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Nigeria and the Selenium Micronutrient: A Review

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Abstract

Local studies have documented the contributions of minerals to the health status of mammals. Selenium (Se) is an example of such minerals. It is essential for the activation and functioning of enzymes. In Nigeria, the mineral has been reported to be present in water, foods and soils. While the soil selenium concentrations determine selenium levels in foods, difference in food concentrations of the mineral atones for the variations in the plasma and tissue selenium level across the geopolitical zones of Nigeria. Areas in Nigeria prone to erosion could be associated with inadequate soil selenium levels and this might lead to low availability of the mineral in the foods consumed by animals and humans. The plasma selenium levels in Nigerians may vary from as low as 0.006mg/L to as high as 0.3279±0.0546mg/L depending on the geographical factors and analytical methods employed. Studies in which the physiological effects of selenium supplementations were investigated revealed an improvement in CD4 counts in HIV positive human subjects, reduction in rats' susceptibility to trypanosomiasis, improvement in reproductive function, acceleration of ulcer healing in animal model of experimental gastric ulcer and mitigation of the adverse effects in animal model of gastric ulcer. Low plasma selenium levels are associated with HIV infection, fertility problems, postpartum cardiomyopathy and diabetes mellitus. Therefore, there is growing need for dietary selenium supplementations in Nigeria.

Keywords: Selenium; Supplementations; Nigeria; Geopolitical; Nigerian; Mineral

Introduction

Nutrition deals with food substances and their effects on health [1]. Food substances including non-energy yielding substances like selenium are required for metabolisms [2] (Figure 1). Selenium is an element of the Periodic Table and it is present in soil, water, rock and food. As far as Nigeria is concerned, studies revealed that the soil concentrations of the mineral vary across the six geopolitical zones of the country. This results in variation in concentration of the mineral in plant and animal foods consumed by Nigerians Rayman [3] and Combs [4] and difference in selenium level in body fluid and tissues [5,6].

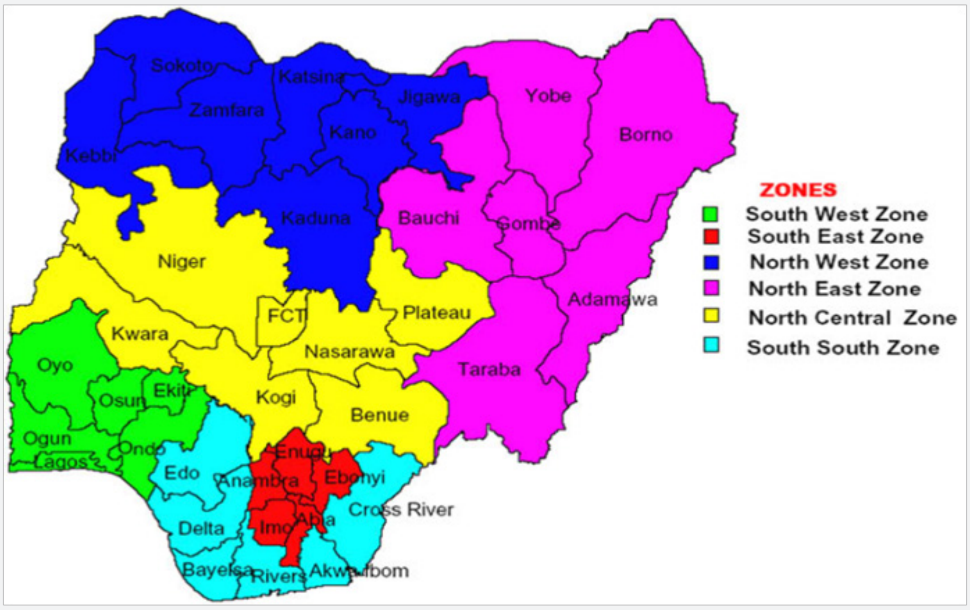

Figure 1: Map of Nigeria [72].

As a vital component of antioxidant enzymes [7] (Figure 2) and iodothyronine deiodinase [8], the mineral mediates many functions in humans and animals. For instance, selenium improved glutathione peroxidase and CD4 count in HIV positive Nigerian patients [9-11]. It also exerted a positive influence on male reproductive function [12] and accelerated gastric ulcer healing in an animal study [13]. The mineral is essential for cardiovascular health [14] and endocrine functions [15]. Selenium has also been shown to possess insulinotropic [16], antioxidant [7] and anticancer effects [12]. Selenium, among other functions, reduced susceptibility to infection in rats [18].

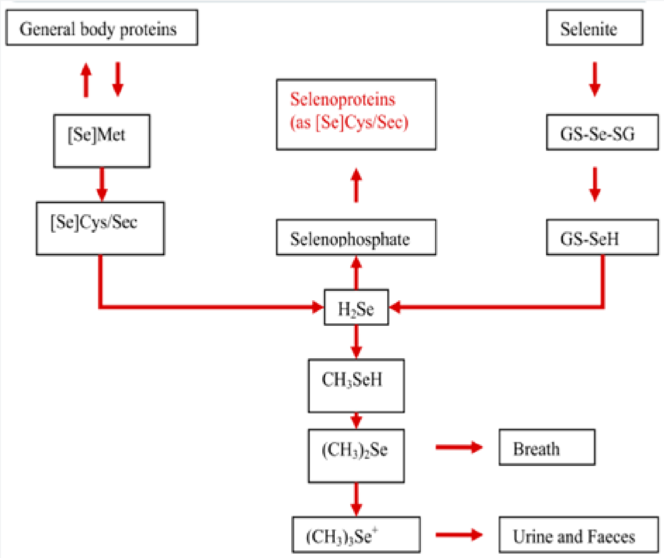

Figure 2: Metabolic pathway of selenium [8].

The purpose of this work is to highlight trends in selenium research and the physiological significance of its supplementations in Nigeria.

Selenium

Chemistry of selenium

Selenium is a metalloid located in period IV and group VI of the Periodic Table. It has atomic number 34 and mass number of 79 with oxidation states of +6, +5, +4, +3, +2, +1 and -1 [19]. It rarely occurs in its elemental state in nature, or as pure ore compounds [19]. Selenium forms two oxides: selenium dioxide and selenium trioxide. Selenium dioxide dissolves in water to form selenous acid. Salts of selenous acid are called selenites and these include silver selenite and sodium selenite, the inorganic forms of selenium. Selenium forms hydrogen selenide (H_2Se) which is toxic and colourless. Selenium forms stable bonds to carbon giving rise into selenols. Examples of selenols are diphenyldiselenide, benzeneselenol and selenomethionine, the organic forms of selenium [19] (Table 1).

Table 1: Mammalian selenoproteins [22].

S/n	Selenoprotein	Proposed Function
	GPx	
1	GPx1	Antioxidant In cell cytosol; Se store
2	GPx2	Antioxidant In gastrointestinal tract
3	GPx3	Antioxidant In extracellular space and plasma
4	GPx4	Antioxidant In membranes, structural protein in sperm: apoptosis
5	GPx5	Unknown
6	GPx6	GPx1 homolog?
7	Thiredoxin reductase (TR)	Multiple roles including dithiol-disulphide oxidoreductase Detoxifies peroxides, reduces thioredoxin (control of cell growth): maintains redox state of transcription factors
8	TR1	Mainly cystosolic, ubiquitous
9	TR2	Expressed by testes

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10	TR3	Mitochondrial, ubiquitous
11	Iodothyronine deiodinases	
12	Types D1 AND D2	Converts thyroxine (T4) to bioactive 3,6,3'-tri-iodothyronine (T3)
13	Types D1 and D3	Converts T4 to to inactive 3',3',5'reverse T3
14	Salenoprotein P	Selenium transport protein, antioxidant in endothelium
15	Salenoprotein W	Antioxidants in cardiac and skeletal muscle
16	Salenophosphate synthetase (SPS2)	Synthesis of selenophosphate for selenoprotein synthesis
17	15kDa selenoprotein (sep 15)	Protects against cancer
18	Selenoproteins H,I,K,M,N,O,P,R,S,T,V	Role largely unknown

The mineral was first discovered in 1817 by Jons Jacob Berzelius when investigating the chemicals responsible for outbreaks of ill health among workers in a Swedish sulphuric acid plant [20]. Klaus Schwarz proved selenium is an essential nutrient necessary for both normal growth and reproduction in animals [21] (Table 2).

Table 2: Selenium concentrations in Nigerian foods [6].

Sample	Mean±SD
Cereals	
Millet (Sorghum vulgare)	5±3.4
Rice (white) (Zea mays)	5±2.5
Meat and Fish	
Fish (dry) (Tilapia nicotilus)	15±4.5
Cray fish (Procambaris clarkia)	20±5.2
Snail (Achatina fulica)	<2±3.2
Wistar strain (albino rat)	<1±8.4
Milk and dairy product	
Milk (powder)	5±3.5
Egg (yolk)	<1±8.4
Egg (white)	<2±3.2
Vegetables	
Water leaf (Talinum triangulare)	5±3.5
Spinach (Ameranthus spp)	<1±8.4
Bitter leaf (Vemonia amygdalina	<1±8.4
Onion (Allum cepa)	<2±3.2
Pepper (Capsicum annum)	<2±3.2

Absorption of selenium

Ingested dietary selenium is absorbed in the small intestine. Both inorganic and organic forms of selenium are all absorbed primarily in the duodenum, jejunum and ileum and to a little extent in the stomach. Vitamins C, A and E speed up selenium absorption [22]. Mercury and phytates may slow down selenium absorption through chelation and precipitation. Dietary selenium in the inorganic form such as selenite elicits greater incorporation of the mineral into glutathione peroxidase than when selenomethionine, the organic forms is the dietary form. Sodium selenite is efficiently absorbed from the digestive tract in a homeostatically independent pattern. They are then incorporated into sulphur containing protein and albumin [22,23]. Selenium replaces the sulfur in cysteine forming selenocysteine, a selenoprotein. There are about twenty-five different types of selenoprotein coded by twenty five selenoprotein genes in humans [24,25] (Table 3).

Table 3: Selenium content in North-Central region of Nigeria [44].

Tuber	City with Highest Selenium Level	City with Lowest Selenium Level
Yam	Makurdi	Bida, Abuja, Lafiagi and Jos
Sweet potato	Bida	Makurdi, Lafiagi and Jos
Yellow yam	Lafiagi	Minna, Bida, Keffi, Makurdi, Otukpo, Lokoja and Ilorin

Storage of selenium

Selenium is stored in the tissues in varying concentrations: 30% in the liver, 30%, in the muscle, 15% in kidney, 10% in the plasma and the remaining 15% throughout other organs [8,26]. Concentrations of free selenium are greatest in the renal cortex and pituitary gland, followed by the thyroid gland, adrenals, testes, ovaries, liver, spleen, and cerebral cortex [8,27,28].

Metabolism of selenium

Selenium undergoes reduction and methylation. Sodium selenite crosses the plasma membranes and reacts with methyl cytoplasmic thiols in the reduction pathway forming selenide, which is then methylated, giving rise to methylated selenium derivatives that are excreted in urine, expired air via the lungs, and feces [29,30]. The proportion of selenium intake excreted depends on dietary intakes [31-33].

Bioassay of selenium

Selenium concentrations are typically measured in plasma [8,12], serum, whole blood, amniotic fluid, and urine as well as hair and toenails [8]. The main methods devised in the assay of the mineral are atomic absorption spectrometry and inductively coupled plasma-mass spectrometry.

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According to the World Health Organization, the proposed optimal concentration of selenium in plasma for healthy adults is 39.5-197.4ng/ml (or 0.0395-0.1974μg/ml) [8]. Glutathione peroxidase reaches maximal activity when serum selenium concentrations are between 70-90ng/mL which can be achieved through dietary intakes of selenium 55-65μg/day. Studies reveal that selenoprotein P is the main supplier of selenium to tissues in the body [8,34]. Selenoprotein P reaches its peak expression when serum selenium concentrations are considerably higher than those required to maximize the glutathione activity, around 125ng/mL [8].

Selenium Distribution in Nigerian Land

Rocks are sources of soil minerals. Like other countries, Nigeria is endowed with three types of rocks: sedimentary, igneous and metamorphic rocks. Sedimentary rocks are present in Niger state, Southern states and North-West. Igneous rocks are located in Jos Plateau. Together with metamorphic rocks, the igneous rocks form the oldest crystalline solid physical foundation of the nation [35].

Soil type in Nigeria includes sandy soils characterizing the northern region in the sahel savanna belt, Laterite soil, forest soil in the south and alluvial soils in the flooded plains of rivers or deltas or along the coastal flats [35]. Apart from rock, soil, plant and animal, selenium is also produced by burning of hydrocarbons, volcanic eruptions, mining and milling of minerals [36].

In West Africa, Senegal has the highest soil selenium concentration [37]. Available evidence shows that the plasma selenium concentration in African countries, such as Burundi, Zambia, Malawi, Zaire and Nigeria is inadequate [25]. Analysis of soil selenium in erosion-challenged Oba and Nanka communities, located in South-Eastern zone of Nigeria showed low concentrations of selenium in soil (0.48±0.32PPM and 0.32±0.32PPM respectively) [5] and water (0.03±0.01PPM and 0.04±0.01PPM respectively). Therefore, in the absence of supplementation, plants and animals grown in these communities may exhibit low selenium levels.

The mean soil selenium level around the derelict Udege Mines of Nassarawa state in the North-Centre geopolitical zone was reported to be 5.03mg/kg, exceeding WHO recommendation (0.5mg/kg) [38]. Despite the fact that seleniferous soils have high soil selenium contents, excess soil and water selenium levels may lead to accumulation of the mineral in plant and animal bodies resulting into deleterious effects in humans [38]. Water selenium levels exceeding reference level (0.01mg/L) may elicit adverse effects.

Oklo et al. [39] documented the soil selenium contents of some areas in kogi state, North-Central region of Nigeria, with low levels recorded in Ojebe and Ofarachi areas and high level in Ogume area only. In the same vein, the average level of selenium in selected areas of Cross river and Akwa Ibom states, South-South geopolitical zone of Nigeria was 2.86± 3.97mgldl [40]. Factors which may account for variation of selenium in Nigeria are:

1. Rainfall: In Nigeria, the coastal region around Niger Delta region in South-Southern region of Nigeria receives annual around 4,000mm (157.5in) of rainfall. In North Eastern state of Borno, the annual rainfall is below 1500mm. In most Southern States, the annual rainfall is above 2,000mm. Selenium tends to the concentrated in the soil of the drier regions of the world [41].

2. Soil pH: In acidic poorly aerated soils, selenium is relatively unavailable to plants because it is present mainly as insoluble selenite complexes [41].

3. Geographical factors: The selenium content of food varies widely depending on geographic locations [42]. For example, Nanka community of Anambra state in South-Eastern Nigeria, is an erosion ridden environment. Soil selenium in this area was reported to be low [5]. Low soil selenium correlates positively with secondary diseases. An example of secondary diseases is Keshan disease, a disease that affects some people that live in South-West China, where the soil is selenium deficient.

4. Soil composition: Phosphates present in rock, shales, limestones and sand stone contain selenium. Sulphide mineral deposit reduces selenium level.

5. Analytic methods: Methods devised in estimating soil selenium level give results which may not be the same [6,43].

Selenium Concentration in Nigerian Foods

Since plants depend on raw materials of soil origin, soil selenium content determines selenium availability in the body. Exposure to selenium is majorly through food. Brazilian nut has the highest selenium concentration 0.54 mg/kg.

In Anambra state, South-Eastern region, analysis of cassava tuber in Nanka and Oba communities showed that selenium contents were low 0.16±0.03PPM and 0.15±0.02PPM respectively [5]. Tubers are a major staple food in Nigeria, especially in rural communities. Decreased selenium in tubers may portend risk to the health of people.

Study by Abulude et al. [6] examined both local and imported products. It is interesting to observe that cassava flour, Cray fish and tilapia had the highest selenium concentrations. Wistar rats, snails, egg yolk, egg white, spinach, pepper and bitter leaf contained low selenium levels. Conversely, in Northern Europe, foods which contained high selenium level include meat, poultry, and fish (49). Difference in soil selenium levels, presence of high level of phytate, sulphur and mercury and difference in analytical methods employed might account for the discrepancy between the low selenium level reported by [5] and the findings of Abulude et al. [6].

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Analysis of average selenium content in root and tuber plants in North-Central by Zarmai et al. [43] showed that sweet potato contains 19.2±5,20μg/kg, yellow yam has 18.3±6.97μg/kg, yam has 13.6±7.12μg/kg and cassava has 13.0±5.84μg/kg. Yellow yam from Lafia had the highest level 76.3μg/kg while Minna, Bida, Keffi, Makurdi, Otukpo, Lokoja and Ilorin had a mean of 18.3±6.97μg/kg. Sweet potato from Bida showed the highest selenium level while Makurdi, Lafiagi and Jos had a mean value of 19.2±5.20μg/kg. Yam from Makurdi contained the highest selenium concentration 81.8 μg/kg while that from Bida, Abuja, Lafia, Gboko, Lokoja, Idah, Ilorin, Lafiagi and Jos showed a mean of 13.6+7.12μg/kg. From the work of Zarmai et al. [43], sweat potato in North-Central region had the highest selenium content followed by yellow yam, yam and cassava.

Study by Orisakwe et al. [44] estimated the levels of selenium in fifty (50) beverages purchased in Nigeria using the Atomic Absorption Spectrophotometer (AAS). The result indicated that selenium levels ranged from 0.24-1.67mg/L for canned beverages and 0.07-1.23mg/L for non-canned beverages. 95% of canned beverages had selenium levels that exceeded the maximum Contaminant Level (MCL) set by United States Environmental Protection Agency (USEPA) (MCL) whereas 90% of the non-canned products had selenium levels above the MCL.

Different brands of bottled beer marketed in Makurdi town exhibited selenium content that exceeded maximum contaminant level. On the contrary, Obahiagbon et al. [45] reported that selenium concentration in vegetable, waterleaf, ewedu leaf, bitter leaf, cocoyam leaf, green pepper leaf and okra leaf were within permissive level.

The above findings showed the variations in food selenium levels. Local foods grown in erosion prone regions may have lower selenium concentrations. This may lead to a decrease in selenium level in animals and humans that consume the foods.

Human Selenium Requirement

The recommended daily allowances (RDA) of selenium at 55μg/day (WHO/FAO/IAEA, 1996) for both adult males and females by Food and Nutrition Board at the Institute of Medicine. This amount is based on the amount of dietary selenium needed for activity of selenium-containing enzyme glutathione peroxidase in the plasma. The tolerable upper limit of selenium is 0.4mg/day (WHO/FAO/IAEA, 1996). Excess consumption of selenium may result in brittle nail, garlic breath, nausea and vomiting. 10 gram oral dose of selenium dioxide can cause death. The lethal doses (LD50) for orally administered selenate in rats are 7 to 22mg/kg body weight [46] and between 3 and 12mg/kg body weight for orally administered sodium selenite in rats [47,48].

Selenium Levels in Nigerians

Kolawole & Obueh [41] reported that the mean serum selenium level of people in selected areas of Akwa Ibom and Cross River state, South-South region of Nigeria, was 0.006mg/L. Okwara et al. [49] got 0.29± 0.09mmol/L (57.6±14.4mg/L) for healthy male adults and 0.28±0.08mmol/L (50.4±16.2mg/L) for healthy adult female in Orlu, South-East Nigeria. Nwagha et al. [50] also found a plasma selenium concentration of 1.38±0.18μmol/l (0.245±0.0324mg/L) in healthy female subjects in the South-East region.

The mean plasma selenium of 88 healthy adults in Abeokuta, South-Western region of Nigeria, was 0.188±0.026mg/L [13]. Arinola et al. [51] obtained a level of 57.05±2.50μg/L (0.057±0.0025mg/L) in healthy female Nigerians in South-Western region. The plasma selenium level in a study by Anyabolu et al. [10] was 9.81±1.6μg/dL (0.0981±0.016mg/L) in children in South-Western region. Sixty healthy subjects of over 18 years of age in an area in Osun state, South-Western region, had a mean serum selenium level of 32.79±5.46μg/dl (0.3279±0.0546mg/L) [52]. Oyedeji et al. [53] also obtained a plasma level of 1.02±0.01μmol/L (0.1836±0.0018mg/L) in healthy female subjects in South-Western region. Karaye et al. [14] obtained a plasma level of 118.4±45.6μg/L (0.118±0.0456mg/L) in a selected area of North-West region of Nigeria.

In addition to plasma selenium level, physiological balance in selenium distribution between body fluid compartments may be important as far as state of health is concerned. For instance, the ratio of serum selenium to seminal plasma selenium was found to be 1:1 in healthy adult male in South-West of Nigeria [12]. In developing country like Nigeria where a sizeable population of people lives on local foods which may not contain high selenium contents due to soil factors, the selenium concentrations in body fluids would be expected to vary across the geopolitical zones. Despite this, the selenium content in Nigeria putting all these studies together may vary from 0.006mg/L to 0.3279±0.0546mg/L.

Factors which may affect the plasma and tissue concentrations of the mineral may interfere with the physiological functions of the mineral. Such factors may include:

a. Age: Plasma selenium is lower in children than adult [54].

b. Genetic variation affects the plasma and tissue levels of selenium [55].

c. Gender: Males have slightly higher plasma selenium than female [54].

d. Pathological conditions including Acquired Immune Deficiency Syndrome [50,57,58], infertility [12], diabetes mellitus [15] and digestive problems [11] decrease plasma and tissue selenium.

e. Pregnancy and lactation [50] decrease plasma selenium level.

f. State of activity: Exercise increases the need for selenium [34] and sedation may reduce plasma selenium level [11].

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g. Kidney dialysis reduces plasma selenium [11].

h. Lifestyle such as smoking, alcoholism and vegetarianism may reduce plasma selenium level [54].

i. Oral contraceptive use [13,58] reduces selenium level.

Physiological Functions of Selenium

Immunity

Many local studies have documented that HIV-positive subjects exhibited low plasma selenium with male subjects having lower serum selenium levels than female subjects [10,11,59]. Report also indicates that HIV positive subjects with and without skin diseases exhibited low serum selenium [60]. The virus is known to incorporate selenium into its Human-Like glutathione peroxiadase leading to a decline in serum selenium and glutathione in the host [61].

The prevalence of HIV infected children is high [10]. Therefore, there is incontestable need for selenium supplementation. Selenium is an active component of selenoproteins which include thioredoxin reductase and glutathione peroxidase. In Nigeria, the plasma glutathione was estimated in a study as 0.127±0.022U/mL. Therefore, selenium supplementation may improve glutathione defense system. Positive immune outcome achieved with respect to selenium supplementation includes improvement in CD4 counts in HIV-positive Nigerian subjects. In west Africa, Senegal has the highest soil selenium contents and this has been linked with lower prevalence of HIV in the country [37].

In animal studies, selenium supplementation together with vitamin E, increased packed cell volume in trypanosome Brucei Brucei infected rats [18]. It also reduced susceptibility of black marshal cockerel to infectious bursal disease [62].

Reproduction

Selenium supplementation may improve testosterone level in male. Testes and ovaries are among organs that contain greatest concentrations of free selenium [27]. Upset in physiological balance between serum and seminal plasma selenium was associated with oligospermia and azoospermia in a study by Akinloye et al. [12]. Selenium supplementation improved reproductive of rabbits does by enhancing follicle stimulating hormone and oxidative enzyme. Low selenium level was found in subjects with prostate cancer [57].

Endocrinology and metabolism

Female diabetics drawn from Calabar showed higher serum selenium level than diabetic male [15]. Together with zinc, selenium reduced blood glucose concentration, restored hepatic functions and reduced hepatic and renal lipid peroxidation of diabetic rats [63]. Ahmed et al. [16] reported that selenium possessed a hypoglycemic property comparable to glibenclamide in rats.

Gastrointestinal health

Selenium supplementation may also exert positive influence on gastrointestinal function and health. In an animal experiment conducted by Adeniyi et al. [13], supplementation with selenium accelerated gastric ulcer healing by facilitating mucosal regeneration and antioxidant activity and by reducing lipid peroxidation. Together with vitamin E, selenium demonstrated tendency to assuage adverse effects in an experimental model of acute gastric ulceration in rats [64].

Cardiovascular health

In South western China, selenium deficiency was associated with cardiomyopathy called Keshan disease. Also in Nigeria, a study by Karaye et al. [14] in an area in North-West region of Nigeria indicated that female subjects with Postpartum Cardiomyopathy had low serum selenium level that was due to insufficient dietary intake of the mineral [65-74].

Conclusion

There are variations in selenium levels across the geopolitical zones in Nigeria with a nadir of 0.006mg/L and a zenith of 0.3279±0.0546mg/L. Hence, there is need for selenium supplementation. This review also provides evidence that selenium supplementations can improve health status of Nigerians.

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