstuffs may tackle down the levels of Se through a number of different techniques. In which, cooking, boiling, grilling and baking processes can decrease Se concentration by volatilization, under particular conditions (Sager, 2006). For instance, about 40% losses of Se in mushrooms and asparagus were detected after being heated for some time (Dumont et al., 2006). Thomson and Robinson (1990), also observed slight Se losses during roasting fish and chicken. Nevertheless, studies conducted by other researchers did not show any losses, but they noticed that exposure to air, cooking or lyophilization processes, considerably increased levels of Se in all kinds of foodstuffs (Zhang et al., 1993). By scrutinizing the incompatible outcomes discovered from wide range of research, further study is desirable in this field in order to elucidate the particular impact which catering practices apply on dietary Se concentration.

4. Recommended intake of selenium

Recent investigations have suggested that diet incorporates the main exposure pathway to PTEs in humans, which alone can exceed permissible safe-levels of Se and other PTEs. Thus, peoples are more likely to be exposed to PTEs through dietary intake of food (Yousaf et al., 2016, 2018). The major source of Se is diet and its contents in food and quantity of food utilized reflect the intake of this essential element (Navarro-Alarcon et al., 2008). In order to provide support for the supreme manifestation of Se enzymes, the diet of an adequate adult must have a minimum Se content of 40 μg/day and for the reduction of cancer risk, possibly with maximum 300 μg/day (Combs, 2001). For both male and female, the RDA (Recommended Dietary Allowance) for Se is 55 μg/day (Food and Nutrition Board, USA Institute of Medicine,

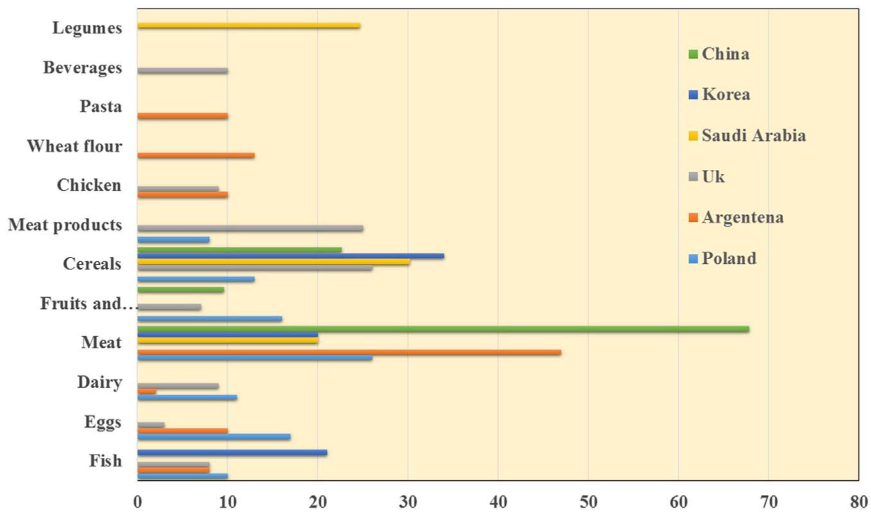

Fig. 3. Percent contribution of some food groups for daily dietary Se consumption.

2000).

Information on literature review (Combs, 2001; Wąsowicz et al., 2003; Kieliszek and Błazejak, 2016) affirms that recommended value for Se intake differs relying mainly on the geographical area. The residents of some selected parts of China consume the highest amounts (7–4990 µg/day), residents of the Venezuela (200–350) while that of the Czech Republic consume the minimum Se dosage (10–25 µg/day). The European Food Safety Authority (EFSA, 2008), reported that the estimated intake of daily dietary Se in the European people is from 20 to 70 µg/day (Slencu et al., 2012; Alfthan et al., 2015; Ros et al., 2016). The estimated intake level of Se in Argentina was suggested deficient, for an adult male and female with 32 and 24 µg/day, respectively (Sigrist et al., 2012). In Bangladesh, the total daily intake of Se is 87 µg/day (Al-Rmalli et al., 2017), in Saudi Arabia it ranges from 75.–121.65 µg/day (Al-Ahmary, 2009), while in Poland its intake level is 30–40 µg/day (Wąsowicz et al., 2003).

The daily intake dose of Se in African country named Burundi, was 17 µg, determined by Benemariya et al. (1993), and they concluded Se deficiency threat for the rural inhabitants. Nevertheless, information regarding Se, are either rare or absent from most regions of Africa, South America and Southern Asia. The percent contribution of different foodstuffs for daily dietary Se intake in each analyzed food is demonstrated in Fig. 3. The daily Se intake from different countries across the world reported by various authors are listed in Table 5, which determine an extensive inconstancy amongst different parts of the world. However we acknowledge a healthy person with a varied and balanced food must consume a proper dietary Se level and the intake of this trace element in excess doses is not required.

5. How selenium enters the food chain

Selenium occurs as organic and inorganic forms in the environment. The main organic forms are SeCys and SeMet, while selenate (SeO_4^{2-}), selenite (SeO_3^{2-}), selenide (Se^{2-}) and elemental Se are the inorganic forms of Se (Bodnar et al., 2012; Wu et al., 2015). Selenium gets into the food chain mainly through the plants, while the intake by drinking water is usually minor (Reilly, 2006). Plants Se content is directly associated with its adjacent soil Se content (Mehdi et al., 2013). The Se uptake, transfer and distribution are influenced by Se form and concentration, plant species, soil reaction, stages of growth, physiological settings such as soil pH and salinity and various other substances (Li et al., 2008; Renkema et al., 2012). Plants have been categorized into three groups based on the total Se accumulation inside their cells (Bodnar et al., 2012).

- Those plants which contain up to < 100 mg Se/kg of dry matter are known as Se non-accumulators. These plants if grow on Se rich soils, results in stunted growth, and volatilize selenium in the form of dimethylselenide, e.g. potatoes, grasses, cereals, crops.
- Secondary selenium accumulators absorb Se and indicate no marks

Table 5
Estimated selenium intake of population in various countries.

Country	Se intake (µg/day	References
Australia	58–85	FSANZ (2003)
Bangladesh	87.7	Al-Rmalli et al. (2017)
Canada	113–224	Combs (2001)
China	69	Zang et al. (2001)
Egypt	49	Hussein and Bruggeman (1999)
Greece	39	Pappa et al. (2006)
Italy	51	Amodio-Cocchieri et al. (1995)
Japan	129	Hirai et al. (1996)
Netherlands	72	Van Dokkum et al. (1989)
Sweden	38	Dumont et al. (2006)
UK	29–39	http://www.food.gov.uk/ultimedia/pdfs/selenium.pdf FSA (2008)
USA	60–160	Navarro Alarcon and Cabrera-Vique (2008)
Korea	57.5	Choi et al. (2009)
France	29–43	Lamand et al. (1994), cited by Rayman (2004)
Serbia	30	Djujic et al. (1995) cited by Rayman (2004)
Poland	30–40	Wąsowicz et al. (2003)
Turkey	30–40	Hincal (2007)
México	61–73	Valentine et al. (1994)
Norway	80	Meltzer et al. (1992)
New Guinea	20	Donovan et al. (1992)
Scotland	30–60	MacPherson et al. (1997)
Spain (South-eastern)	72.6	Díaz-Alarcon et al. (1996)
Switzerland	70	Dumont et al. (2006)
S Arabia	75–121.65	Al-Ahmary (2009)
Finland[a]	25	Aro et al. (1995)
Finland[b]	67–110	Anttolainen et al. (1996)
Belgium	28–6128–61	Robberecht et al. (1994)
Portugal	< 50	Fairweather-Tait et al. (2011)
Libya	13–44	El-Ghawi et al. (2005)
Lithuania	100	Golubkina et al. (1992)
Argentina[c]	32	Sigrist et al. (2012)
Argentina[d]	24	

Note:.
[a] Before using Se fertilizer.
[b] After using Se fertilizer.
[c] Adults men.
[d] Adults women.

of toxicity up to 100– 1000 mg Se/Kg dry matter e.g. *Aster, brassica, Astragalus, Helianthus, Atriplex, Medicago sativa* etc. (Galeas et al., 2007).

- Hyperaccumulator plants can absorb maximum Se amounts in their cells i.e., > 1000 mg Se/Kg dry matter and can survive well in Se rich areas of the world. These plants include *Stanleya*, *Conopsis*, *Astragalus species*, *Neptunia*, *Xylorhiza, Stanleya, Haplopappus* etc. (Ježek et al., 2012).

The bioavailability of Se or total amount absorbed and consumed by the organism is of great priority to know, as generally only a part is absorbed and converted into a biologically accessible form (Cabañero et al., 2007). Preferably, a comprehensive assessment of bioavailability should include measurements of entire nutrient level, absorbable portion, actual quantity absorbed, and the percentage consumed by the organism. Studies regarding in vivo bio-accessibility are equally laborious and expensive, and the probability of calculating specific parameters is frequently limited during the experiments (Cabañero et al., 2007). *In vitro* bio-availability approaches of simulated digestion are the substitute to in vivo bioavailability methods for the percent calculation of an element which is converted into absorbable forms in the digestive zone. The outcomes of these bio-accessibility approaches are typically conveyed in the form of soluble section of the element under certain experimental settings of enzyme addition, pH, temperature, and contact period (Cabañero et al., 2007).

Selenium uptake by plants can be inhibited considerably by the simultaneous existence of maximum organic matter content in soil, clay minerals and Fe hydroxides, all of these can bind or adsorb Se (Fordyce et al., 2000). The bioavailability of Se is also influenced by Se speciation in soils: selenate is highly soluble, mobile and less adsorbed than selenite (Fordyce, 2005). Selenium transformation and accumulation in plants is in relationship with sulfur metabolism. Mostly, plants adopt selenite because of its similarity with sulfate and absorb it through the sulfur assimilation channel (Mehdawi et al., 2011). Se toxicity in plants is primarily attributed to its relations with sulfur metabolism. Sulfur cysteine and methionine (amino acids) replacement by Se amino acids may interfere the enzymatic functions and biochemical reactions inside the cells (Ježek et al., 2012).

6. Why role of selenium is important?

For both humans and animals, very minor amounts of food Se are essential to keep good health. The dietary functions of Se in human beings are attained through 25 selenoproteins in which selenocysteine is at their energetic center. The selenocysteine addition for the formation of a selenoprotein is defined by the UGA codon in mRNA under explicit conditions, however, several other intermingling features are also vital (Kryukov et al., 2003). The formation of some selenoproteins like glutathione peroxidase and GPx4 are given preference over that of others, under low Se level (Reeves et al., 2009). Selenium and other PTEs may interfere with the body organs function, endocrine system, malfunction and can disturb the nervous system or they can perform as secondary factor several other diseases (Ali et al., 2017). Several types of selenoproteins, tissue distribution and their health consequences/functions are listed in Table 6.

7. Health consequences of selenium

In humans, chronic Se toxicity results in selenosis (Goldhaber, 2003) categorized by fingernails changes and brittleness, hair loss, gastrointestinal disorders, garlic breath, skin rash, and irregular working of the nervous system. Other related toxic effects are synthesis of thyroid hormones and hormones growth, a disruption of endocrine function, and an insulin-like growth factor metabolism.

7.1. Mortality

Generally, high Se status has been related to low mortality rate in at least three potential studies. The relationship observed among Se level, all-cause and cancer mortality in 13887 mature people was non-linear, monitored up in the US 3rd National Health and Nutrition Examination Survey for about 12 years (Bleys et al., 2008). Decreased mortality incidences were associated with increased serum Se contents (135 μg/L) (Akbaraly et al., 2005a). In a study of Women's Health and Aging at the Baltimore city in older women, low status of serum Se was an important independent predictor regarding all-cause five years mortality (Ray et al., 2006). On the contrary, no relationship was found among total casualties and standard serum Se (mean 73 μg/L) in 57 years old Chinese people (n = 1103), who were surveyed for almost 15 years (Wei et al., 2004). However, these investigations are susceptible to mystifying, as plasma Se levels are higher in well-nourished and fit mature people as compared to those who are poorly nourished, fragile and not well (Bates et al., 2002), probably showing a higher level of inflammatory cytokines and lessening of Se in acute-phase response (Hesse-Bahr et al., 2000). Status of Se could have decreased years afore death due to suboptimal function of kidney i.e. kidney produces plasma GPx3, and subclinical inflammatory courses.

7.2. Antioxidant activity of Se

High organic Se performs several functions in an organism, possibly antioxidant activity is considered one of the most significant method, in which oxidative damage to the body is protected (Kunwar et al., 2013; Brummer et al., 2013). The production of free radical under normal situations are critical and the presence of sufficient antioxidants neutralize these free radicals (Santhosh Kumar and Priyadarsini, 2014). The spacious oxidation process improves the production of free radicals, which causes oxidative stress and are known as extremely complex compounds (Kunwar et al., 2009). The control of these radicals is important, otherwise, it could harm the biotic works in the whole body instigating protein carbonylation, lipid peroxidation, fractures of DNA constituent and finally causing numerous medical issues (Kunwar, 2009).

A self-protection system exists in living cells for protection against oxidative stress via the antioxidant activities. Two kinds of antioxidants are present, one is internal and the other is called complementing antioxidants. Glutathione peroxidase (GPx), and superoxide dismutase (SOD), are internal antioxidants enzymes, produced inside the cells and play a primary role in controlling of free radicals in the system (Szymonik-Lesiuk et al., 2003), while supplementing or complimenting antioxidants such as selenium and vitamins are considered secondary security system regarding control of free radicals. The free radicals which are extremely reactive can be neutralized with the help of Se containing enzymes and GPx (Kieliszek and Bła˙ zejak, 2013).

Glutathione peroxidase (GPx), helps in maintaining the membrane reliability, by converting the GSH (reduced Glutathione) to GSSG (oxidized glutathione) whereas effectuating the reduction of peroxides via transfiguring these peroxides to an innocuous liquors (Kunwar et al., 2007; Kieliszek and Bła˙ zejak, 2013). For adjudicating the antioxidant action, Redox prospective of Se compounds provide vital facts for the activity. For this purpose, Priyadarsini et al. (2013) collected data regarding redox potential of numerous compounds of Se in addition to their antioxidant events. A deficient state of Se holding interior antioxidants may take place due to the shortage of selenium intake, ultimately may result in some clinical sicknesses.

7.3. Cardiovascular disease

The implicit cardiovascular effects of Se are strengthened by an indication that oxidative amendment of lipids are prevented by selenoproteins, obstruct the accumulation of platelet, and also decrease the

Table 6
Types of selenoproteins with known purposes, their distribution in tissues and health effects.

Selenoproteins	Distribution (tissues)	Functions or health consequences	References
Glutathione peroxidase (GPxs)	All	It remove lipid Hydroperoxides, hydrogen peroxide, cholesterol hydroperoxides and phospholipid (GPx4): Intimate of antioxidant enzymes	Reeves et al. (2009)
Glutathione peroxidase 1	All	Decreases retroviral virulence via stopping viral changes: its deficiency Lead to cardiomyopathy	Beck et al. (2003)
Glutathione peroxidase 2	All	Antiapoptotic role in large intestine crypts, also supports to keep intestinal mucosal veracity	Florian et al. (2010)
Glutathione peroxidase 3	All	Acts as an antioxidant in extracellular solutions; source of GPx3 is kidney in plasma. It also provide thyroid shelter against H_2O_2 in follicular lumen and thyrocytes	Reeves et al. (2009) Schmutzler et al. (2007)
Glutathione peroxidase 4	All	Associated with membrane and mostly its level is high in the testis, where it's role is crucial for the motility and viability of sperm	Foresta et al. (2002)
Iodothyronine-deiodinases i.e. Dio1, Dio2, Dio3	Kidney, Liver, thyroid, central nervous system, and placenta	Produce an energetic thyroid hormone called T3, and reverse T3 (rT3)	Schomburg and Kohrle (2008)
Selenoprotein S (SePS1)	All	Anti-inflammatory, may guard cells from Endoplasmic reticulum (ER) stress-induced apoptosis; also associated with insulin sensitivity and glucose metabolism	Curran et al. (2005) Reeves et al. (2009) Gao et al. (2011)
Selenoprotein P (SePP1)	plasma	Transport Se, has some antioxidant activities, required for brain; its deficiency lead to spasticity, abnormal movements, also necessary for male fertility	Burk and Hill (2009)
Selenoprotein N (SelN)	Endoplasmic reticulum	It control mobilization of calcium which is important for initial muscle growth; alterations may cause myopathies containing multiminicore disease	Reeves et al. (2009)
Selenoprotein 15 kDa (SeP15)	Endoplasmic reticulum	May affect folding of glycoprotein, helps in cancer prevention	Reeves et al. (2009)
Thioredoxin reductases (Trx R1, TrxR2, Trx R3)	All	Vitamin C recycling and antioxidant action at skin; regulates activity of transcription influences, apoptosis, cell proliferation; lessening of expression cause relaxed tumor-cell development	Reeves et al. (2009)
Selenoprotein K	Skeletal muscles, Heart	Acts as an antioxidant	Lu et al. (2006)
Selenoprotein M	Thyroid, brain	Play role in redox function	Reeves et al. (2010)
Selenoprotein R (SelR)	Cytosol	Antioxidant	Lee et al. (2009)
Selenoprotein W (SelW)	Heart, Muscle, tongue and brain	Antioxidant; expressed in the skeletal muscle and other tissues	Noh et al. (2010)

process of inflammation (Rayman et al., 2011; Rayman, 2011) along with several cardio-metabolic consequences which are linked to divergence or polymorphism in Glutathione peroxidase 1(GPx1), Glutathione peroxidase 3 (GPx3), iodothyronine deiodinase 2 (Dio2) and Selenoprotein P (SEPS1)(Rayman, 2012). Nevertheless, randomized investigations regarding supplements of Se have not revealed an important protective result on cardiac disease or terminal mortality (Lippman et al., 2009; Flores-Mateo et al., 2006) however, a significantly inverse relation among status of Se and threat of disease named CHD (coronary heart disease) were found in comprehensive meta-investigation of 25 experimental studies, mostly in people whose Se intake level were low (Flores-Mateo et al., 2006). On the other hand, no relationship was observed in an investigation of young adults (3112) in America amongst coronary-artery calcium score and thickness of carotid intimamedia, concentration of toenail-selenium and sub-clinical atherosclerosis measures (Xun et al., 2010).

A potential study was carried out on levels of Se in serum and cardiac disease, stroke, total deaths and some other diseases by Wei et al. (2004). Their study conducted in randomly selected 1103 persons from China (Linxian), showed the standard level of serum Se. Later, an exploring association between standard or baseline Se in serum and the consequent threat of casualty from stroke and heart disease with a trail of about 15 years from 1986 to 2001 was performed. An inverse correlation tendencies amongst Se concentration and casualty due to heart disease ($p = 0.07$) were found. Results of these studies were nearly uncertain, for instance, if changes are biological or etiological concerns of several cardiopathies, it has not been resolved yet. However, the relationship of increased threat of coronary cardiac disease was determined with a serum Se level < 55 µg/l. Furthermore, the fact that low Se levels in some people can predict cardiovascular disease and mortality was reported by Helmersson et al. (2005). In their study, they explored the longitudinal relationship among serum Se and numerous typical indicators of oxidative pressure such as prostaglandin F2α and F2-isoprostane, in a follow-up time period of 27 years of a total of 615 Swedish men with 50 years of age. High serum Se level predicts reduced oxidative stress levels and subclinical cyclooxygenase-mediated without cytokine-mediated inflammation. So, the relationship amongst inflammation, oxidative stress and Se, might concern with Se protective properties of cardiovascular disease (Helmersson et al., 2005)

The association between increased Se level and higher plasma cholesterol have been found in many cross-sectional studies (Rayman et al., 2011). In the United Kingdom Prevention of Cancer by Intervention with selenium (UK PRECISE) randomized trial of elderly persons ($n = 501$) having low level of Se (Rayman et al., 2011), the total serum and non-HDL cholesterol were considerably decreased after complementing with 100 and 200 µg Se/day, however not more than this per day, but still HDL cholesterol level raised considerably through this amount. By adding increased dose of Se, entire cholesterol to HDL cholesterol ratio decreased significantly, recommending possibly the useful response of supplementation in that population which are at cardiovascular risk. No significant change was calculated between treatment groups in other two minor trials (Luoma et al., 1984; Yu et al., 1990).

A five years longitudinal research on 70–79 years old women ($n = 632$) was carried out by Ray et al. (2006). Their results indicated a significant association of carotenoid levels and high serum Se with a minor threat of death. Nearly, half of the five most important studied reasons of mortality were linked with cardiovascular system. The primary reason was heart disease with 32.6%, while stroke was ranked three with 9% (Ray et al., 2006).

Some medical investigations firmly support valuable effects of Se over cardiovascular functioning. Derbeneva et al. (2012) found some positive variations in patients, these variations were related to better action, overall improved health and enhanced physical functions with cardiovascular diseases in suffered persons. In another study, positive correlation was also investigated among cardiovascular entanglements and Se level, by Turan (2010). Cominetti et al. (2012) investigated better lipid profile and Se status in fat persons after Brazilian nuts consumption, particularly levels of lipoprotein cholesterol with high-density, thus curtailing the risks of cardiovascular diseases. Schnabel et al. (2008) also concluded that supplementation of Sodium selenite improved the antioxidant potential via GPx-1 action in coronary artery malady and in endothelial cells in suffered persons. In spite of considerable research, the protecting role of Se remains ambiguous against cardiovascular diseases. In some works, Se protection was found reliable with suppositious risk limit of around 79 μg/l in plasma, and that coincides with the limit prescribed to enhance antioxidant GPx (Thomson, 2004)). To achieve the valuable responses of Se, more clinical studies in future are desired.

7.4. Selenium and cancer

Some indications have been provided by potential research, for a valuable impact of Se on the risk of lung, (Zhuo et al., 2004) colorectal, (Peters and Takata, 2008) bladder (Amaral et al., 2010), liver (Yu et al., 1999), gastric-cardia (Wei et al., 2004), esophageal (Wei et al., 2004), prostate cancers (Peters and Takata, 2008; Rayman, 2010, 2009) and thyroid (Glattre et al., 1989).

The impact of antioxidant additions on primary cancer prevalence and mortality was determined by Bardia et al. (2008) through a meta-analysis study. Se supplementation was linked with decreased number of cancer incidence in men as compared to women (Bardia et al., 2008). The WCRF (World Cancer Research Fund) meta-analysis report on prostate cancer and Se, recommend Se as more efficient in protecting against hostile prostate cancer and its development, so is considered vital for prostate cancer patients (Hurst et al., 2012). Analysis of large collection of several studies issued on the Se effect regarding gastro-intestinal cancers reported a reduction of almost 60% in gastrointestinal cancers after the supplementation of Se (Jayaprakash and Marshall, 2011; Ma et al., 2012; Ibiebele et al., 2013). In China, a nutritional intrusion experiment revealed a significant reduction in incidence of esophageal cancer and mortality (Qiao et al., 2009).

The three utmost currently published studies on prostate cancer (Allen et al., 2008; Gill et al., 2009; Steinbrecher et al., 2010) and an analysis of all (Peters and Takata, 2008) demonstrate an invariably detection of more significant defensive relations among Se and risk of improved, instead of sub-standard or localized prostate cancer, and smokers are the candidates for powerful associations.

The trial of NPC (Nutritional Prevention of Cancer) revealed a guarding influence of yeast additions enriched with Se (200 mg/day) on over-all incidence and total mortality of cancer (Clark et al., 1996). Although, the performing ways of chemo-protective effects are mysterious, but it can be set through Se, depending upon redox systems present in cells or by the activity of T cell (Cheng et al., 2012). The foremost constituents for the removal of cancer are T cells, and their activation and synthesis depend on Se (Roth et al., 2006; Shrimali et al., 2008; Carlson et al., 2010).

Results of the SELECT (Selenium and Vitamin E Cancer Trial) did not figure out Se effect over (i) prominent disease risk, for that an outstanding effect have been suggested in several studies (Cooper et al., 2008; Peters and Takata, 2008; Rayman, 2010;) meanwhile just 1% of incidents were general; (ii) death incidence due to prostate cancer, since prostate cancer caused the death of one participant only(Lippman et al., 2009); (iii) existing smokers (the powerful protecting effects for whom have been perceived) (Peters and Takata, 2008), consequently their number was about 7.5% in total SELECT inhabitants; or (iv) low Se rank men, since hardly a limited numbers in the trail were involved (Rayman et al., 2009). Certainly, while in the NPC pilot, almost third of men were not having optimum Selenoprotein P (SEPP1) or even level of GPx or action prior to additions, in SELECT, for men this is supposed to be factual, because majority would comprise of greatest selenoprotein actions or the levels at beginning (Rayman et al., 2009).

It was concluded by Connelli-Frost et al. (2006) that higher levels of body Se were related to reduced frequency regarding colorectal adenoma. However, apoptosis condition did not appear the expected system through that Se was associated with incidence of adenoma. Future experimental/medical tests aimed at Se just as prospective chemo-preventive operator for colon cancer and colon adenomas, were suggested in their study. Peters et al. (2006) found the relationship of progressive colorectal carcinoma with serum Se and stated that possibility of rising progressive colorectal adenoma can be diminished by Se, mostly amongst the higher threat smoker groups.

7.5. Type-2 diabetes

The information regarding Se effect on diabetes in living persons are deficient and frequently differing in the present outcomes. Earlier investigations have determined reduced Se level in diabetic patients in comparison to control persons (Steinbrenner et al., 2013). According to the data issued by the health experts, the incidence of diabetes was higher in men with low Se status.

It is ambiguous that through which true mechanism Se is performing in diabetic patients (human or animal). The antioxidant potential of Se might be one approach that is keeping the oxidative stress (the focal reason of diabetes) counterbalance (Fatmi et al., 2013). The impact of Se on metabolism of glucose is one more conceivable mechanism. In diabetic patients, the appearance of NF-kB is reduced through Se supplementation. The NF-kB (a protein complex) which is liable for inflammatory proteins expression like, tumor necrosis influence and interleukins (Pillai et al., 2012). According to the studies carried out by Laclaustra et al. (2009) reported that diabetes incidence increased with advancing Se levels (Laclaustra et al., 2009).

The symptoms concerning Se to glucose breakdown is incompatible (Steinbrenner et al., 2011). Advanced Se level was linked with lower prevalence of diabetes in three case-control investigations (Navarro-Alarcon et al., 1999; Rajpathak et al., 2005; Kljai and Runje, 2001), whereas in the prospective Epidemiology of Vascular Ageing (EVA) study (Akbaraly et al., 2010b), higher Se status in plasma associated with a reduced threat regarding start of hyperglycaemia in male members in the course of about 9-year follow-up duration. On the contrary, higher Se levels in serum were correlated with higher incidence of diabetes in the enormous NHANES (National Health and Nutrition Examination Surveys of US (Bleys et al., 2007; Laclaustra et al., 2009)). Moreover, the investigators documented positive associations among plasma Se and fasting glucose test both at starting point and follow-up, in the France SUVIMAX trail people (Czernichow et al., 2006).

Outcomes obtained from haphazard trials in which type-2 diabetes was a secondary result also differ. Results of SELECT showed that after, supplementation with 200 μg Se/day as selenomethionine of American men (35 533), had no impact on threat of type-2 diabetes once an average follow-up of five years and six months (Lippman et al., 2009). On the other hand, a considerably enlarged threat of type-2 diabetes was observed in those supplemented with 200 μg Se /day as Se yeast with 7.7 years followed up, in southeastern USA during a post-hoc study of the NPC test in 1312 members (Stranges et al., 2007).

7.6. Fertility and reproduction

For sperm mobility as SePP1 and GPx4 in men, Se is indispensable (Meseguer et al., 2004, 2007; Shalini et al., 2005). The synthesis of SePP1, took place in the liver from where it is received and absorbed through the testis via receptors named apoEr2 and increases the antioxidant prospective. The midpiece cover of the sperm tail, which is important for the protection of sperm through its antioxidant capability during early stage, is build up by GPx4 present in mitochondria. Afterward, it creates cross channel in the midpiece with proteins and grows into a fundamental portion for sperm motility (Ursini et al., 1999). Several studies have addressed infertility and deficiency of Se in men. The analysis of sperm samples in Italy showed that Se deficiency caused infertility, deficiency of morphological variations and feasibility and mobility in men (Papaleo et al., 2011; Busetto et al., 2012).

Experimental trials carried out in sub-fertile men (with low Se ingestion) revealed that supplementation of 100 µg Se/day considerably improved paternity and motility of the sperm (Rayman, 2000). A study conducted by Scott et al. (1998) on human sperm motility revealed that selenomethionine supplementation in men (100 µg/day) consuming initially a low Se level with low motility status, resulted in the progress of motility after 90 days. One of the previous study allocating (200 µg/day) either as sodium selenite or Se-enriched yeast exhibited no any significant consequence on capacities of semen quality (Iwanier and Zachara, 1995). In many studies, for pregnant woman, Se status was correlated with eclampsia. Se level was frequently decreased in pregnant females, due to higher volume of plasma and can also cause pre-eclampsia (Ghaemi et al., 2013).

A study conducted in UK by Rayman et al. (2003), revealed that average level of Se in toenail clippings (mostly laid down prior to pregnancy) from women having pre-eclampsia with average gestational period of about eight months was considerably lower than that of controls ($p < 0.001$). In the lowermost tertile regarding toenail Se, women with a significantly (4. 4 times) more probable chances to have pre-eclampsia as compared to those present in upper tertiles.

In order to establish the curative consequences of Se on fertility, advanced quality mediations are needed. Data until now recommends that higher dietary Se intakes could be harmful like deficiency for male fertility, therefore knowing an optimum limit for well-being is considered extremely vital.

7.7. Immune function

Although the evidence found from animal and in-vitro studies demonstrated Se importance regarding immunity/modulation, but the evidence in humans is occasional (Hoff mann, 2007; Hoff mann et al., 2010). Some organs such as liver and spleen are regulated by immune cells having plenty of Se, which indicate the most important role of Se in immunity. Information regarding Se deficiency on the reduction of the T cell role and weakened lymphocyte variations is available. Se supplementation demonstrated the immunostimulant influence like rising in cytotoxic cells and CD3, and T cell (Ren et al., 2012). A study conducted by Roy et al. (1995) stated that sodium selenite supplementation (200 mg) improved the reaction of T cell (Rayman, 2000), while an increase was observed by Wood et al. (2000) in the number of T cell via the usage of 400 µg Se in yeast. A significant rise in the proliferative reaction against antigen contest to the maximum edge of the ordinary range regarding adults was reported after the supplementation of 100 µg selenium in yeast per day in mature Belgian inhabitants for time period of 6 months (Rayman, 2000).

A correlation of the levels of plasma Se and respiratory distress syndrome was also found in preceding studies. The response of cell-mediated immunity was significantly increased in those cancer patients who had undertaken radiotherapy, after the supplementation of 200 g Sodium selenite /day (Kiremidjian-Schumacher et al., 2000). According to Broome et al. (2004), sodium selenite supplementation (100 g/day) eliminated polio virus desperately as compared to placebo. They also reported some fascinating antiviral actions of Se.

8. Conclusions and suggestions for future directions

Selenium is necessary and biologically important element for humans. Exposure of humans to Se mostly depends on its dietary intakes in food system and waters. Several changes in geological status considerably regulate its dietary intakes. In the recent past, our knowledge has been improved regarding the importance of Se in human food and its role in biological processes. The present information concerning Se role in both health and disease is vital so as to evaluate the health risk related to lower status of Se in people. Food is the main source of Se for all humans and its bioavailability arises most generally from organic forms of Se (> 80%). The food Se status can clearly be determined from its content in the soil and the average intake of total Se. Higher content of Se in soil had a direct influence on the concentrations of Se in native plants and animals and ultimately enters to body fluids in the form of biomarkers of dietary status of the people. Huge portions of Se contents present in different types of foodstuffs are still missing since anonymous forms of Se marks it challenging to describe the potential and actual health effects. Moreover, data about the bioavailability of some Se species excluding selenite and SeMet is lacking. As soon as further forms of Se could be recognized and distinguished, more and more accesses would be exposed for studying additional bioactivity and bioavailability which can reveal maximum crucial facts which are scarce or missing until now.

The influences of Se on human health are complex and multiple requiring more research as to improve the advantages and decrease the threats of this effective trace nutrient. Experiments should be carried out only in populations having low or comparatively low Se status. Moreover, since the status of Se and risk of disease are influenced by polymorphisms in selenoproteins, so

The future works must be genotype participants. In future, study aimed at knowing the possible relations among selenoproteins and extremely widespread disease of type-2 diabetes may also be considered a priority work. The fundamental issue that desires to be focused is the complicated U-shaped relation with status of Se; extra Se intake such as from diet strength or supplements may provide well advantages only to those population having low Se status. Nevertheless, people of high status or adequate Se could have adverse impacts and they should avoid Se supplements.

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