Trace Elements, Nutritional Anthropology and Zinc

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KEY WORDS: Trace element. Zinc. Deficiency. Nutrition.

ABSTRACT: Some knowledge of the biology of zinc is central to any understanding and discussion of human zinc deficiency. Zinc is the most important essential elements after iron with regards to abundance in the human body. The function of zinc can be divided into three categories, namely catalytical, structural and regulatory. The element plays a significant role in the metabolic activity of a large number of enzymes of the body and also has a prime function in the synthesis of DNA, cell division and wound healing. It is required for normal growth and development during pregnancy, childhood, and adolescence. The present paper is an effort to illustrate the implication of zinc in public health along with the discussion on its pervasive biology, resultant deficiency and strategies to overcome deficiency of this trace element. The prevalence of zinc deficiency among the vulnerable sections of Indian populations has also been discussed.

INTRODUCTION

Elements can be broadly classified into major and trace elements depending in their concentrations in the human body. Major elements are those elements that make up more than 0.1% by weight of the body. Trace elements are those elements that are present in quantities that are less than 0.1% by weight, or 100 parts per million quantities in the body and as such they are measured in μg/g or in parts per million (ppm). Trace elements are again classified into two types, essential trace elements and toxic trace elements. As the name implies, essential trace elements are important for the various life process and metabolic function in the human body. These elements include zinc, iron, copper and chromium. On the other hand, there are some heavy elements (metals) which are detrimental to human health even in minute quantities. These are grouped under toxic trace elements. Elements such a lead, arsenic and mercury make up this group.

Trace Element Analysis in Anthropological Studies

Application of trace element analysis in the fields of palaeo-anthropology, archaeology and forensic anthropology are increasing. Their role in public health and human bio-monitoring is undeniable. As a matter of fact, the Association of American Physical Anthropologists in their annual meeting way back in 1984 has voiced its concern about the accumulation of hazardous substances in the environment. The meeting recommended that documenting population exposure to hazardous substances should form a part of research in physical anthropology. Accordingly there have been some studies in this broad field of environmental and occupational exposures of human populations to toxic elements. Subsequently, physical anthropologists have made significant contributions on the effect of toxic elements on human exposure, human growth, age at menarche and reproductive wastage (Sen and Das Chaudhuri, ’95, ’96, 2001; Frishancho and Ryan,’91; Schell, ’91; Schell and

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Denham, 2003; Denham *et al.*, 2005; Sen and Chaudhuri, 2007, 2008).

Other areas of study with most wide application are palaeo-demography and palaeo-ecology. The elements whose analysis provides wealth of information about the biological status of a population under study are lead, strontium, zinc, calcium, copper, iron and barium (Elias,'80; Elias *et al.*,'82; Schutkowski, '94; Kniewald *et al.*,'94). The potential trace elements in the context of excavated human remains for the reconstruction of natural, socio-cultural environment and palaeo-nutrition were very pertinently discussed by Wolfsoerger ('92) and Grupe ('87). Bone levels of various trace elements provide a window to the knowledge of diagnosis and aetiology of various diseases of prehistoric populations (Cejkova *et al.*, 2000; Glen-Haduch *et al.*,'97; Gonsalez-Reimers and Arnay-de-la-Rosa,'92). Different elements present in bone have now become a very important research tool of physical anthropology, as they offer possibility of examining diet of the concerned population (Sillen and Kavanagh,'82; Klepinger,'84; Szostek and Glab,'95; Schutkowski and Herrmann,'99). A study has also reported on pollution levels using trace elements from a prehistoric population (Pyatt *et al.*, 2005). Nord *et al.* (2005) pointed serious damage to buried skeletal remains by modern day pollution, a similar suggestion was also put forth by Grupe ('87).

Teeth are the most stable elements of the skeleton and are a very useful in trace element analysis (Glen-Haduch *et al.*,'97; Reynard and Balter, 2014; Forshaw, 2014; Alvira *et al.*, 2010). Hair remains from prehistoric graves have also been used (Benfer *et al.*,'78; Egeland *et al.*,'99; Wilson *et al.*, 2001; Pessanha *et al.*, 2016). The above human remain needs proper consideration for biogenic and diagenetic changes in the upcoming research (Kempson *et al.*, 2003; Bertrand *et al.*, 2003; Sandford and Kissling,'94). Such analysis of trace element also has forensic application. Trace element analysis also helps to distinguish fragmented or taphonomically altered material such as osseous, dental and non-skeletal (Zimmerman *et al.*, 2015).

Trace Element Studies in Nutritional Anthropology

Nutritional anthropology has been defined as 'the study of the interrelationship between diet and culture and their mutual influence upon one another' (Freedman,'76). In this sense the nutritional anthropology revolves around the theories of socio-cultural anthropology to solve the various problems of humanity related to diet and health. Later on effort has been made to give more interdisciplinary approach with the inputs from biological anthropology, public health and epidemiology (Haas and Pelletier,'89, Ungar *et al.*, 2006). However, it is not fully accomplished. Anthropometry remains unique to biological anthropology and a vast repository of literature has been develop which can be incorporated within the ambit of nutritional anthropology along with this emerging field of trace element analysis to assess the nutritional status. The incorporation is well justified in the light of five direct methods put forth by D. B. Jelliffe in the year 1966 for the assessment of nutritional status by anthropometric measurements, biochemical assessment, clinical examination and dietary survey. It thus gives more comprehensive approach to the field of the nutritional anthropology. The nutritional status of populations is well documented using blood and hair for trace element analysis (Santos *et al.*, 2007; Hambidge *et al.*, 2006; Ohno *et al.*, 2006). The higher prevalence and risk of iron deficiency among overweight and obese children and adolescents has been consistently observed (Hutchinson, 2016). The study has shown the alteration on the biochemical parameters of zinc in obese women along with its relation with waist circumference and body mass index (Dourado Ferro, 2011). Mild maternal zinc depletion was strongly associated with intrauterine growth retardation (Simmer,'85). The studies have clearly showed essential trace elements are related with different growth parameter (Ruz, 2006; Song *et al.*, 2007; Gibson *et al.*, 2000; Umeta *et al.*, 2000). The standard and reference for various essential elements needs further consideration (Andriollo-Sanchez *et al.*, 2005; Monge-Rojas *et al.*, 2005; Skalny *et al.*, 2015; Mikulewicz *et al.*, 2013).

However, it was centuries after the recognition of the biological role and importance of iron in humans that the role of zinc was established. It was only about 80 years ago that animal studies by Todd *et al.* ('34) first documented the essential function of zinc for growth and survival. This element is now observed to play a significant role in the metabolic activity of a large number of enzymes of the human body. Zinc also has a prime function in the synthesis of DNA and cell division. The important of zinc deficiency in humans became a focus of study only about some years back and here the pioneering studies of Hambidge *et al.* ('86) and Prasad ('91) are mentionable. During the last few years there has been a lot of research initiated on the role of zinc on disease resistance and immune function. Its role in the growth and cognitive development has been elucidated. Studies also began to be initiated on the in-vivo effects of zinc deficiency. In-vitro studies on the importance of zinc at the cellular level also began to gain impetus.

FUNCTIONS OF ZINC IN THE HUMAN BODY

It has been reported that more than 10% of the human genome codes are for zinc-containing proteins (Lichten *et al.*, 2001). On the cellular level, the function of zinc can be divided into three categories, namely catalytical, structural and regulatory (Bhowmick *et al.*, 2010). All known types of enzymes are observed to be dependent on zinc. It has been observed by Fierke (2000) that this element is an essential component of the catalytic site or sites of at least one enzyme in every enzyme classification. Zinc is an important structural element of proteins and plays an integral part in protein synthesis (Rosado,'98). Moreover, this element is also a determinant of the structure and the function of cell membranes. Depletion of zinc from cell membranes leads to oxidative damage. In fact, zinc has a recognized action on more than 300 enzymes by participating in their structure or in their catalytic and regulatory actions (Brandaõ-Neto *et al.*,'95). One very important aspect is the zinc finger motif which determined the binding of proteins to DNA (Berg and Shi,'96). This is the most common recurring motif in transcription proteins. The configuration of these "fingers" is determined by the single zinc atom at their base. The linking of these zinc fingers to corresponding sites on DNA initiates the transcription process and gene expression (Hambidge *et al.*,'86). Zinc finger proteins have been observed to act as transcription factors and regulate gene expression. This element also has an important role in cell signaling, hormone release and nerve impulse transmission. The zinc atom has the ability to take part in strong but readily exchangeable ligand binding. This feature along with the flexibility of zinc's coordination geometry has proved to be very useful in biological systems (Williams,'89). The incorporation of this trace element into mammalian biological systems has been further facilitated by the lack of redox properties of the zinc atom, which, in contrast to iron and copper, allows its utilization without the risk of oxidant damage (Hambidge *et al.*,'86). Although a lot remains to be known about the role of zinc as an intracellular regulatory ion, Cousins ('98) believes that the potential importance of zinc in this role is an important area of research. Other areas of significance include cellular growth, cellular differentiation and gene expression. The metal also has a flexible coordination geometry, which allows proteins using it to rapidly shift conformations to perform biological reactions (Stipanuk, 2006).

It has been observed that zinc is closely associated with bone metabolism vis-à-vis- the functions of somatomedin-c, osteocalcin, testosterone and thyroid hormones. It has been documented that zinc levels in bone is appreciable high when compared with its levels in other tissues of the body. Zinc also enhances vitamin D effects on bone metabolism through the stimulation of DNA synthesis in bone cells (Branda˜o-Neto *et al.*,'95). Zinc also plays a significant role in wound healing (McCarthy *et al.*,'92). It is required for proper sense of taste and smell (Prasad *et al.*,'97) and supports normal growth and development during pregnancy, childhood, and adolescence (Simmer and Thompson,'85; Maret and Sandstead, 2006). It also possesses antioxidant properties, thus protecting the body against accelerated aging (Fabris and Mocchegiani,'95). Zinc signaling is used to communicate between the cells of the salivary gland, prostate, immune system and intestines (Hershfinkel *et al.*, 2007). In the brain, zinc is stored in specific synaptic vesicles by glutamatergic neurons and can modulate brain excitability (Bitanihirwe and Cunningham, 2009). It plays a key role in synaptic plasticity and learning (Hambidge and Krebs, 2007; Nakashima and Dyck, 2009). It also can be a neurotoxin, suggesting zinc homeostasis plays a critical role in normal functioning of the brain and central nervous system (Bitanihirwe and Cunningham, 2009).

SIGNIFICANCE OF ZINC IN HUMAN NUTRITION

For a research to comprehend the significance of zinc in human nutrition, two important issues appear to stand out. The first is the ubiquity and versatility of zinc, while the other is the role of this element in gene expression, cellular growth and differentiation. According to Hambidge *et al.* ('86), some knowledge of the biology of zinc is central to any understanding and discussion of human zinc deficiency. The ubiquity and versatility of zinc in subcellular metabolism suggest that zinc deficiency may well result in a generalized impairment of many metabolic functions (Williams,'89). A variety of factors are responsible for zinc-dependent metabolism and the severity of the zinc deficiency. So very often the researcher faces a potentially large range of manifestations of zinc deficiency that are typically difficult to detect and confirm. It has been suggested by Williams ('89) that given the ubiquity and versatility of zinc in sub-cellular metabolism, zinc deficiency in humans may result in a generalized impairment of many metabolic functions. In fact, Hambidge (2000) goes on to observe that even a partial understanding of the fundamental importance of zinc in cellular growth and differentiation alerts researchers to the special vulnerability to an inadequate supply of zinc of the rapidly growing embryo, fetus, infant and young child or of the patient mounting an immune response or requiring tissue repair. The pattern of zinc dependent metabolism is also dependent on a number of other host and environmental factors.

A BRIEF HISTORY OF HUMAN ZINC DEFICIENCY

Although the role of zinc in human metabolism was well known for decades, the history of the recognition of the significance of zinc in the fields of human nutrition, epidemiology and public health is comparatively recent. It was only late in the 19th century that the first role of zinc in a microorganism was recognized and reported. Another 50 years passed before zinc deficiency was described in mammals, but this was followed quickly by recognition of the practical importance of zinc deficiency in animal husbandry, especially among pigs. By the late 1950s it was well accepted that zinc was a necessary micronutrient for humans and abnormalities of human zinc metabolism began to be documented. But even at that time, researchers working in the field of human nutrition continued to dismiss the presence of human zinc deficiency. The first major conceptual breakthrough came in 1961 when Prasad *et al.* ('61) hypothesized that zinc deficiency was a major etiological factor in the syndrome of "adolescent nutritional dwarfism" that had been identified mainly in the mid-Eastern countries. The second major development occurred about a decade later when severe zinc deficiency began to be documented in the industrialized countries, notably with the recognition that the phenotypic expression of the rare autosomal recessively inherited disorder acrodermatitis enteropathica was attributable to a defect in zinc metabolism (Moynahan,'74). Another important development was iatrogenic severe zinc deficiency, which was attributable to the failure to add zinc to intravenous infusates for patients who were totally dependent on intravenous feeding. Iatrogenic severe zinc deficiency was numerically larger and persisted throughout the 1970s. Also there has been recurring interest in the possible occurrence of zinc deficiency, or disturbed zinc metabolism, as a factor in a wide range of disease states, from the common cold to wound healing in surgical patients since the 1960s. There have also been numerous individual case reports of secondary zinc deficiency.

The history of understanding of the role of zinc in human nutrition and disease is an excellent example of the mutual benefits of closely linking nutrition research in the countries of the developed world with that in the developing world. The roots of documenting nutritional zinc deficiency were the results of a series of randomized controlled studies of dietary zinc supplementation in young children in Denver during the decades of the 1970s and 1980s. These indicated the occurrence of growth-limiting zinc deficiency in otherwise apparently normal infants and young children (Hambidge,'86; Walravens *et al.*,'89). The success of these studies has led to a large number of randomized, double-blinded controlled studies of dietary zinc supplementation in the 1990s. Samples for these new studies were primarily drawn from the developing countries in the 1990s (Brown *et al.*,'98; Bhutta *et al.*,'99). The results of these new studies led to the advancements of the knowledge relating to the public health importance of global human zinc deficiency. These studies also provided the basis for the understanding of the etiological role of zinc in several diseases and clinical circumstances and in disturbances of normal physiology, growth and development.

DETECTION OF ZINC DEFICIENCY

The principal cause of human zinc deficiency appears to be a diet that remains low in highly bio-available zinc. Diets based on plant foods, especially those diets rich in phytate, a potent inhibitor of zinc absorption. As a result, many countries are introducing food fortified with zinc. Other causes include illnesses that impair food intake, provoke catabolism or mal-absorption or increase zinc excretion. The research into human zinc deficiency has focused also into the detection of zinc deficiency in human populations. It has been pointed out by Hambidge and Krebs ('95) that a major hurdle was the lack of adequate laboratory biomarkers and the lack of pathognomonic clinical features of zinc deficiency states. This brings in the issue of biomarkers. A biomarker is basically an objective biological measure that is utilized to assess health or make a diagnosis of disease. A number of definitions of the word "biomarker" can be found in the scientific literature. A recent definition is that of Rockett and Kim (2005) which defines a biomarker as "any biological index capable of being measured, which is associated with or indicative of a defined biological endpoint such as development or disease stage". The definition proposed by the National Institute of Health (NIH) may also be referred to here. The official NIH definition of a "biomarker" is " a characteristic that is objectively measured and evaluated as an indicator of normal biologic processes, pathogenic processes, or pharmacologic responses to a therapeutic intervention" (Biomarkers Definitions Working Group, 2001). Biomarkers thus have a vital role to play in the fields of public health and primary prevention.

Blood plasma is a useful biomarker to zinc. Concentrations of zinc concentrations in human plasma have been shown to be useful in identifying children who exhibited a growth response to zinc supplements (Brown,'98) or diarrhea (Bahl *et al.*,'98). However, it is believed that plasma zinc lacks the sensitivity so as to consider it to be a strong biomarker of zinc status. Other biomarkers such as hair too have analytical problems, even though they yielded useful data (Ferguson *et al.*,'93). Toe and finger nails have been used as other emerging biomarkers of exposure (Sisodia *et al.*, 2014; Goulle *et al.*, 2009).

CLINICAL ASPECTS OF ZINC DEFICIENCY IN HUMANS

The consequence of zinc deficiency need to be given due emphasis and this is where animal experiments assume paramount importance. This is because zinc is essential for normal fetal growth and development. It is also important for milk production during lactation and necessary during the first years of life when the body is growing rapidly. In fact, intrauterine growth retardation is just one consequence of zinc deficiency that increases the risk of morbidity and mortality of infants.

Based on the metabolic role of zinc, it is now increasingly becoming likely zinc-dependent metabolic functions are impaired in all tissues in cases of zinc deficiency. The specific biochemical correlates underlying the clinical features have not been easy to identify. An example is the case of patients with classic acrodermatitis enteropathica, which is an autosomal recessive disorder. It may be recalled that individuals affected with this disease typically died in later infancy and it was only after the recognition of the therapeutic benefits of oral zinc supplementation that they began to survive. A better understanding of the metabolism that underlies each of the clinical features of acrodermatitis enteropathica remains the first criterion for the management of patients not only afflicted with this disease and also with other severe zinc deficiency disorders. Beyond the value to the individuals affected with these diseases, elucidation of the clinical features of severe zinc deficiency states and their biochemical correlates is of value in the understanding of milder zinc deficiency states. Although less impressive in their clinical presentation, the latter are of numerically much greater importance. Moreover, most of the clinical features of acrodermatitis enteropathica were documented in milder zinc deficiency states. Three important features stand out in how clinical and laboratory observations in acrodermatitis enteropathica have assisted in the identification of parallel consequences of milder acquired zinc deficiency states. These are as follows:

a) Diarrhea remains an important clinical symptom in almost all cases of acrodermatitis enteropathica.

b) A wide variety and severity of immune defects that includes compromised T-cell function) have long been recognized in acrodermatitis enteropathica. Although in advanced cases it is difficult to separate the effects of zinc deficiency from those of secondary protein energy malnutrition, the rapidity of immune function improvement with the initiation of zinc therapy speaks to a specific and direct role for zinc deficiency.

c) Similar observations apply to the function of the central nervous system. The initiation of zinc therapy in acrodermatitis enteropathica is followed with remarkable rapidity by an increase in motivation, alertness and responsivity. There is a correspondingly rapid decrease in irritability, nervousness and restlessness.

Among humans, organ systems such as the epidermal, gastrointestinal, central nervous, immune, skeletal and reproductive systems are clinically affected by severe zinc deficiency states (Hambidge and Walravens,'82). This is a reminder that zinc is an essential element with a significant role in the metabolic activities of the body. There has been a rapid progress in research into the issues of the public health significance of milder, but clinically important, zinc deficiency states, especially in the developing world. This has resulted into considering zinc as a micronutrient of special importance in human nutrition.

AN OVERVIEW OF ZINC DEFICIENCY IN INDIA

Zinc deficiency was responsible for 453,207 deaths (4.4% of childhood deaths), and 1.2% of the burden of disease (3.8% among children between 6 months and 5 years) in the three regions of Africa, Asia and Latin America in 2004. Zinc deficiency accounted for 14.4% of diarrhea deaths, 10.4% of malaria deaths and 6.7% of pneumonia deaths among children between 6 months and 5 years of age. The largest number of deaths attributable to zinc deficiency in Asia occured in India, which contributed 18.6% of all zinc deficiency deaths globally (Fischer Walker *et al*., 2009).

A national stunting prevalence rate has been suggested as the proxy indicator to ascertain population zinc deficiency among children. The assumption is based on more than 28 supplementation trials assessing the effect of zinc on growth. The magnitude of the effect size of zinc on height is dependent upon the baseline height-for-age Z score (HAZ) score of the population and thus zinc has a greater effect on linear growth when given in populations with the mean HAZ <-2. Using this data, it was recommended that childhood stunting prevalence rates ≥ 20% would serve as a proxy for identifying population zinc deficiency among children below 5 years of age (Fischer Walker and Black, 2007). In India overall stunting among under-five years old is 48.0%, which is 54.0% among tribal children (NFHS-3).

A nation-wide study among children under five years of age, reports highest zinc deficiency (serum zinc < 70 ìg/dl) in Odisha (51.3%), followed by Uttar Pradesh (48.1%), Gujarat (44.2%), Madhya Pradesh (38.9%) and Karnataka (36.2%) with the overall prevalence of zinc deficiency of 43.8% among the people of low socio-economic condition (Kapil and Jain, 2011). A study conducted among adolescent school children (11-18 years) of the National Capital Territory of Delhi reports 49.4% children (50.8% males, 48.2% females) with zinc deficiency (Kapil et al., 2011). Another study reports 73.3% of zinc deficiency at baseline among children from the adjoining area of Delhi. Kawade (2012) found high prevalence of micronutrient deficiencies among the girls (10-16 years) of two secondary schools of Pune and Maharashtra, using Adolescent Micronutrient Quality Index (AMQI), an important tool to access the micronutrients in absence of a reliable biomarker.

Other vulnerable sections of population are pregnant and lactating women. Maternal nutrition is very important for the course and outcome of pregnancy. Lactation represents a stage wherein health and nutritional status of the infant are dependent on the mother. Successful pregnancy and lactation require adjustments in maternal body composition, metabolism and function of various physiological systems. A diet that meets maternal nutritional needs is required for these adjustments, so that maternal well-being is safeguarded with birth of a healthy infant (Udipi *et al*., 2000; Sengupta, 2010). Otherwise it can lead to low birth weights of newborns, intra-uterine growth retardation and stunting. A study has reported 73.5 % prevalence of zinc deficiency among pregnant women of Haryana along with the presence of multiple micronutrients deficiency (Pathak *et al*., 2004). Another study from Haryana also reported that 62.6 % of pregnant women suffering from zinc deficiency (Pathak *et al*., 2008). Pregnant women with lower BMI and socio-economic status from Assam showed 12 % below normal zinc levels along with iron and copper (Mahanta *et al*., 2012).

There are 705 different tribal communities which constitute 8.6 % total population of India (Census of India, 2011). In spite of India's recent economic growth, health and human development indicators of Scheduled Tribes (ST) or Adivasi (India's indigenous populations) lag behind national averages (Mohindra and Labonte, 2010). These vulnerable section of society mostly depend on their indigenous foods, which usually consist of wild unconventional forest products and a very few have started cultivation (Osei and Hamer, 2008). The most frequently used cereals are maize, millet and rice which forms a part of daily meal (Kapil *et al*., 2011) and they are unable to afford animal food which is a main source of zinc. Absorption of significant amount of micronutrients present in the plant based tribal diets is hindered by high phytate content of plant (Osei and Hamer, 2008).

In such background a recent study has found 52 % prevalence of zinc deficiency with mean ± SD serum zinc concentration of 10.8 ± 1.6 µmol/L among the rural tribal women of Maharashtra (Herbst *et al*., 2014). An earlier study by Kapil *et al.* (2003) assessed the serum zinc levels of tribal adults in Jharkhand and found that 53% of the study subjects were zinc deficient, with deficiency occurring more frequently among women (61.3%) than men (38.7%). Prevalence of multiple micro-nutrients among the tribal population of Maharashtra has been reported by Menon *et al*., (2011) with 58% among the tribal women compare to 39% among non-tribal rural women from the Ramtek block Nagpur, Maharashtra.

STRATEGIES TO OVERCOME ZINC DEFICIENCY

Supplementation of children with zinc and with other micronutrients may be beneficial during periods of greatest vulnerability such as pregnancy and early childhood and when the diet is low in animal products and based on high phytate cereals and legumes (Allen,'98). Adolescents also have very high zinc requirements to maintain skeletal maturation, especially in females after menarche and during pregnancy. However, it can be difficult for infants and young children to meet their zinc requirements during the transition from milk to solid foods.

The forms of zinc used in many supplementation trials are zinc acetate, zinc gluconate, amino acid chelates such as zinc methionine, zinc carbonate, zinc chloride, and the most frequently used forms, zinc oxide and zinc sulfate. There are five zinc salts listed as generally recognized as safe by the US Food and Drug Administration (FDA): zinc sulfate, zinc chloride, zinc gluconate, zinc oxide, and zinc stearate. However, no zinc compounds have been approved as safe by the FDA for direct addition to food. Nevertheless, the total quantity of zinc salts used has notably increased since 1970, and the compounds used most are zinc sulfate and zinc oxide.

An integrated approach using targeted supplementation, fortification, and dietary strategies should be used to eliminate zinc deficiency in developing countries. Zinc salts that are readily absorbed and at levels that will not induce antagonistic nutrient interactions should be used. There are three common strategies to combat nutrient deficiencies: supplementation, fortification, and dietary modification and diversification. Supplementation is appropriate for populations where zinc status must be improved over a relatively short period and the requirements cannot be met from habitual dietary sources. Food fortification with zinc is recommended when its deficiency is endemic or when it is targeted in specific regions or for certain high-risk groups within a country. One critical factor in developing a food-fortification program is the choice of the food product to be fortified, which has to be widely or preferentially consumed by the risk groups. Another important aspect is the bioavailability of the fortificant considered, which has to be readily absorbed and utilized; resistant to any dietary inhibition of zinc absorption; safe, stable, and acceptable. The third strategy involves changes in food-selection patterns or traditional household methods for preparing and processing foods with the aim of enhancing the availability, access, and utilization of foods with a high content and bioavailability of zinc.

ACKNOWLEDGEMENT

The authors acknowledge the co-operation and help of the Department of Anthropology, University of North Bengal, during the preparation of the manuscript. Financial assistance in the form of a UGC-NET Fellowship [{F.15-6(Dec., 2011)/2012(NET) dated 27.07.2012}] to the first author is also acknowledged.

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