
Review of Literature

The review of literature pertaining to the study entitled, “**Bioavailability of iron and zinc from regional diets**” is reviewed under the following headings.

- A. Studies on food consumption pattern
- B. Iron and zinc metabolism in the body
- C. Prevalence and causes of iron and zinc deficiencies among adolescent girls
- D. Factors influencing bioavailability of iron and zinc
- E. Studies on bioavailability of iron and zinc from regional diets
- F. Household strategies to enhance iron and zinc bioavailability
- G. Impact of interventions on anaemia

A. STUDIES ON FOOD CONSUMPTION PATTERN

The diets of India vary between the different provinces and the diverse kinds of regional cuisines dates back to thousands of years which are evolved by geographical factors, availability of food, economical, and local practices. Across the nation, vegetarian diets are the most common due to religious reasons. Hence, Indian diets will be more often based on rice, lentils, and vegetables, rather than fish and poultry. Also, the major feature of Indian diets are the spicy seasonings, including curries, mustard oil, cumin, chili pepper, garlic, ginger, and a blend of several spices, the garam masala (<http://www.food-india.com/>).

Indian diets are culturally diverse and strongly related to local food availability. In addition, India covers a huge geographical area comprising many different agricultural practices and cultural approaches to food as well as large socio-economic inequalities. When exploring the health and environmental

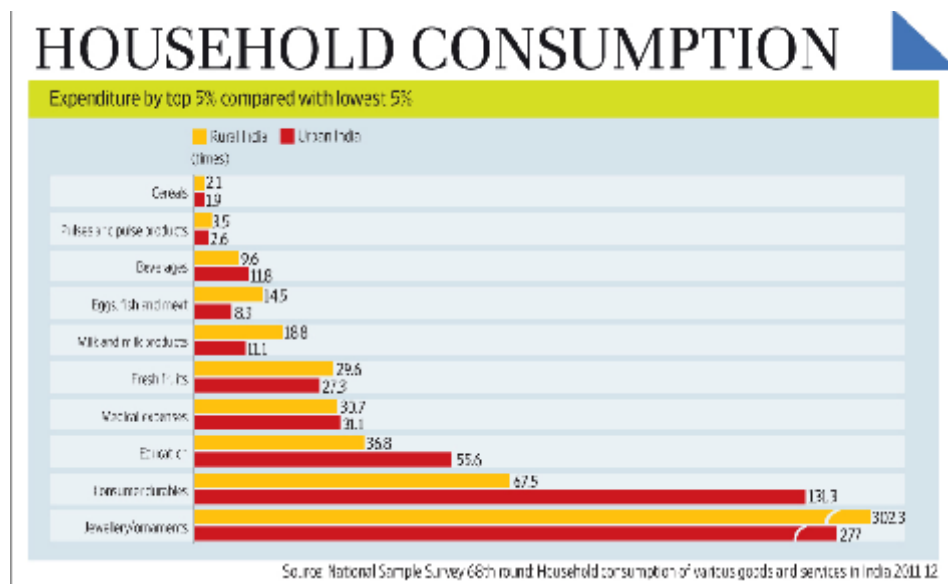
impacts of Indian diets, it therefore makes little sense to describe an average population diet.

Usually diets evolve over a period of time which is influenced by factors such as beliefs, culture, tradition, income and individual preferences. Moreover, they are also influenced by geographical, environmental, social factors in a complex manner and will shape into the dietary consumption patterns.

According to the reports of the National Council of Applied Economic Research (2014) on the analysis of the changing food consumption pattern in India it was found that increasing income among the households resulted in consuming cereals such as rice and wheat and avoiding the nutritionally dense millets.

It is important to improve access to food subsidy in food-insecure settings by addressing gaps in Public Distribution System which offers subsidized access to food and essential commodities, viz. wheat, rice, sugar, and kerosene or in alternative approaches that are being currently debated (The National Food Security Bill, 2011).

PLATE I
HOUSEHOLD CONSUMPTION PATTERN OF INDIA



Many studies illustrated the emerging food consumption patterns in India. It is noted that there has been a clear shift in recent decades from the grain consumption to non-grain food and animal products consumption. The per capita grain consumption is decreasing since 1980's. This decline is due to various reasons, including income growth and urbanization and associated changes in life styles. Agrawal *et al.*, (2014) in their study on the association between the type of vegetarian diet, obesity and diabetes in adult Indian population reported that dietary patterns followed by majority of the Indians (64 per cent) were mostly a non-vegetarian diet either daily, weekly or at least occasionally whereas one-fourth is lacto-vegetarian. Other dietary patterns are a smaller percentage of Indian population are semi-vegetarian (5.2 per cent), lacto-ovo vegetarian (3.2 per cent), pesco-vegetarian (2.2 per cent) and vegan (1.6 per cent).

The change in dietary pattern, results in “nutrition transition” that includes both quantitative as well as qualitative changes in the diet. The dietary changes includes shift in the structure of the dietary pattern towards a high calorie dense diet with fat rich and added sugars in the foods. The consumption of saturated fat intake mostly from animal sources and reduced intakes of complex carbohydrates such as whole grains and millets, and reduced fruit and vegetable intakes will lead to life style diseases as well as hidden hunger coupled with sedentary life style can aggravate the conditions.

B. IRON AND ZINC METABOLISM IN THE BODY

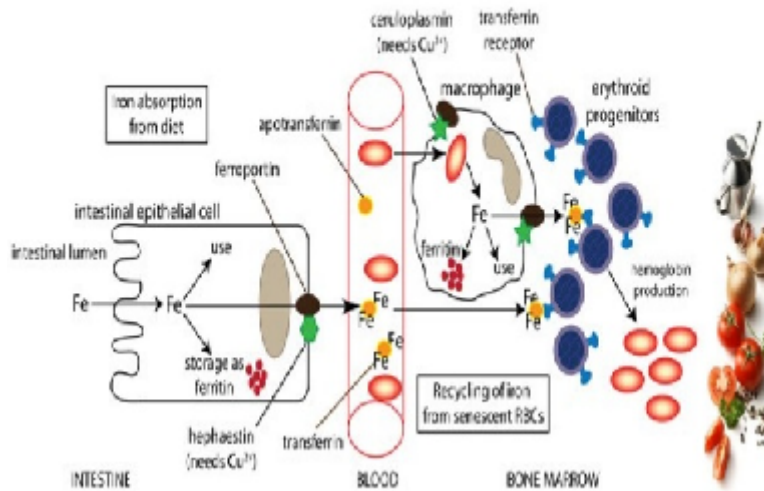
1. Metabolism of iron in the body

In normal individuals iron is continuously recycled between the bone marrow and reticuloendothelial (RE) cells with serum transferrin acting as a shuttle to deliver iron to the erythron from RE cells and enterocytes. The “information” on erythron and body iron status is transferred to crypt cells of the distal duodenum by Transferrin (Tf): the extent of Tf saturation with iron acts as the “signal” that is transferred through the transferrin receptor: (TfR) / HFE pathway to the stem cells of the crypts. This sets the level of “free iron pool” in the crypt cell that will also be reflected in the mature enterocytes on differentiation and migration to the villus.

PLATE II

ABSORPTION AND METABOLISM OF IRON IN THE BODY

IRON ABSORPTION IN HUMAN BODY



Source: <http://www.slideshare.net/princy77malik/role-of-iron-in-human-health>

The free iron pool through regulatory proteins (IRP) will dictate the level of expression of apical and basolateral iron transporters in the mature enterocytes of the villus and in turn of iron absorption. Plate I shows the iron absorption and metabolism.

2. Metabolism of zinc in the body

Zinc is a vital compound of a large number (>300) of enzymes and participates in the metabolism of carbohydrates, lipids, proteins, nucleic acids as well as in the metabolism of micronutrients. It also plays a pivotal role in the immune system (FAO/WHO, 2004).

The effects of marginal, mild or sub clinical zinc deficiency is not clear. Growth retardation and impairments of immune defences are the only clearly demonstrated signs of mild zinc deficiency in humans. Other signs of zinc deficiency includes, impaired taste and wound healing, which have been claimed to result from a low zinc intake, are less consistently observed (Hambidge, 2000).

Zinc is essential for maintaining the normal concentrations of vitamin A in the plasma, which is essential for normal mobilization of vitamin A from the liver. Zinc deficiency hampers the synthesis of Retinol Binding Protein (RBP) in the liver leading to low levels of RBP in the plasma and thus influences the absorption, transport and utilisation of vitamin A. Approximately 70 per cent of zinc is bound with serum albumin (a plasma protein) and the factors that affect serum albumin in turn will affect the serum zinc levels. Serum zinc has the potential of rapid turnover to meet the tissue needs.

Zinc is mostly lost from the body through the skin and kidneys (together 0.5-0.8mg/day). When excessive sweating happens, more zinc is lost from the body, as in hot weather and during tiring activities. Nearly, half of all zinc is lost from the body as the shedding of epithelial cells in the gastro intestinal tract (0.5- 3mg/day) and though a significant amount is secreted through both biliary as well as intestinal secretions, most of these secretions are reabsorbed and thereby regulating the zinc balance in the body. Starvation and muscle breakdown also leads to increased zinc loss through the urine (<http://www.metabolics.com/blog/a-practitioners-guide-to-zinc-supplements/>).

Regarding zinc absorption, protein enhances while a phytate rich diet inhibits the absorption of zinc. Also, zinc will compete with iron to bind with blood transferring which illustrates the importance of a balance of these minerals.

Recent studies on the absorption of zinc using stable isotopes among Indian adolescents have shown that there is fractional absorption in the range of 27 to 30 per cent (Nair *et al.*, 2013). Zinc absorption is inhibited by phytate, wherein a diet that has a phytate: zinc molar ratio of 10 or higher is inhibitory in nature. Presence of divalent cations such as iron and calcium in high quantity also inhibits the absorption of zinc. Non-vegetarian diets will enhance the absorption of zinc from cereal-based diets as these form stable chelate complexes with amino acids such as cysteine, histidine and methionine.

Zinc is absorbed in the jejunum and ileum by specific transporters. This absorbed zinc is transported to different tissues through the plasma bound mostly

with the albumin. In the body, about 99 per cent of total zinc is found in intracellular and there are no known storage sites and organs for storing zinc. The highest concentration of zinc is seen in the choroid of the eye and optic nerve, which is followed by the other organs such as prostate, bone, liver and kidneys. The total plasma zinc content constitutes about 2.5 mg, which represents 0.1 per cent of the total body zinc. This will vary according to age, sex and physiological status (IZiNCG, 2004).

The majority of the zinc in plasma is taken up by liver and will eventually appear in the pancreas in the insulin granules and kidney. Unlike iron, zinc is excreted from the gastrointestinal tract regularly by 1.5 mg/day. Urinary excretion of zinc accounts to about 0.63 mg/day and other endogenous losses of zinc through sweat, semen, menstruation and desquamation of the skin and absorptive epithelium (~3 mg /day). Reabsorption of secreted zinc in gut lumen serve as an important role to maintain the zinc balance of the body (FAO/WHO, 2001).

The amount of dietary zinc absorbed is therefore to meet these losses and maintain a positive zinc balance in the body. Changes in fractional absorption, endogenous fecal zinc excretion and urinary resorption along with devoted retention of zinc released from selected tissues such as bone are required to maintain plasma zinc concentrations within a tight range

The absorption of zinc in the small intestine is performed by a carrier mediated mechanism. The amount of zinc absorbed is difficult to find out since zinc is also secreted into the gut. When zinc is administered in aqueous solutions to fasting respondents it is absorbed efficiently upto 60 to 70 per cent, whereas absorption of zinc from solid diets is very low and varies according to the zinc content and diet composition (FAO/WHO, 2004).

Recent studies have shown that different absorption rates of zinc for different population groups are based on their type of diet as well as phytate: zinc molar ratio. Absorption of zinc is concentration dependent and will increase with increasing the dietary zinc up to a maximum rate. In addition to this, the zinc

status of the body also influences zinc absorption. Subjects with deprived zinc status will have an increased absorption of this element with increased efficiency, whereas subjects with high zinc diet show a reduced efficiency of absorption (Krebs, 2000).

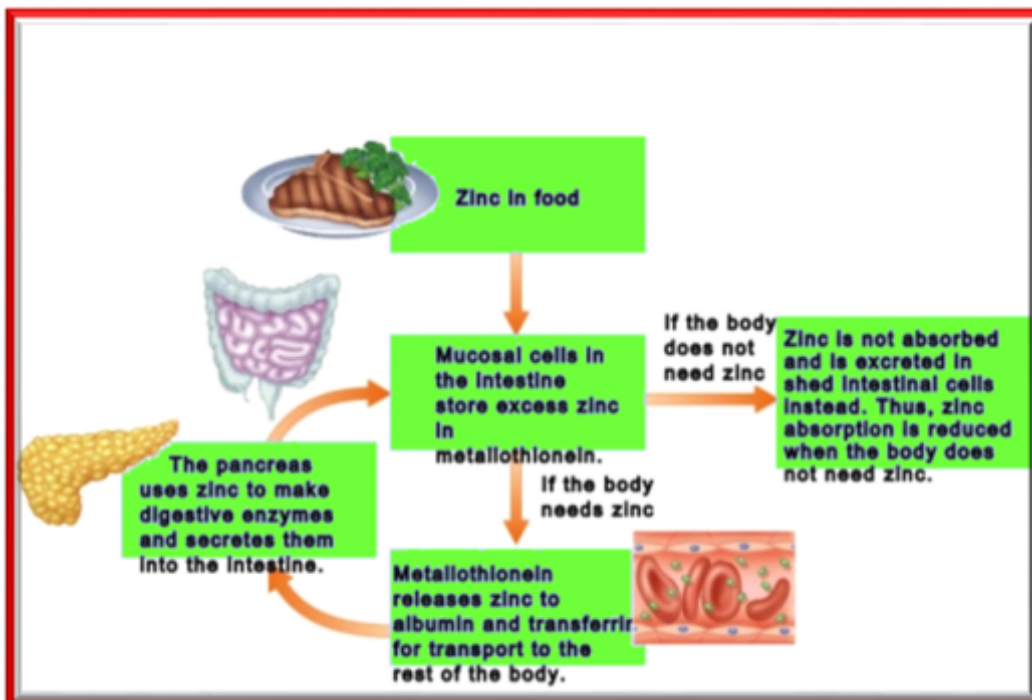
As per IZiNCG (2004), zinc supplementation is suggested on the following conditions :

- >25 per cent of the population receives below mean requirement of zinc
- >20 per cent of children below 5 years have (stunting) HAZ scores $\geq 2SD$ and
- >20 per cent of population have serum zinc below cut-off values

Figure shows the absorption and metabolism of zinc in the body.

PLATE III

Absorption and metabolism of zinc in the body



Source: <http://www.slideshare.net/obanbrahma/trace-minerals-60303676>

C. PREVALENCE AND CAUSES OF IRON AND ZINC DEFICIENCIES AMONG ADOLESCENT GIRLS

Micronutrient deficiencies are a significant cause of malnutrition and associated ill health throughout the world. This is particularly true in the developing world, where nearly 20 per cent of the population suffers from iodine deficiency, about 25 per cent of children have subclinical vitamin A deficiency, and more than 40 per cent of women are anaemic. Anaemia not only affects the present health status, but also has deleterious effects in the future. Learning, cognitive function, and scholastic performance is also severely affected. The rates of low birth weight, pre-maturity, neonatal and infant mortality among children born to undernourished adolescent girls is high. Later on, these undernourished girls become anaemic and produce low birth weight babies (Deshpande *et al.* , 2013)

1. Global Scenario

Around 842 million people or one in eight people in the world - do not have enough to eat. 98 per cent of the world's undernourished people live in developing countries. Hunger is the worst in Asia: 552 million; Sub-Saharan Africa: 223 million, Latin America and the Caribbean: 47 million (State of Food Security in the World , 2013)

2. Indian Scenario

In India, iron deficiency anaemia (IDA) arises due to an inadequate intake of foods that are rich in iron or poor bioavailability of iron from the plant based foods due to inhibitors or due to excessive losses of iron from the body during menstrual bleeding (Gupta *et al.*, 2014). Other non-biological factors included lack of education, large family size, family income, age, birth spacing, antenatal care and Body Mass Index (BMI) also play role in anaemia (Sinha *et al.*, 2013).

Iron and zinc deficiencies are most common in developing countries with the former being more widespread affecting children, adolescent girls, pregnant and lactating women. Correlations have been identified between iron and zinc status of individuals. The highest deficiency and thereby prevalence of both iron

and zinc deficient have been reported in children from low-income families (Stevens *et al.*, 2013).

In humans, the absorption of haem iron varies little with the composition of the meal. Absorption is inversely related to the quantity of iron stores in the body, i.e. absorption ranges from 15 to 25 per cent in iron-repleted subjects and 25 to 35 per cent in iron-deficient subjects.

3. Prevalence of Zinc deficiency

Worldwide and in India, the problem of iron deficiency and subsequent anaemia is the foremost of public health concerns and subclinical zinc deficiency is now recognized to be widespread. Zinc deficiency accounts for about 17 per cent of the world's population at risk (Wessells and Brown, 2012) and 4.4 per cent under five years child death globally (Black *et al.*, 2008).

A study conducted among 479 adolescent girls resided in a social welfare hostel in southern India (aged 10 to 16 years) revealed that 37.6 per cent girls had normal serum zinc level awhile 62.4 per cent were marginally deficient in zinc . This study also points that along with increasing in age there will be a decreasing trend of serum zinc level (Sucharitha, 2013). Results of another study carried out among 632 school going girls of 10 to 16 years from secondary schools in western India (Pune and Maharashtra) found that average zinc intake was only 3.6 ± 1.2 mg/day which accounts for only 40 per cent of RDA. In that study, 72.5 per cent of the adolescent girls were found below 0.7 mg /L plasma zinc and 23.6 per cent with low erythrocyte zinc levels (Kawade, 2012).

D. FACTORS INFLUENCING BIOAVAILABILITY OF IRON AND ZINC

According to Hurrell and Egli, (2010), bioavailability is generally referred to as the fraction of a nutrient that is absorbed from the diet and used for normal body functions. Bioavailability or biological availability or Bioaccessibility is important as it is to nutrient effectiveness, which is defined as the proportion of nutrient in the food that can be absorbed and utilized (Jackson, 1997).

The bioavailability of a nutrient is affected by external and internal factors. External factors include the food matrix and the chemical form of the nutrient, whereas gender, age, nutrient status and life stage (e.g. pregnancy) are among the internal factors. Because aspects such as nutrient status also determine whether and how much of a nutrient is actually used, stored or excreted, some definitions of bioavailability restrict themselves to the fraction of a nutrient that is absorbed (Heaney, 2001)

The first step in making a nutrient bioavailable is to liberate it from the food matrix and turn it into a chemical form that can bind and enter the gut cells or pass between them and this process is referred to as bioaccessibility (Holst and Williamson, 2008).

Nutrients are rendered for bioaccessible by the processes of chewing or mastication. The initial enzymatic digestion of the food will take place in the mouth later upon swallowing, the masticated food gets mixed with acid and further enzymes in the gastric juice and finally is released into the small intestine, which is the major site of nutrient absorption. Here, more enzymes which are supplied by the pancreatic juice, continue in breaking down of the food matrix. Apart from the bodily means of mastication as well as the enzymatic action, the digestibility of food matrices, especially those of the plant foods, is aided by cooking and pureeing the food. For example, raw carrots are good sources of dietary fibre but on cooking them permits the human body to extract a much larger fraction of the carotenoids contained in it.

Minerals such as iron and zinc exist in diverse chemical forms in the food will influence their bioavailability in the body. In the case of dietary iron, it exists in two types, haem and non-haem iron. The non-haem iron is only found in meat, fish and poultry, whereas the haem occurs in foods of cereal and plant.. Haem iron mainly stems from the haemoglobin and myoglobin molecules responsible for oxygen transport and storage in the blood and muscles, respectively. Once released from the food matrix the haem molecules act like a protective ring around the central iron atom and it prevents the iron from interacting to other food components and makes it soluble in the intestine, where

they are absorbed intact through the specific carrier on the surface of the gut cells (Shayeghi *et al.*, 2005).

On the other hand, non-haem iron is weakly soluble in the intestinal conditions and are also affected by other compounds of the diet and hence, only a small fraction is absorbed by the cells (Hurrell and Egli, 2010). Earlier studies also proved that, the bioavailability of iron and zinc is minimal from plant foods (Sandberg, 2002). It is affected by multiple factors such as the presence of anti-nutrients, like phytates, oxalates, tannins and polyphenols in foods, also a person's requirements, fibre intake, interaction with other nutrients as well as the acidity of intestinal environment (Paul *et al.*, 2004).

E. STUDIES ON BIOAVAILABILITY OF IRON AND ZINC FROM REGIONAL DIETS

Hemalatha *et al* (2007a) conducted an investigation on the bioaccessibility of iron and zinc from cereals and pulses consumed in India. The findings were, the bioaccessibility of zinc and iron was lowest in sorghum (5.51 per cent and 4.13 per cent, respectively) and highest in rice (21.4 per cent and 8.05 per cent, respectively). Whereas in pulses the iron bioaccessibility ranged from 1.77 to 10.2 per cent lowest in cowpea and highest in french beans.

Gupta *et al* (2006) investigated the relative influence of oxalic acid, phytic acid, tannin and dietary fibre on *in vitro* availability of iron from green leafy vegetables.

Singh and Kawatra (2006) studied on ionizable iron contents of products such as pakora, vada, namakpara, kurmura biscuit and cake prepared with addition of fresh and dried powder of amaranthus leaves. The results showed that ionizable iron content of products ranged between 1.3 in kurmura to 2.9 mg/100 g in biscuits prepared from dried powder of amaranthus leaves. The ionizable iron expressed as per cent of total iron was highest in biscuit (57.4 per cent) followed by cake (27.5 per cent) and namakpara prepared with dried and fresh amaranthus leaves (25 per cent and 23.7 per cent, respectively), pakora with fresh leaves (19.3 per cent), kurmura with dried leaves (16.1 per cent), vada (16.2 per cent) and kurmura with fresh leaves (22.4 per cent).

Gupta *et al* (2014) studied the *in vitro* bioavailability of iron of the products prepared from the leaves of the weed, Indian sorrel (*Oxalis Corniculata*). The leaves were incorporated at 10 per cent, 20 per cent and 30 per cent respectively into three recipes such as peanut chutney, lemon drink and idli with their standard ingredients. The iron content ranged from 27.05 to 60.55 mg/100g and the soluble and ionizable iron were also calculated at two different pH i.e. 1.35 and 7.5. That ranged between 9.35 to 13.26 mg/100g, 4.48-6.89 mg/100g, 8.02-12.03 mg/100g, 3.38 -5.58 mg/100g, respectively. The highest iron content was found in peanut chutney. i.e. 60.55 ± 20.58 .

Zimmerman *et al* (2005) found that addition of 12 mg of iron per day regularly to the snack foods increased iron status in Thai women with low iron stores. Snack foods fortified with ferrous sulphate improved iron status to a greater extent than snack foods containing electrolytic and hydrogen-reduced iron. It is well established that ascorbic acid enhances iron absorption when added to meals (Diaz, 2003). Carotenoids including lutein and zeaxanthin have been shown to enhance iron absorption when added to a wheat based breakfast (Gracia, 2006).

Different acidulants such as, lime juice, tomato puree, raw mango powder and tamarind pulp were added to the selected products and evaluated organoleptically for different sensory parameters and the level of acidulants to be incorporated was decided based on organoleptic acceptability

There was a significant difference in total zinc content of the fenugreek bhaji on addition of acidulants, the total zinc content decreased significantly in the treated samples (2.0 to 2.2 mg/100g) compared to control (2.60 mg/100 g). The bioaccessibility of zinc varied significantly with addition of acidulants. Every 100 g of bhaji with tomato puree contained 1.41 mg of bioaccessible zinc followed by raw mango powder, lime and that without acidulant (1.27, 1.25 and 1.23 mg respectively).

Hemalatha *et al* (2005) showed that addition of raw mango powder enhanced the bioaccessibility of zinc from food grains viz., rice, whole and

decorticated chickpea and decorticated green gram. The usage of lime and raw mango in combination with rice in preparations such as 'lemon rice' and 'mango rice' that constitute a part of South Indian diet, such a practice could thus prove advantageous in terms of zinc absorption. While, least increase in bioaccessible zinc was recorded in tamarind added bhaji, which may be due to presence of tannins and tartaric acid as main acid which may have counteracted to this kind of effect. Thus, among the four common acidulants examined in fenugreek bhaji, tomato puree added bhaji exerted a positive influence on mineral bioaccessibility compared to other acidulants.

High levels of calcium exacerbate the inhibitory effect of phytate on zinc absorption in humans by forming a calcium - zinc - phytate complex in the intestine that is even less soluble than phytate complexes formed by either ion alone (Fordyce *et al.*, 1987) and also tamarind is known to contain high amounts of tannins which are known to inhibit the mineral absorption.

F. HOUSEHOLD STRATEGIES TO ENHANCE IRON AND ZINC BIOAVAILABILITY

Cereals and leguminous grains as well as and nuts are considered to be good sources of dietary minerals since they accumulate them during plant growth to be used for further needs (germination, reproduction). However, these plant products also contain oxalic acid, phytates, dietary fibres and polyphenols, that act as mineral binders or chelators, thus reducing bioavailability of minerals, due to the formation of extremely insoluble salts, or very poorly dissociated chelates (Suliburska and Krejpcio, 2014)

Cereals and leguminous grain products are staple foods for most of populations worldwide, they are also major sources of essential minerals, depending on a particular plant variety, agricultural practices, soil and climatic conditions, as well as technological and culinary practices applied (Afridi *et al.*, 2010).

The total contents of Fe, Zn, Ca and Mg in a given food product are not the only criteria determining its nutritional quality, as it also depends on their bioavailability from that product. In order to determine whether a product is a good source of a particular mineral, it is necessary to determine the amount of that mineral released or absorbed in the animal or human organism (Gibson *et al.*, 2010)

The concentrations of minerals (Fe, Zn, Ca and Mg) depended on the type of food product. The highest concentrations of Fe were found in green lentils. The bioaccessibility of minerals *in vitro* also varied considerably, depending on the mineral and the type of the food matrix. Generally, the best sources of bioaccessible Fe, Zn, Ca and Mg were found to be pulses and nuts.

According to Ragae *et al* (2006), among the millets, pearl millet (Bajra) has the highest macronutrients as well as micronutrient contents such as iron, zinc, Magnesium, phosphorus, folic acid and riboflavin.

G. IMPACT OF INTERVENTIONS ON ANAEMIA

Nutrition education programmes will need to pay special attention to addressing the issue of iron deficiency within different population groups with varying dietary habits, socio-economic situations and nutritional and health status. The complexity of interactions between inhibitors and enhancers within diets needs to be translated into practical and simple messages with suggestions for optimal diets within a given cultural, agricultural and socio-economic environment.

Food-based approaches aim at improving nutrition by increasing the availability and consumption of a nutritionally adequate and micronutrient rich diet made up from a variety of available foods. Food based approaches are recognised as an essential part of an urgently needed more comprehensive strategy to combat iron and other micronutrient deficiencies. Tandon (2002) opines that from “pill” to natural food is a difficult challenge but should be considered as the best and most natural solution to the problem of iron deficiency in India.

Fortification of a micronutrient-poor staple with a concentrated micronutrient-rich food is an under explored strategy with household/community-level income-generating and gender-empowering potential (Underwood, 1998). Some traditional household food preservation and preparation practices, such as fermentation (e.g. of fish, soy, and milk products), favour micronutrient retention or enhance bioavailability, particularly of iron, and are important components of a household food-to-food fortification strategy. Food- to-food fortification is one of the promising strategies to combat anaemia among vulnerable groups.

Traditional processing methods can increase the availability of iron from a wide range of foods which could be used in standardization of iron enriched recipes. The mineral content of legumes is generally high, but the bioavailability is poor due to the presence of phytate, which is a main inhibitor of Fe and Zn absorption. Some legumes also contain considerable amounts of Fe-binding polyphenols inhibiting Fe absorption. Efficient removal of phytate, and probably also polyphenols, can be obtained by enzymatic degradation during food processing, either by increasing the activity of the naturally occurring plant phytases and polyphenol degrading enzymes, or by addition of enzyme preparations. Biological food processing techniques that increase the activity of the native enzymes are soaking, germination, hydrothermal treatment and fermentation (Sandberg, 2002).

Thompson and Amoroso (2011) reported that food-based approaches like dietary diversification in the form of under exploited and locally available as well as culturally accepted foods can be used at household level to combat anaemia. Enhancing the of micronutrient density of usual diets by a sustainable, economic, feasible and more culturally acceptable method that can be used to alleviate multiple micronutrient malnutrition. Studies using supplementation as an approach to alleviate the nutrient deficiencies especially that of iron and zinc by enriching beverages, salts, or foods with multiple micronutrient combinations found to have significant impact on the iron nutriture of the subjects (Kumar and Rajagopalan, 2008)

Fortification of refined cereals also will enhance the micronutrient bioavailability. However, the drawbacks of this is, the most soluble forms of iron causes oxidation as well as rancidity of fats and leads to colour changes in foods during the storage. Hence, for the longer shelf lives, reduced iron is chosen, but this will not be well absorbed unless the size of the particles is very small.

Fortification of wheat and maize flours with iron, folic acid and other micronutrients is advised in settings where these foods are major staples. Periodic deworming with medicines, without previous individual diagnosis, for should be given for once a year. ([http://www.who.int/nutrition/publications / infantfeeding/essential_nutrition_actions/en/](http://www.who.int/nutrition/publications/infantfeeding/essential_nutrition_actions/en/).)