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BARRIERS TO MICRONUTRIENT SUPPLEMENTATION ADOPTION AND PRACTICAL CHALLENGES - AN INDIAN PROSPECTIVE ON THE PERSISTENCE OF MICRONUTRIENT DEFICIENCIES

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ABSTRACT: Micronutrient deficiencies are an important driver of morbidity and mortality associated with non-communicable diseases. According to the World Health Organization, more than two billion individuals are micronutrient deficient worldwide, with India home to over half of them. India needs to actively fight against the severe effects of malnutrition since, despite the nation's strong economic growth and declining poverty rate a sizeable section of the population still has sub-optimal nutrition. This review primarily focuses on the current situation of micronutrient status in the nation, including driving factors that contribute to micronutrient deficiency, clinical perspective and challenges, role of supplementation, long-term and sustainable strategies to reduce micronutrient deficiency, as well as challenges in adapting the micronutrient supplementation practices as in the developed world by the Indian community. To achieve India's optimum nutritional status, it is required to identify strategic initiatives to overcome practical challenges and implement the right balance of biofortification, nutritional diversification, and sufficient supplementation.

INTRODUCTION: Vitamins, minerals, and other trace elements, collectively known as "micronutrients," are essential components of our diet and play a major role in the sustenance and maintenance of good health. Micronutrients must be provided by the diet, as the body cannot produce them [1]. It is very difficult to ascertain whether the food we eat will provide us with all the essential nutrients to maintain good health; hence, the role of dietary supplements in complementing the diet may not be overlooked [2].

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Over two billion individuals worldwide experience micronutrient deficiencies, with India contributing nearly half of these cases [3]. The National Nutrition Monitoring Bureau's reports this as an alarming sign in 70% of the population, intake of several important micronutrients is 50% below the Recommended Dietary Allowance (RDA) [4].

Inadequate levels of vitamins and minerals at any stage of life can increase general morbidity and mortality without apparent clinical symptoms or signs to indicate deficiency. In general, numerous micronutrient deficiencies coexist and can be a contributing factor to risk of infection, diabetes, hypertension, osteoporosis, asthma, depression, neurological disorders, cardiovascular disorders, endocrine disorders, *etc*. in apparently healthy population [5]. To maintain and promote good health, taking dietary supplements is common practice in

developed countries. More than 50% of US adults routinely take dietary supplements to augment their daily dietary intake [6]. However, this percentage is estimated to be very low in developing countries like India. Out of 121 countries, India ranked 107 in the Global Hunger Index (GHI) 2022 with its child wasting rate at 19.3 percent in <5year old, the highest in the world. As per Global Hunger Index (GHI) 2012, 43.5 percent of children under five in India were underweight [7]. Undernourished percentage of total population increased from 14.8 % in 2015-2017 to 16.3 % in 2019-2021 in India. This corresponds to 132.48 million undernourished people in India out of a total 828 million undernourished people worldwide [8].

While prevailing poverty in India might be central to the suboptimal nutrition, the rapid growth of the Indian economy cannot be ignored. India achieved remarkable rates of economic expansion, approaching 8% gross domestic product (GDP) growth. According to the Global Multidimensional Poverty Index 2022, around 415 million people in India climbed out of poverty between 2005-06 and 2019-21, with the incidence of poverty falling from 55 % to just over 16 % during this period [9]. This is not limited to India, similar situation exists in other South Asian countries like Afghanistan, Pakistan, Bangladesh, Nepal, Sri Lanka and Maldives. Despite the robust economic growth and declining rate of poverty, they continue to encounter challenge in ensuring nutrition security for a large population, referred to as the 'South Asian Enigma' [10]. Economic growth has the potential to be nutrition-sensitive if it increases food production, expands access to health care, educates women, lowers fertility rates, and reduces family poverty [11].

However, alone, it is insufficient, and India is a prime example of rapid economic growth without commensurate advancements in nutrition [12]. Recent hits from the COVID pandemic have further contributed to already impacted health outcomes especially when it comes to service delivery, food security, and social security. These factors have a direct impact on the nutrition status of the vulnerable population especially women and children [13]. Hence, this review article aims to discuss the extent of suboptimal nutrition in India, contributing factors, barriers, practical challenges in addressing the issues, and strategies to combat this at the population level.

Prevalence of Micronutrient Deficiencies in India: The latest global nutrition data shows that India is way behind in meeting three of the global nutrition targets (anemia in women of reproductive age, stunting, and wasting in kids) when compared to developed countries, as shown in **Fig. 1** [14].

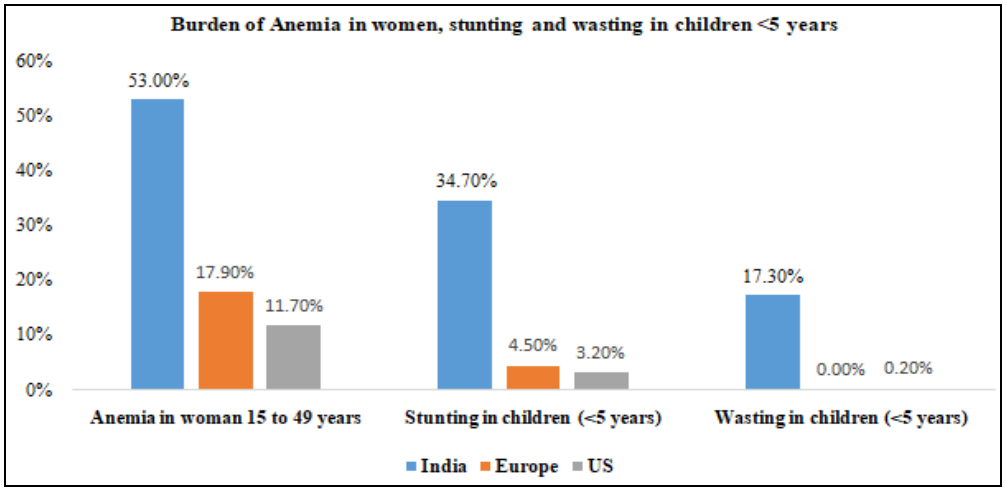

FIG. 1: GLOBAL BURDEN OF ANEMIA IN WOMEN, STUNTING AND WASTING IN CHILDREN <5 YEARS

As per the Comprehensive National Nutrition Survey (2016-2018) in India, anemia is reported as the most prevalent malnutrition problem across all the age groups. Around 447 million Indians are estimated to have anemia, contributing almost one quarter to the global burden of anemia [15]. Stunting and wasting in children is another big problem due to suboptimal nutrition, primarily of zinc. Stunting and wasting are observed in 34.7% and 17.3% of children under the age of 5 years, respectively **Fig.**

1. According to the Comprehensive National Nutrition Survey 2016-18 (CNNS) of children between 0 and 19 years, zinc deficiency was observed in 19% of preschoolers and 32% of adolescents, whereby 23% of preschoolers and 37% of adolescents were deficient in folate [15]. Another study found zinc deficiency and low serum zinc concentrations in adolescents from the Gond, Bhil, and Korku tribes [16]. In a study of 2700 children, the prevalence of goiter, underweight, and severe stunting was 7.22%. 3.9% and 16.8% respectively. A significant association was observed between goiter due to iodine deficiency and the age group of 6-11 years in the children ($p<0.00001$). In a similar study, goiter was associated with the prevalence of stunting ($p<0.00001$) and underweight ($p<0.05$) as well [17].

Many studies draw attention to the issue of micronutrient deficiencies in the Indian population. The most often seen deficiencies in these investigations were those of zinc, calcium, iodine, folic acid, iron, vitamin A, vitamin B12, and vitamin D (**Table 1** – refer Annexure 1). Across these studies, vitamin D deficiency ranged from 39 to 61% **Table 1**. It has been linked to osteoarthritis in adults and rickets in children [18].

In the overall Indian population, vitamin B12 deficiency rates vary from 33-53% **Table 1** [19-26]. A lack of vitamin B12 can affect immunity, cognition, anxiety, and stress levels [27]. Qudsia *et al* has shown that the maintained level of vitamin B12 helped in controlling neuropathy and anemiain diabetes mellitus patients [28]. The range of vitamin A deficiency was 14-19% in the overall population. Vitamin A deficiency may cause blindness and impair immune function and was an important public health problem among the tribal population despite the rich biodiversity [22].

A systematic review conducted for the Indian population (2015 to 2020), showed that the overall prevalence of iodine, folic acid, vitamin B12, vitamin D, and vitamin A deficiency were 17%, 37%, 53%, 61% and 19% respectively **Fig. 2** [5].

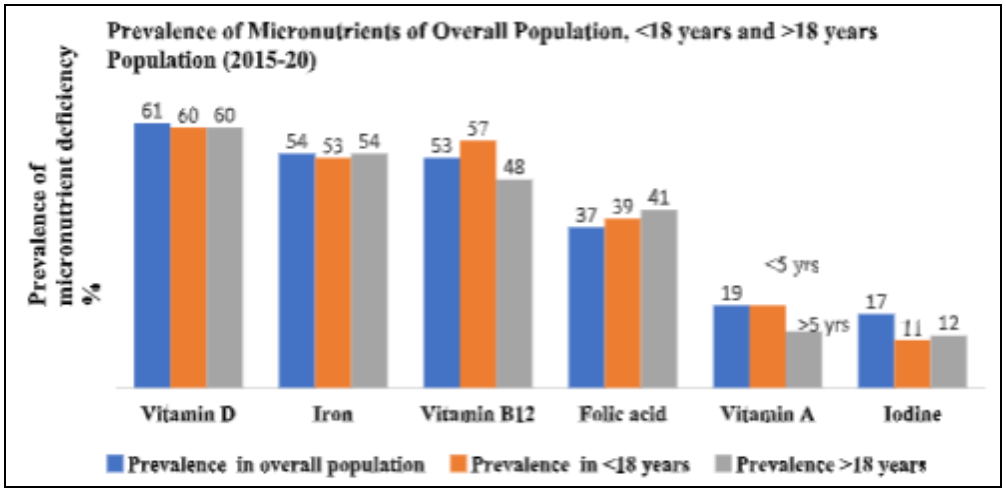

FIG. 2: PREVALENCE OF DEFICIENCY OF MICRONUTRIENTS OF OVERALL POPULATION, <18 YEARS AND >18 YEARS POPULATION IN INDIA (2015-20); PREVALENCE DATA FOR VITAMIN A IS DIVIDED AS OVERALL, UNDER 5 YEARS OF AGE AND OVER 5 YEARS OF AGE

Annexure 1:

TABLE 1: PREVALENCE OF MICRONUTRIENTS DEFICIENCY IN INDIA

S. no.	Author, Year (Ref)	Study Design	Time Duration	Age Group	Population	Prevalence of disease / deficiency
			Prevalence of deficiency of Iron			
1.	NFHS-5 [19]	Health Survey	2019-21	Children		67% Anemia
				Non pregnant women	2,81,429 overall population	57.2%
				Pregnant women		52·2 %
2.	Venkatesh 2021 [5]	Systematic review	2015-20	<5 years		55%
				5–18 years		53%

				Adults		54%
				Pregnant women		61%
3.	CNNS [15]	Health Survey	2016-18	1-4 years		40.5% Anemia
				5-9 years		23.4
				Adolescents		28.4
4.	Sarna, 2020 [21]	Data from CNNS		1-4 years (11 624)	26,765 children	36·5% (1-4 years) Anemia
				5-9 years (15,141)		
5.	Awasthi, 2022 [20]	Multi-center cross-sectional study	April 2019 - Feb 2020	6 to 11 years and 12 to 16 years	2428 participants	49.4%
6.	Meshram 2020 [22]	Community-based cross-sectional study	2020	Preschool children	185	27% Anemia
				Nonpregnant	249	40%,
				Lactating mothers	151	44%
				Pregnant women	46	52%
Prevalence of deficiency of Iodine						
1.	Bhattacharyya, 2022 [17]	Cross-sectional study		Children (6 to 11 years)	2700	7.22 % Goiter rate
2.	Venkatesh 2021 [5]	Systematic review	2015-20	Overall population		17%
				<18 years		11%
				>18 years		12%
				Non-specific		59%
Prevalence of deficiency of Folic acid						
1.	Sundarakumar, 2021 [23]	SANSCOG* study cohort		1,648 Adults	(872 males and 776 females)	11.1%
2.	Venkatesh 2021 [5]	Systematic review	2015-20	Overall population		37%
				<18 years		3%
				>18 years		41%
				Non-specific		25%
Prevalence of deficiency of Vitamin B12						
1.	Awasthi, 2022 [20]	Multi-center cross-sectional study		6 to 11 years and 12 to 16 years	2428 children	33.4%
2.	Venkatesh 2021 [5]	Systematic review	2015-20	Overall population		53%
				<18 years		57%
				>18 years		48%
				Nonspecific		68%
3.	Sundarakumar, 2021 [23]	SANSCOG* study cohort		Adult population	1,648 subjects	42.3%
4.	ICMR [24]	Multi-centre pan India study			4613 individuals	21%
Prevalence of deficiency of Vitamin A						
1.	Kundu, 2021 [25]	CNNS	2016–18	Children (0-5 years)		17.54%
2.	Venkatesh 2021 [5]	Systematic review	2015-20	Overall population		19%
				Nonspecific		28%
				<5 years		19%
				>5 years		13%
3.	Reddy 2021 [26]	CNNS	2016–18	Children (5-9 years)	10,298	19.3%
				Adolescents (10-19 years)	9,824	14.4%
4.	ICMR [24]	CNNS	2016–18	Children (1-4 years)		15.7%
Prevalence of deficiency of Vitamin D						
1.	Awasthi, 2022 [20]	Multi-center cross-sectional study		Children	2,428	39.7%
2.	Sundarakumar, 2021 [23]	SANSCOG* study cohort		Adult population	1,648	39.1%
3.	Venkatesh 2021 [5]	Systematic review	2015-20	Overall population		61%
				<18 years		60%
				>18 years		60%
				Non-specific		63%
Prevalence of deficiency of Zinc and Calcium						

1.	Kotnis A, 2022 [16]	Cross-sectional community	adolescents (10-19 years)	844	42.6 % Zinc inadequacy
2.	Awasthi S, 2022 [20]	Multi-center cross-sectional study	children	2428 children	59.9% Calcium

A sample across seven geographical regions of India, Delhi, Bihar, Odisha, Maharashtra, Gujarat and Karnataka, representing North, South, East and West is showcased in **Fig. 3** [15]. It gives an indication of varied impact from factors that contribute to deficiencies in these states. While deficiencies are recognized to be widespread across the spectrum, there are differences in the deficiency levels of Vitamin D, Vitamin B12, folate & iron regional populations **Fig. 3.** Folate deficiency was found to be highly prevalent in Karnataka, Maharashtra, Gujarat and Odisha. Vitamin D deficiency was more prevalent in Punjab, Delhi, Gujrat & Bihar. Iron and vitamin B12 deficiency was widespread in Delhi, Karnataka, Maharashtra, Punjab, and Gujarat [15]. The micronutrient deficiency is a challenge across all the life stages, starting from infancy to old age. Suboptimal nutritional status is a contributing factor to the prevalence and severity of non-communicable diseases (NCDs), including cardiovascular, cognitive, musculoskeletal, immune, metabolic and ophthalmological functions. NCDs have a significant negative impact on mortality and quality of life, which gets worse as people get older. Old age, rural-community Indians have high burden of vitamin D (59.6% in women and 20% in men), B12 (42.7% in women and 41.8% in men) and folic acid (21.8% in women and 18.5% in men) deficiencies [23]. A recent study found that when it comes to healthy life expectancy, India lags behind many Asia Pacific nations [29]. Average healthy life expectancy is reported to be 78 years in Singapore, 75 years in Japan, 73 years in Australia, 68 years in China, however, 59 years in India [30]. Currently, NCD prevention efforts have primarily concentrated on therapeutic interventions, paying less attention to the significance of optimizing adequate essential and semi-essential nutrient intakes and nutrient-rich diets across all stages of life [31].

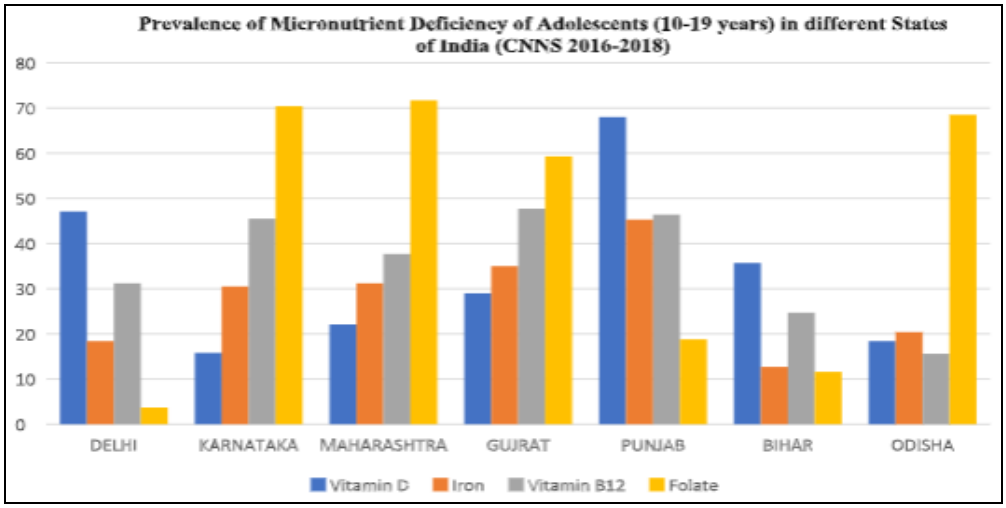

FIG. 3: PREVALENCE OF MICRONUTRIENT DEFICIENCY IN ADOLESCENTS (10-19 YEARS) ACROSS DIFFERENT STATES OF INDIA [15]

Factors Contributing Towards Micronutrients Deficiency: Prevalence of micronutrient deficiency can be due to various factors including changing Indian dietary patterns caused by agricultural, economic, lifestyle, health and nutrition transitions, unmet micronutrient requirements during pregnancy and lactation, diseases, advancing age, infections, or surgery. Nutrition, infection, and immunity all have a bidirectional relationship in which changes in one component impact the others. Understanding the causes of suboptimal micronutrient insufficiency in the population, regardless of age groups, geographic locations, and other factors, will not only aid in identifying and developing the intervention strategy, but also in its successful implementation [32].

Lack of Adequate Public Knowledge and Awareness: There is an association between nutrition knowledge and a healthy diet. In addition, nutritional knowledge, attitude, and practice have the potential to contribute to improving dietary quality [33]. A recent systematic analysis of dietary data from 195 different countries, including India, identified poor diet as the main risk factor for death in 2017, with excessive sodium intake being responsible for more than half of diet-related deaths [34]. In another study of 100 adolescent junior college students in Hyderabad, only one fourth (25%) of the adolescent girls had good nutrition knowledge [35]. The education intervention program for 8–9 months among 714 tribal women of 15–60 years, in 15 hamlets of Coimbatore district, Tamil Nadu proved to be effective in attaining their nutritional security (the mean body mass index for 15–20-year-old girls increased from 18.65 at baseline to 19.30 period after the intervention) [36]. Lack of awareness of nutritional food, irrational beliefs about eating habits, and inappropriate child-rearing and feeding habits all lead to undernutrition in the family [33].

Gender Equity: Women are undervalued in Indian society and "eat least and last." This is considered a particularly strong factor in the high rates of maternal and child malnutrition. Women have restricted access to resources, healthcare services, and ignorance of or attitude towards self-care, and their decision-making power impacts their nutrition status mainly during pregnancy and lactation [37]. Pregnant mothers without optimal nutritional intakes have children with suboptimal health status, including impaired physical and mental development, setting the infant on a deleterious course of stunting, increased likelihood of infection, and developmental delays. In time, these children themselves enter their reproductive years at a nutritional disadvantage, and the cycle continues [38, 39].

Inadequate Purchasing Power Due to Low Per-Capita Income: Modern India is a paradoxical condition in which a substantial portion of society (the poorest two-fifths of the country's population) remains mostly unaffected by the country's developing economy [40]. Due to a lack of employment and income opportunities, inadequate purchasing power continues to exist. Poor and underprivileged people cannot afford to buy the desired quantity and quality of food for their families due to their limited purchasing power. Poverty limits their ability to perform physical labor, and as a result, they earn less. This instance also contributes to a vicious circle of poverty, undernutrition, reduced labor capability, and low achievement. The average daily calorie consumption in India is below the recommended 2503 kcal/capita/day across all groups, except for the richest 5% of the population [41].

Heterogeneous Economic Expansion and Impact on Agricultural Development: In light of India's economic boom, it is important to note that growth has mainly been concentrated in the service and technology sectors, rather than the agricultural sector, in which the bulk of the population (particularly in rural India) is economically engaged. Of all the sectors, agriculture has the largest impact on a nation's ability to meet its goal of adequate nutrition [42]. Furthermore, due to urbanization, the migration of rural people has drastically increased. The proportion of the rural population in India fell from 73% in 1995 to 65% in 2016 as cities expanded and created jobs. Agriculture's labor-intensiveness decreased with modernization, and agriculture employment decreased from 61% in 1995 to 43% in 2016 [43]. Moreover, India has witnessed the success of 'Green Revolution', which other regions with chronic malnutrition, notably Sub-Saharan Africa, have yet to experience. Nonetheless, despite improved agricultural productivity and calorie availability, malnutrition rates are still higher in India, this alludes to much deeper challenges than food security and availability [44].

Focus Limited to Food Security Instead of Nutrition Security: Farming techniques and food processing result in the loss of plant micronutrients [32]. According to a World Bank report, despite a large rise in agricultural productivity following the "green revolution," health outcomes did not improve [45]. Some of the green revolution's interventions, such as the use of pesticides and the adoption of hybrid crops, violate the natural order of balance and function. These unsustainable practices reduce food quality and contribute to poor nutrition, which has a detrimental impact on health [46].

Buyer's Attitude Towards Food: In addition to affordability, experts have stated that low diet diversity may also be caused by buyers' attitudes towards food (in a market-driven ecosystem). It has been noted that a typical spending on non-food products has climbed while spending on food items has dropped during the past few decades [38, 47]. Indians do not consume adequate amounts of fruits, vegetables, and non-cereal proteins in their diets for example use of millets in the diet is not widespread even though millets are a source of high-quality proteins, micronutrients and fiber [48]. An average Indian household consumes more calories from processed foods than from fruits [49]. This highlights the lack of awareness and willingness to take account of their nutritional condition. Most only eat to satisfy appetite rather than for keep a healthy diet.

Role of Restrictive Diets: A larger population in India is vegetarian and reluctant to choose proper diet habits for themselves. The rates of subclinical deficiency of vitamin B-12 are high in elderly and vegetarian populations. The majority of the population can avoid B-12 deficiency by eating B-12-rich foods, but these are mostly of animal origin, including dairy and eggs, so there is a higher prevalence of vitamin B-12 deficiency among those who cannot consume animal products due to economic, cultural, or religious reasons [50]. Indians enjoy deep-frying, and overcooking food to improve flavor also causes a loss of micronutrients between 25 - 40% [51].

Influence of Urbanization on Indian's Eating Habits: Unlike Western world, Indians do not prefer to take vitamin supplements. Historically, Indian culture has always placed a high value on good nutrition and focuses on a balanced, nutritious diet through which one can fulfill the bodily requirement of optimal nutrition that significantly impacts overall functioning. The diet should consist of locally grown fruits, vegetables, grains, and cereals [52]. Indians do not measure the number of calories and, nutritional value in their diet. In contrast to Western nations, where people are more inclined to grab a meal on-the-go, the Indian diet traditionally includes less processed products and more natural components, and its culture is more focused on a sit-down meal with family or friends. However, a strong influence of western eating habits and urbanization has changed Indian dietary habits and led them to move away from traditional healthy food habits [53]. Today the modern culture of eating out or 'food ordering service' is rapidly changing the mindset of Indian society. Several fast-food brands have established themselves, as they have found a growing market in India due to the fast-moving lifestyle, busy schedules, , increase in the number of working women, and peaking nuclear family concept [54]. Additionally, insufficient intake of food owing to weight-reducing and imbalanced diets, increased consumption of junk food leads to unhealthy snacking habits, eating disorders, as well as emotional and/or physiological stress, which are roadblocks for India to achieve nutrition success [53].

Socio-cultural Factors among Adolescents: Adolescents have a dislike for healthy food and a remarkable taste-driven food preference. Adolescents acknowledged that their food choices were largely shaped by their liking for savory foods that "taste better", an inclination towards 'street food' over home cooked meals. On one hand, this led adolescents to frequently turn to street foods with a tendency to avoid healthy food, in spite of knowing the health benefits offered by the healthy food. In a study of 51 children aged 16-20 years in India, the adolescents consumed less protein, vitamins, iron, and dietary fiber and more calories, fats, and carbohydrates than the suggested dietary allowances. They had reached the borderline BMI and were approaching obesity [55].

A systematic review among adolescents in low- and middle-income countries showed that undernutrition was associated with determinants at the personal level (age, sex, birth order, religion, ethnicity, educational and literacy level, working status, and marital status), household level (parental education and occupation, household size and composition, income, and socio-economic status) and community level (residence, sanitation, school type and seasonality). The consequences of adolescent under nutrition were mostly related to education and cognition [56].

Smoking and Tobacco Chewing: Nearly 267 million adults (15 years and above) in India are users of tobacco, according to the Global Adult Tobacco Survey India, 2016-17 [57].

Cigarette smoking is directly responsible for lower circulating concentrations of selected antioxidants, and micronutrients. The micronutrients most strongly influenced by smoking are vitamin C and provitamin A carotenoids [58].

Alcohol Abuse: Heavy alcohol consumption leads to malnutrition by reducing the absorption or/and accelerating the loss of micronutrients like Zinc [59].

An accumulation of toxins caused by excessive alcohol consumption can prevent enzymes involved in fat metabolism from operating normally [60]. Additionally, ghrelin levels can be affected by persistent heavy drinking, which can result in overeating of fatty or sugary foods [61].

Inappropriate use of Drugs Affecting Nutrition: The long-term use of prescription and over-the-counter drugs can have a significant impact on nutrition in several ways. Some drugs may directly affect nutrient absorption, metabolism, or utilization, while others may lead to changes in appetite or eating habits [62, 63].

The patient's nutritional status prior to the beginning of the treatment is one of the key variables that affects drug-nutrient interactions. Interactions between drug and nutrients are more likely to occur when nutrient deficiencies, comorbidities, and polypharmacy are involved [64].

Infection and Immunity: In India, the mortality rates for enteric infections were 1165.83 per 100,000 in 2019 [65]. As per cross-sectional data analysis from the National Sample Survey Organization (2017–2018), among the overall ailing population, more than 33% were still afflicted by infectious diseases in India [66]. Micronutrient deficiencies or low levels have the potential to severely affect immune function and may consequently reduce resistance to infections and diseases. The ESPN practical guideline also recommends micronutrient intake be improved in both quality and quantity to compensate for the decrease in endogenous availability brought on by illness [67]. Implementing these recommendations may reveal a different reality, though.

Challenges in Indian Prospective – Clinical Context: The majority of the healthcare practitioners (HCPs) acknowledged that micronutrients have a significant impact at the molecular and cellular levels and that insufficient amounts of these micronutrients may result in sub-clinical symptoms that can progress to more serious consequences [68]. Micronutrient deficiency begins long before any clinical signs of a deficiency show up and progresses through several sub-clinical phases that are not clinically visible, leaving a person more susceptible to a variety of implications like frequent infections **Fig. 4** [69].

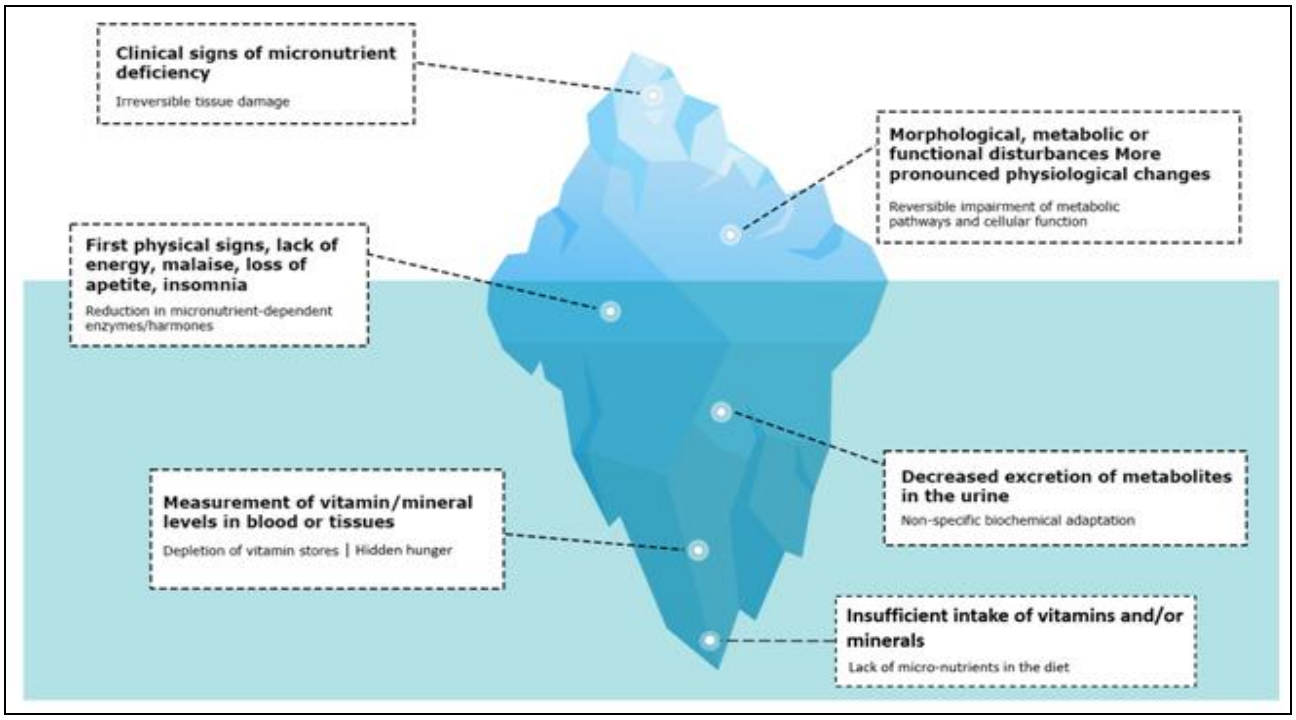

FIG. 4: PROGRESSIVE STAGES OF VITAMIN DEFICIENCY AND ASSOCIATED CLINICAL SIGNS

No Pain, No Attention: micronutrient deficiencies often go unnoticed until reach at a dire state. This is partially due to unclear specific symptoms thus often referred to as 'hidden hunger' [31]. Rarely is the issue of diagnosing micronutrient insufficiency addressed, making a search of laboratory biochemistry references necessary. Doctors might not be able to interpret an anomalous laboratory result, such as a blood reading below the reference range for a vitamin, despite the reality that knowledge of micronutrients is even less established than dietary knowledge [65]. Furthermore, a deficiency in one micronutrient can manifest multiple symptoms and deficiencies in multiple micronutrients may have similar or overlapping symptoms [70]. For instance, anemia may result from a number of variables, including a lack of micronutrients (such as iron or vitamin B12), genetics, long-term chronic illnesses, cancer, *etc*. However, this may be misleading because anemia is frequently mistaken for an iron deficiency [71].

This underscores the need to reconsider micronutrient supplementation due to insufficient and brief physician-patient interactions that limits the time and attention a physician can spend for each patient in the clinic. Medical doctors per 10,000 population (WHO) in India is very low (7:22/10,000) as compared to the US and China which causes an inadequate time period for physician-patient interactions [30]. The time spent by the physician providing health education and observing the effects of treatment has an important bearing on patient satisfaction [72]. It also impacts the proper attention of physicians to patients and the lack of focus on full-scale examinations. This in turn adds to the burden of the patient's waiting time at the clinic, causes resistance to follow-up visits, and paves way for improper use of therapeutic supplementation without consideration for proper diagnosis and treatment guidance.

Each individual in a healthy population may not actually require nutrient intake at par with the RDA levels (which is the 97.5th percentile of the distribution of nutrient intake in the population) on a daily basis [73]. In fact, intake of nutrients as per the RDA levels comes with a risk of excess intake. Therefore, the estimated average requirement (which is the median of the distribution of nutrient intake in the population) is being recommended [73]. Moreover, the requirement of micronutrients varies depending upon the physiological stage, growth, exercise, infection, and immunity, so using the same measuring scale for different needs is not the right approach [70, 73].

Implications and General Population Outcomes: Micronutrient deficiency is likely to be established when an individual develops clinical signs, as deficiencies begin three to six months prior. Dementia, for example, can be the first clinical sign of iron deficiency; vitamin B12 deficiency can result in neurological disorders; folic acid deficiency can result in hematological disorders; and vitamin D deficiency can result in muscle weakness, bone pain, and fatigue [4]. Inadequate micronutrient intake at any stage of life is a vicious cycle that has negative consequences throughout an individual's life span and continues across decades, with far-reaching implications on healthy aging [4]. Zinc deficiency can cause thymic atrophy, reduction in lymphocyte number and activity, and enhance the oxidative stress and inflammation by altering cytokine production. As a result, the risk of all types of infection (bacterial, viral, and fungal) is increased, particularly diarrhea and pneumonia [69].

Challenges in Strategies to Control Micronutrient Deficiency: Food fortification, dietary diversification, nutritional education, micronutrient supplementation, agricultural interventions, maintenance of environmental sanitation and hygiene are the various available measures taken to tackle the problem of micronutrient malnutrition [74]. With an aim to reduce malnutrition challenges, the government of India has implemented several nutrition initiatives, including the National Food Security Act 2013, Anemia Mukt Bharat Abhiyan, Integrated Child Development Services (ICDS), and the mid-day meal scheme. To end malnutrition by the year 2022, the Indian government has started the National Nutrition Mission (NNM), also known as POSHAN Abhiyaan [75].

Despite constant attempts by the government, India still faces the enormous challenge of providing optimal nutrition to its 1.4 billion people. A retrospective comparative analysis was carried out to understand the progress on the micronutrient deficiency problem in India where data on iron,

vitamin B12, and folate deficiency were collected from 48,317 subjects (during the years 2012–2014) and compared with data collected from 4,775 individuals (during the period of April 2019–March 2020). The findings showed a minor decrease in iron deficiency from 66.73% (2012–2014) to 56.8% (2019–2020), although the prevalence of vitamin B12 and folate deficiency remained unchanged [76]. Unfortunately, micronutrient supplementation, food fortification, and other strategies have been only partially effective. There are still considerable gaps in identifying the effective intervention strategies, research initiatives, programs, and policies addressing micronutrient deficiencies in India. Although food fortification, nutritional supplementation can be promising, they may not be the only answers to the widespread nutritional deficiencies and may need the help of other interventions. Determining the reason for the delayed improvement in the nation's nutritional position is therefore essential [5]. In addition, the country's diverse landscape in terms of age, culture, eating habits, priorities, and socioeconomic status demands a diversified approach rather than standardizing design, which has been inherently followed over the years [77]. Understanding the causes of suboptimal micronutrient insufficiency in the population, regardless of age groups, geographic locations, and other factors, will not only aid in identifying and developing the intervention strategy, but also in its successful implementation [31].

Adoptation of Micronutrient Supplement in the Developed World vs India: Practical Challenges: In a pooled analysis of 24 nationally representative surveys conducted between 2003 and 2019, the estimated prevalence of deficiency in at least one of the three core micronutrients (iron, zinc, and folate) was lowest in high-income countries among preschool-aged children and non-pregnant women of reproductive age [71]. High-income nations handle the problem of suboptimal nutrition through education, dietary modification, food distribution, agricultural interventions, supplementation, and fortification, either singly or in combination [74].

More than half of US adults and one-third of American children consume more than one dietary supplement (DS), with consumption being particularly high in older adults [78]. The prevalence of DS use increased from 48.4% to 56.1% in the US population from 2007–2008 to 2017–2018. The rise in overall DS use was primarily fueled by adult users rather than children, whose DS use stayed steady from 2007 to 2018 [79]. With increasing age, an increase in the usage of several dietary supplements, nearly one-quarter of individuals 60 and older (24.9%) reported using four or more dietary supplements **Fig. 5** [79]. The most popular dietary supplements used by adults of all ages were multivitamin-mineral supplements, followed by vitamin D and omega-3 fatty acid products.

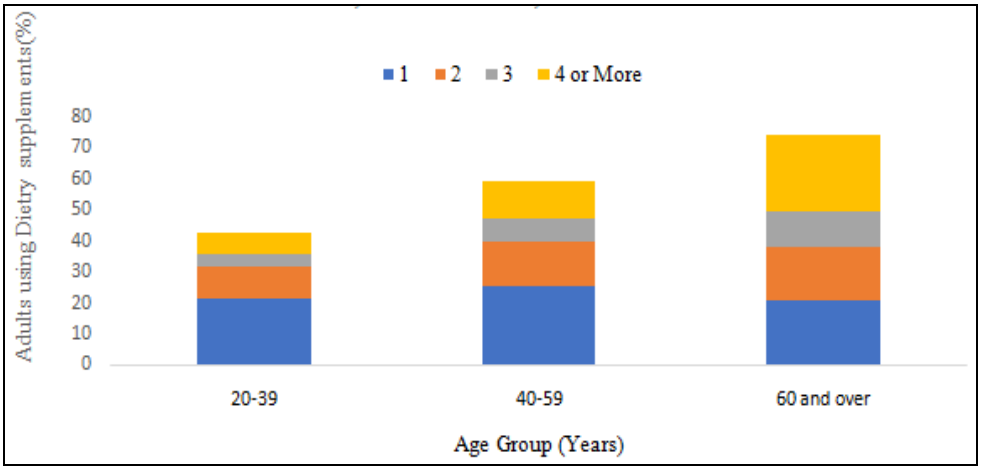

FIG. 5: NUMBER OF DIETARY SUPPLEMENTS USED BY ADULTS AGED 20 AND OVER, UNITED STATES, 2017–2018

These facts suggest that use of supplementation as a key tool in addition to other's strategies to support solve the nutritional security problem in the developing countries like India. Micronutrient malnutrition continues to be a serious issue for

India's public health despite the efforts of numerous national health initiatives.

Role of Micronutrient Supplementation in Health: Malnutrition is a multi-dimensional problem, especially in a country like India with a wide variety of dietary options, cultural practices, climatic variations, and socioeconomic conditions. To combat the hidden epidemic of micronutrient deficiencies, there is an urgent need to understand the causes of micronutrient deficits in India, identify and implement strategies to address them [31].

The current risk of 'hidden hunger' is severe in India due to serious deficiency risks across an array of essential micronutrients. It is difficult to achieve optimal micronutrient intake for immune defenses through diet alone. Supplementation with multiple micronutrients has significant benefits for maintaining health as we age. For instance, there is a rationale for micronutrient supplementation to restore concentrations to recommended levels, especially after an infection, and to support immune function and maintenance.

Daily intake of adequate levels of micronutrients is essential in functioning of barriers (physical & biochemical) and the immune cells (in innate & adaptive immunity) themselves. Micronutrients in frank deficiency, sub-optimal and sometimes even with marginal inadequacy can lead to impairment in the functioning of the immune system predisposing the sufferer to frequent episodes of infections. Supplementation with multi-nutrients has been shown to be beneficial in immune function, restoration of infection resistance even in acute infection states [1].

As per the health survey data received from 220 HCPs in urban India (Mar-Apr 2021), almost 85% of Indian doctors (GPs, ENTs, Internal Medicine experts), and 93% of Indian nutritionists believe that the daily Indian diet only meets 70% (or even less) of our micronutrient requirements in urban adults aged 25-45 years [80]. The majority of the HCPs agreed that among micronutrients, consumption of calcium, iron, folic acid, zinc, vitamin D3, and B12 are below RDA guidelines in the Indian population. Among various micronutrient deficiencies, iron deficiency anemia, vitamin A deficiency, and riboflavin deficiency are highly prevalent in the Indian population [4].

Addressing the GAP with Daily Micronutrient Supplementation: With a variety of religions, cultures, traditions, socioeconomic strata, and agricultural practices coexisting peacefully for millennia, India is one of the earliest continuously civilizations. The holistic approach to health and culinary techniques is a significant component of Indian tradition [81].

Based on the Ayurvedic concept that there is "nature's wisdom" in what is seasonally accessible, food would be season-specific (i.e., "warming" foods in winter and vice versa). Traditional meals were predominantly plant-based and included grains (cereals, millets), legumes, and vegetables, a variety of spices (like pepper, cumin, coriander, and ginger), local seasonal vegetables and fruits, as well as a milk-based product (yogurt, buttermilk, and cottage cheese) to meet the daily energy, macronutrient, micronutrient, fiber and antioxidants requirements [82, 83]. India is undergoing rapid modernization, which includes significant dietary and lifestyle changes, such as prolonged indoor working hours and the consumption of fast food. Agriculture has become more mechanized, reducing time spent in the heat. Long workdays spent indoors, modernization of culture and lifestyle resulting in a shift in clothing habits, and sun aversion. The desire for food is changing as more people move into cities. As a result, India's new nutrition issue the issue of excessive consumption and obesity began to appear. All of this took place in a single generation and made up

"The Nutrition Transition," which was characterized by both chronic undernutrition and emerging overnutrition. As a result, the proportion of people who are typically nourished did not change [43]. More than 10% of an individual's lifetime earnings and 2 to 3% of the country's GDP are lost in productivity as a result of inadequate nutrition. The expense of treating malnutrition is 27 times more than the cost needed to prevent it [84]. Nutrition Supplementation of micronutrients is an effective solution against an unbalanced nutrition state on short term basis and there is a need to revisit traditional Indian food wisdom, healthy ancient culinary practices and changes in lifestyle

on long term basis. Micronutrient supplementation should be empirical (based on observation or experience rather than cumbersome evidence generation at an individual level e.g., extensive nutrient profiling), comprehensive (cover a greater number of nutrients with lower dose and better compliance) and long term (lesser chances of overdosing, nutrient fulfillment over longer periods). Furthermore, use of interventions to improve the nutrition quality of crops, focus need to be shift from pro food to pro nutrition [85].

Raising awareness for diet supplements at both individual as well as government level, adapting western world practices, practices towards early diagnosis of nutrition deficiency in all age group including children, women, men, elderly are major steps to be taken to contain this situation. Indian council of medical research (ICMR) has also launched 15 dietary guidelines for Indians to provide nutritionally adequate diet to infants, children, adolescents, pregnant and lactating women and elderly people [86]. Context-specific tailored solutions are needed, not only to ensure nutrients but also to ensure acceptability and sustainability. Further research is needed on how these micronutrients and vitamins could be enriched in local foods, which would ensure greater reach, acceptability, and sustainability [87].

Progressive stages of vitamin deficiency are associated with clinical manifestations at different stages of life. Non-communicable diseases (NCDs), which affect immunological, metabolic, musculoskeletal, cardiovascular, and ophthalmological systems, are more common and more severe when a person's nutritional status is suboptimal [31]. NCDs can be well managed by implementing diet correction, micronutrient supplementation and therapeutic intervention. According to the WHO, "There is convincing evidence indicating a reduction in the risk of osteoporosis in older persons with adequate consumption of vitamin D and calcium combined." Furthermore, docosahexaenoic acid (DHA) supplementation enhances cognition and several behaviors associated with impulsive behavior, schizophrenia, bipolar disorder, and attention deficit hyperactivity disorder. Older populations, in particular suffer more from the additive effects of NCDs and have reduced resilience and ability to maintain healthy homeostasis. By providing adequate nutrient supplements, it is possible to increase the resilience and ability to maintain healthy homeostasis in an aging population. More accurately, optimal nutritional status needs to start before a senior age is reached and before the consequences of the disease process are irreversible [88].

CONCLUSION: Children, adolescents, and pregnant women are at a greater risk of undernutrition, as the demands during these stages of life are higher. The effects include but are not limited to poor growth and cognitive development, anemia, night blindness, osteoporosis, cardiovascular diseases, and even cancers [85]. These unintended consequences may have far-reaching consequences, affecting individual's development potential, work productivity, healthy aging and ultimately inhibiting the development of society and nations. That is why, India must use a more effective combination of intervention measures to treat its micronutrient deficiencies, including the optimum combination of dietary diversity of foods high in micronutrients like millets, food fortification, and micronutrient supplementation. These interventions should be optimized using complementary approaches, geared toward specific demographics, and evolving in line with India's changing socioeconomic and infrastructural development. It is essential that we change the current mindset that solely considers energy security when discussing food security. Cereals cannot satisfy hunger on their own and cannot guarantee nourishment and good health. A balanced diet that is sufficient in macro and micronutrients should be the aim. Reassessing traditional Indian culinary knowledge, implementing long-term lifestyle modifications, and returning to healthful historic cooking practices are necessary.

To assure micronutrient security, laboratory, clinical, and community-based research is required. It is necessary to determine the ideal ratio of biofortification, nutritional diversification, and adequate supplementation. Nutritional inadequacies must be quickly identified and effectively treated. The media must help in efforts to raise awareness and encourage compliance with achieving optimal nutrition for all.

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