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Review article

Selenium distribution in the Chinese environment and its relationship with human health: A review

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ABSTRACT

This paper reviewed the Se in the environment (including total Se in soil, water, plants, and food), the daily Se intake and Se content in human hair were also examined to elucidate Se distribution in the environment and its effects on human health in China. Approximately 51% of China is Se deficiency in soil, compared with 72% in the survey conducted in 1989. Low Se concentrations in soil, water, plants, human diet and thus human hair were found in most areas of China. The only significant difference was observed between Se-rich and Se-excessive areas for Se contents in water, staple cereal, vegetables, fruits, and animal-based food, no remarkable contrast was found among other areas ($p > 0.05$). This study also demonstrated that 39–61% of Chinese residents have lower daily Se intakes according to WHO/FAO recommended value (26–34 μg/day). Further studies should focus on thoroughly understanding the concentration, speciation, and distribution of Se in the environment and food chain to successfully utilize Se resources, remediate Se deficiency, and assess the Se states and eco-effects on human health.

1. Introduction

Selenium (Se) is an essential micronutrient for humans and animals (Thomson, 2004; Fordyce, 2013; Mao et al., 2016). It acts as the active center of selenoenzymes and selenoproteins and plays an important role in energy metabolism and gene expression in organisms (Izquierdo et al., 2010). Therefore, it has many important biological functions, such as antioxidant, immunoregulatory, and antagonistic roles (Roman et al., 2014). Considering the narrow range between a dietary deficiency and toxic concentration of Se, researchers have examined it both as a nutrient and as an environmental contaminant (WHO, 2004; Kikkert and Berkelaar, 2013; dos Santos et al., 2017). An insufficient Se intake in humans is linked to Keshan disease (KD) and white muscle disease (Wang and Gao, 2001; Fordyce, 2013; Shi et al., 2017), whereas an excessive Se intake can result in adverse health problems, such as hair and nail loss, skin lesions, nervous system disorders, paralysis, and even death (Hira et al., 2004; Bajaj et al., 2011; Fordyce, 2013). Therefore, an adequate daily Se intake is required to maintain human health, prevent disease, and slow down the aging process (Rayman, 2012; Fordyce, 2013).

An estimated 15% of the global population (500–1100 million) is Se-deficient (Tan et al., 2016). The WHO has reported that China is one of the 40 Se-deficient countries (Xu et al., 2012). A national nutritional survey revealed that over 105 million people in 366 counties, which accounts for 72% of the country's total area, are facing adverse health impacts due to Se deficiency (Wang et al., 2017a).

The Se concentrations in soils, plants, and animals are fundamentally determined by geology. The lowest and highest concentrations, as well as the flux, of Se have been reported in the Chinese environment (Wang and Gao, 2001). Thus, cases of both endemic Se deficiency and selenosis have been recorded in China. Se-deficient areas primarily include the low-Se geological belt from the northeastern to the southwestern regions of China where the Se content in soil is < 0.125 mg/kg (Yao et al., 2011; Chen, 2012; Li et al., 2012a; Panchal et al., 2017). By contrast, endemic selenosis occurred in areas where high Se concentration in soil derived from the local Se-rich rocks (Li et al., 2012a). The food chain is the major source of Se for the human body (Hartikainen, 2005; Emmanuelle et al., 2012); in turn, soil, water, plants and livestock are the major sources of Se in the food chain. Therefore, the distribution of Se concentration and speciation in various environmental media must be investigated comprehensively. However, numerous reports conducted on Se-deficient and Se-excessive areas

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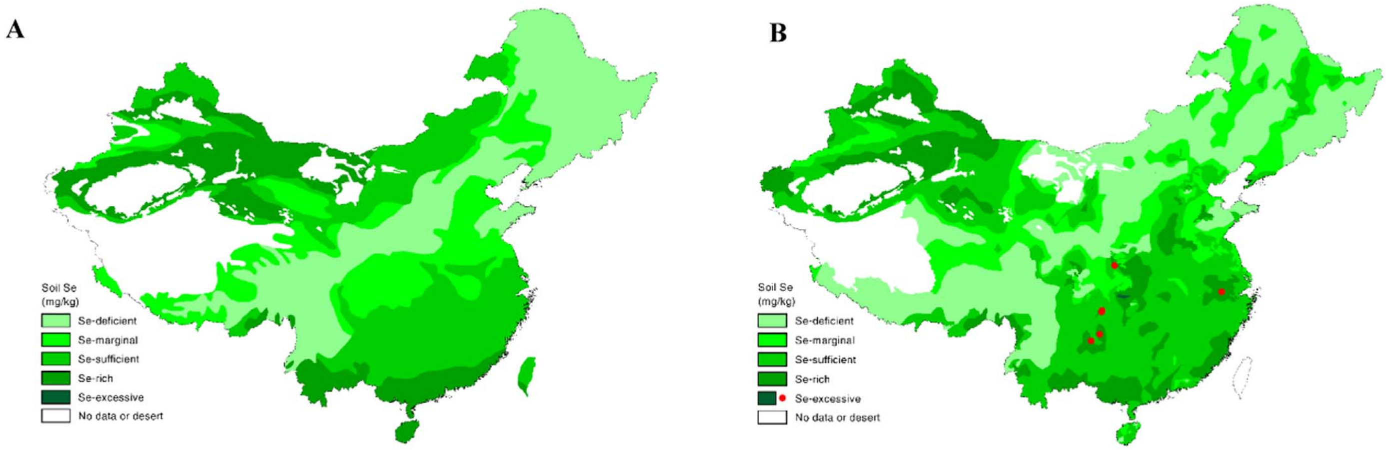

Fig. 1. Distribution pattern of soil selenium concentration in China. A) Adapted by Tan (1989) B) interpolation based on data collected during 1990–2017.

have indicated that the content, distribution, bioavailability, and ecological effects of Se in China are complex. The Se content was below 0.200 mg/kg in Se-deficient regions, which traversed the northeastern region of China–including the Taihang mountain ranges, the Qinling mountain ranges, and the Loess plateau–until the eastern region of the Tibetan plateau (Li et al., 2009b; Li et al., 2012a). In comparison, the Se content in soil can reach up to 79.08 and 36.69 mg/kg with a mean of 27.81 and 17.29 mg/kg, respectively, in Se-excessive areas, such as Enshi and Ziyang (Yuan et al., 2012; Tian et al., 2016), which are distributed as belts or points in Se-deficient areas. As such, the health risks associated with Se deficiency and toxicity are difficult to assess.

In addition, the assessment of Se status is a challenging task (Hawkes et al., 2008). Although the daily dietary Se intake depends on the amount of food consumed (Huang et al., 2013), food records cannot accurately estimate the Se intake (Swanson et al., 1990; Longnecker et al., 1991), because the same food in different areas may reflect different Se levels. Therefore, food records are effective only when foods are analyzed for Se content. Aside from the Se content in the blood, the Se content in the hair is a widely used indicator because it can reflect dietary intake (Hawkes et al., 2008). As such, it can serve as an indicator of long-term intake as well as an indirect test for physiological deficiency, excess, or maldistribution of Se in the body (Amaral et al., 2008; Hao et al., 2016; Momcilovic et al., 2016).

In this paper, the concentration and distribution of total Se in soil, water, plants, food, human intake, and human hair were reviewed to understand the Se distribution in the environment and its effects on human health in the local environment of China.

2. Data collection and sources

The literature was searched through four scientific databases: PubMed, Web of Knowledge, Chinese National Knowledge Infrastructure (Cnki), and Wanfang. The search process was conducted by using a combination of keywords, which included China, selenium, distribution, soil, water, plant, daily intake, food chain, food composition, hair, human health, Keshan disease, and Kashin–Beck disease; identical Chinese terms were used for the Cnki and Wanfang databases. Only works in the English and Chinese languages were included in the searched documents. Only articles that reported on the Se content in the environment, food, and hair in China were included in the analysis. Literatures published in the recent three decades were used in the evaluation of the Se changes in soil with respect to those reported by Tan (1989), because the Se biofortification strategy was adopted in China in the 1990s (Pray and Huang, 2007; Fang, 2010). Many studies on the Se content in the environment in China were published corresponding period, and the recent data accurately revealed the Se statuses in the environment and the amount of Se consumed daily under the current conditions. Publications that did not meet these criteria were rejected.

For the analytical evaluation, this study collected and used Se concentration values from 187,732 soil samples, 3183 cereals samples, 1088 vegetables samples, 904 fruits samples, 1116 animal-based foods samples, 595 drinking water samples, and 4709 hair samples collected from 30 provinces across China.

3. Se in the environment

3.1. Distribution characteristics of Se in soil

The global Se content in soil is highly variable, typically ranging from 0.01 mg/kg to 2.00 mg/kg, with a mean of 0.40 mg/kg; it can reach 1200 mg/kg in a seleniferous soil (Fordyce, 2013; Jones and Winkel, 2016). In China, the Se distribution in soils is extremely uneven and site-specific. The significant differences in the Se distribution in different areas of China are due to the variations of geology (Yu et al., 2016). Tan (1989) proposed abundance and deficiency thresholds based on the total Se concentration in soil. Accordingly, the Se concentrations were categorized under five levels: Se-deficient (< 0.125 mg/kg); Se-marginal (0.125–0.175 mg/kg); Se-sufficient (0.175–0.40 mg/kg), Se-rich (0.40–3.0 mg/kg), and Se-excessive (> 3.0 mg/kg). Using the concentration values of 187,732 soil samples collected from 30 provinces by previous studies, we conducted an interpolation and analysis of the spatial distribution of Se concentrations in China (Fig. 1). The distribution of Se concentration in soil varied across China in the range of 0.005–79.08 mg/kg (Table S1). In terms of Se concentrations in the topsoil, the different areas followed the descending order as: Northwest > South > Central > East > Southwest > Northeast > North China (Fig. 2). Approximately 51% of China is affected by Se deficiency, which lowers than 72% in the survey conducted by Tan in 1989. Se-deficient and Se-marginal areas are distributed along the geographic belt from the northeastern to the southwestern regions of China. The incidence of diseases induced by Se deficiency (e.g., KD and KBD) were reportedly high in these regions (Wang and Gao, 2001; Tan et al., 2002). Consistent with the Se distribution map created by Tan (1989), the Se-rich areas were mainly distributed in Xinjiang Uygur Autonomous Region, the eastern and southern parts of China stretching from Fujian to Tibet, and parts of Qinghai province. However, some new Se-rich areas were discovered low Se parts of China area as belt or spot (Fig. 1). The total Se contents in a number of areas were slightly higher than those recorded in 1989; this finding was also reported by Wang et al. (2014). For example, the total Se in soil had increased from 0.064 mg/kg to 0.088 mg/kg in Mouding county of Yunnan province in the past 28 years (from 1984 to 2012) (Wang et al., 2014). The same trend was observed in the