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Review Article

Dietary diversity as a sustainable approach towards micronutrient deficiencies in India

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The silent epidemic of micronutrient deficiencies (MNDs) continues to be a major public health challenge in the developing world, including India. The prevalence of iron, iodine, zinc, vitamin A and folate deficiencies is alarmingly high worldwide. India is additionally facing a high prevalence of vitamin D and B12 deficiencies. To combat the hidden epidemic of MNDs, various governments around the world have mostly relied on supplementation or fortification-based interventions. India launched salt iodization programme in 1962 and vitamin A and iron-folate supplementation programmes in 1970. Yet, even after decades of these programmes, MNDs are still widespread in the country. Due to slow progress in alleviating the burden of most MNDs, the Government of India aims to scale up fortification-based intervention programmes. However, there are safety and effectiveness concerns with such approaches. Hence, overdependence on supplementation and fortification alone may be counterproductive. Instead, food based dietary diversification approach can be the way forward. In this article, we list the common MNDs in India, evaluate major policy interventions, discuss concerns pertaining to fortification and suggest the need for a concurrent food-based approach, in particular dietary diversification, as a long-term and sustainable strategy to address population-based MNDs.

Key words Anaemia - dietary diversity - fortification - iodine deficiency - iron deficiency - micronutrient deficiencies - supplementation - vitamin A deficiency

The vast majority of people in developing parts of the world, including India, continue to deal with the silent epidemic of micronutrient deficiencies (MNDs)[1,2]. Morbidity and disability associated with MNDs result in a substantial disease burden (*viz*. years lived with disability and years of life lost) and economic losses[1,2]. Micronutrients principally include fat- and water-soluble vitamins, minerals and trace elements[3]. There are at least 30 micronutrients that cannot be adequately synthesized by the human body, and hence, their intake through food is crucial[3]. It is, therefore, not surprising that more than two billion people in the world are unable to meet their daily requirement of micronutrients through food, especially in low- and middle-income countries[1,3].

Globally, most common MNDs exist for iron and folate (causing microcytic anaemia), vitamin A (causing night blindness), iodine (causing goitre) and zinc;

however, regional variations do exist[1,2]. A little more than 30 per cent of people (~two billion) worldwide are estimated to have iron deficiency[1]. Around 33.3 per cent of pre-schoolers and 15.3 per cent of pregnant women are reported to have vitamin A deficiency (VAD), 17.3 per cent have zinc deficiency, while around two billion people suffer from iodine inadequacy[1,2,4].

Although nationwide data on the prevalence of most MNDs in India is not available, several small- to medium-sized studies from various parts of the country reflect the gravity of the situation[5]. In a recent survey by the Ministry of Health and Family Welfare, 32 per cent of pre-schoolers (1-4 yr), 17 per cent of school-aged children (5-9 yr) and 22 per cent of adolescents (10-19 yr) (31% female and 12% male adolescents) were reported to have iron deficiency[6]. Furthermore, in the same survey, 19 per cent of pre-schoolers, 17 per cent of school-aged children and 32 per cent of adolescents were reported to have zinc deficiency[6]. Other studies have reported a much higher (up to 60-70%) prevalence of low ferritin levels among Indians[5] and zinc deficiency of 43.8 per cent among children aged 6-60 months, 49.4 per cent in adolescents and 64.6 per cent in pregnant women[5]. The situation appears to be a little better for iodine, yet it is far from ideal. As per an estimate, 350 million Indians may be at risk of iodine deficiency[7].

Although the prevalence of clinical VAD in India has been reported to be low, as indicated by less than one per cent prevalence of Bitot spots among pre-schoolers and school-aged children, sub-clinical VAD as assessed by serum vitamin A is still high[5]; in fact, the same is estimated to be the highest in the world[8]. In a recent nationwide survey, 19.3 per cent of school-aged children and 14.4 per cent of adolescents were reported to have sub-clinical VAD[9]. Other studies have reported a much higher prevalence (up to 62%) of sub-clinical VAD among pre-schoolers[10]. Prevalence of vitamin D, B12 and folate deficiencies has also been reported to be quite high among Indians. As per estimates, 70-100 per cent of Indians have vitamin D deficiency[11]; nearly 23 per cent of pre-schoolers, 28 per cent of school-aged children and 37 per cent of adolescents are folate deficient[6]; and 16-77 per cent of general population and 43-74 per cent of pregnant women are vitamin B12 deficient[12]. In fact, Muthayya *et al*[13] in their study reported India to be one of the 20 countries, with the highest burden of multiple MNDs (others being 18 African countries and Afghanistan).

To combat the hidden hunger of MNDs, various governments around the world have adopted different approaches at various times in diverse populations[14]. Most of these approaches, however, can be classified as either supplementation or fortification-based interventions[14]. Much like the rest of the world, the central and various State governments in India have also initiated several such interventions for MNDs in the past six decades[15]. India started with the iodine fortification in 1962 and supplementation for vitamin A, iron and folate in 1970, which are indeed credited with a reduction in the prevalence of common MNDs[7,16,17]. However, evidence suggests that the rate of reduction is rather slow and unsatisfactory[18,19]. Due to this, many public health and nutrition experts have been advocating for a revamp of supplementation and fortification-based policies[19]. However, there are experts who assert that nutrient supplementation and food fortification are not the ultimate measures for controlling MNDs, rather food-based approaches such as dietary improvement and diversification should be considered as long-term strategies[20,21].

India's commitment towards reducing the burden of MNDs and malnutrition is evident from recent ambitious initiatives such as National Nutrition Mission or *POSHAN Abhiyaan* launched in March 2018 and *Anaemia Mukt Bharat* launched in September 2018[22,23]. *POSHAN Abhiyaan*, on one hand, aims at cross-sectoral convergence and real-time monitoring to address multi-dimensional factors affecting malnutrition; on the other hand, it aims to convert nutritional awareness into a people's movement or *Jan Andolan*[22]. Similarly, *Anaemia Mukt Bharat* also lays a greater thrust on community-specific approaches such as behaviour change communication[23]. While these initiatives are promising and appear to be in the right direction, these are still heavily dependent on micronutrient supplementation. Recently, in view of the rising burden of anaemia as revealed by the National Family Health Survey (NFHS)-5, universal fortification of rice with iron has been announced[24,25]. Therefore, at this juncture, it seems worthy to appraise ongoing programmes, discuss the concerns raised by experts with respect to such interventions and explore more sustainable approaches to alleviate the burden of MNDs.

In this review, the performance of the existing approaches of fortification and supplementation have been gauged to capture emerging concerns that argue for a holistic, dietary diversity-based approach in the long run.

Major interventions for common micronutrient deficiencies (MNDs)

To alleviate the burden of common MNDs, various governments around the world have introduced two classes of interventions, namely supplementation and fortification-based strategies[15,26].

Universal salt iodization (USI) for iodine deficiency: One of the earliest programmes launched by the Government for any of the MNDs was for iodine deficiency in India in 1962[7]. In the backdrop of the success of Kangra Valley study (1956-1961), a National Goiter Control Programme (NGCP) was launched with an aim to promote the consumption of iodized salt in goitre-endemic areas of India[7]. However, until 1983, NGCP was considered a low priority as goitre was perceived to be only a cosmetic concern[27,28]. It was only in 1983 that the central government recognized all Indian States as goitre prone and took the policy decision to strive for USI[27,28]. In 1986, the Government of India (GoI) announced the policy of USI[27,28]. In 1992, the programme was revised and renamed as National Iodine Deficiency Disorders Control Programme and the central government advised all the States to ensure mandatory fortification of salt for human consumption with iodine[7,27]. In 1997, Prevention of Food Adulteration Act was amended to ban the sale of non-iodized salt for direct human consumption[29]. The ban was lifted in 2000; however, the withdrawal of the ban severely affected the household coverage of iodized salt and hence was eventually reinstated in 2005[28,30,31].

Arguably, iodine fortification to combat iodine deficiency has been the most successful intervention for any MND undertaken by the GoI. Data reveal a steady decline in both visible goitre as well as iodine deficiency disorders throughout the country since the inception of NGCP[28,32]. Available data show that nearly 91.7 per cent of Indian households have access to iodized salt[32]. However, 14.2 per cent of people continue to consume inadequately iodized salt and 8.3 per cent consume non-iodized salt[32]. Even after six decades of NGCP and more than three decades of USI, a larger number of districts in India (337 of 414 districts surveyed) were still endemic for goitre in 2015-2016 and as many as 350 million Indians may be at the risk of iodine deficiency[7,33].

Iron and folate supplementation for anaemia: The National Nutritional Anaemia Prophylaxis Programme (NNAPP) was initiated in 1970 to bring down the prevalence of anaemia in the country[17]. Under NNAPP, iron and folate prophylaxis and treatment were given to mothers and children[17]. Pregnant and lactating women were given one large tablet (containing 60 mg of elemental iron and 500 µg folic acid) daily, severely anaemic women were given two large tablets daily and children (aged 1-5 yr) were given one small tablet (containing 20 mg elemental iron and 100 µg folic acid) daily for 100 days[17,34]. In 1991, NNAPP was revised and renamed as National Nutritional Anaemia Control Programme (NNACP) and 60 mg of iron was increased to 100 mg in the large tablet[17,35].

In 2007, the programme was again revised and a provision for liquid formulation (containing 20 mg elemental iron and 100 µg folic acid per ml) for children (6-60 months) was included[36]. The programme was expanded to include schoolers aged 6-10 yr (who were given 30 mg elemental iron and 250 µg folic acid daily for 100 days in a year) and adolescents aged 11-18 yr (who were given the adult dose)[36].

In 2013, NNACP was revised and renamed as National Iron Plus Initiative (NIPI) and its purview was further expanded[37]. Under NIPI, infants and children aged 6-59 months are to be given 20 mg elemental iron and 100 µg folic acid biweekly, 45 mg elemental iron and 400 µg folic acid weekly for children aged 5-10 yr and adolescents aged 10-19 yr and women of reproductive age group are to be given 100 mg elemental iron and 500 µg folic acid weekly throughout the year[37]. Pregnant and lactating women are given 100 mg elemental iron and 500 µg folic acid daily for 100 days[37].

Despite five decades of iron and folate supplementation programmes, controlling anaemia in the country remains a daunting task. As per NFHS-5, anaemia was found among 57.2 per cent of non-pregnant women, 52.2 per cent of pregnant women and 67.1 per cent of children (of age group 6-59 months)[24]. Other studies have reported even higher (up to 84.9% among pregnant women, 90% among children and 90.1% among adolescent girls) prevalence of anaemia[38,39]. Scrutinizing the data from NFHS (Table), it can be inferred that there was no perceptible improvement in the burden of anaemia between NFHS-2 and NFHS-5[24,40-42]. Although a significant reduction in the prevalence of anaemia among pregnant women was reported in some of the States (such as Chhattisgarh, Assam, Haryana, Odisha and Kerala) between NFHS-3 and NFHS-4, this cannot be attributed to iron and folic acid (IFA) supplementation because the

Table. Per cent prevalence of anaemia in India from National Family Health Survey-2 to National Family Health Survey-5

Age group	NFHS-2[40]	NFHS-3[41]	NFHS-4[42]	NFHS-5[24]
Children age 6-35 months	74.3	78.9	66.8	
Children age 6-59 months		69.5	58.6	67.1
Non-pregnant women age 15-49		55.2	53.2	57.2
Pregnant women age 15-49 yr	49.7	57.9	50.4	52.2
All women age 15-49 yr		55.3	53.1	57.0
Men age 15-49 yr		24.2	22.7	25.0

NFHS-5, National Family Health Survey-5

coverage of the supplementation was poor in these particular States[17,41,42]. For instance, in Chhattisgarh, the prevalence of anaemia among pregnant women came down from 63 per cent in NFHS-3 to 41 per cent in NFHS-4; however, the coverage of IFA supplementation in this State was as low as 30.3 per cent of all the eligible candidates[17]. The recently published NFHS-5 report shows a worrisome trend with an increase in the prevalence of anaemia in both genders and all the evaluated age groups since NFHS-4[24,42].

Further, it is increasingly being recognized that anaemia has multifactorial aetiology and only about 14-20 per cent of cases of anaemia among pre-schoolers and 16-25 per cent among non-pregnant women of reproductive age can be attributed to iron deficiency[43]. Iron deficiency, apart from inadequate intake of iron, can be the result of its inefficient absorption in the gut[44]. Several dietary substances such as iron-binding polyphenolic compounds that are widely found in tea and coffee, phytates and tannins in cereal-based food, *etc*. can inhibit iron absorption, whereas others like ascorbic acid can enhance it[44]. This implies that the premise behind IFA supplementation as the main intervention for controlling anaemia stands challenged. Persistently, high burden of anaemia in India and a multifactorial aetiology of anaemia suggest that we should look beyond iron-based interventions.

In fact, the GoI, in the recent past, has been fairly proactive in recognizing the need to go beyond supplementation-based interventions and explore other approaches such as community-based Social and Behaviour Change Communication (SBCC)[23]. In this context, the *Anaemia Mukt Bharat* programme was launched in September 2018, with a key objective to bring down the prevalence of anaemia by three per cent points per year till 2022[23]. This initiative intends to give an intensive focus on prophylactic IFA supplementation, deworming, digital methods of anaemia testing, *etc*. *Anaemia Mukt Bharat*, in contrast to previous programmes, has a focus on community-specific SBCC[23].

Universal mega-dose vitamin A supplementation for vitamin A deficiency (VAD): A National Prophylaxis Programme against Nutritional Blindness (NPPNB) due to VAD was initiated by the GoI in 1970 initially in 11 States which, subsequently, was extended to other States as well[16,34]. Under NPPNB, children aged 1-5 yr were to be administered 200,000 i.u. of vitamin A orally once in six months[34]. In 1994, the programme was revised and the age group of children eligible for the intervention was restricted to nine months to three years[16]. However, in 2006, the age group was once again revised to include children between six months and five years[45].

Although the magnitude of clinical VAD in India has declined over the last 40 years, it is still higher than in neighbouring countries[8,16]. In fact, studies have revealed that although visible symptoms of VAD such as the prevalence of Bitot spot among pre-schoolers are low, sub-clinical VAD is widespread[45]. In a survey conducted by the National Nutrition Monitoring Bureau, 62 per cent of pre-schoolers were found to have low serum retinol, indicating sub-clinical VAD[22]. The high prevalence of sub-clinical VAD suggests that NPPNB has not proven to be as effective in controlling VAD as initially expected. Moreover, several studies have reported poor outreach and rampant irregularities in the implementation of NPPNB, implying that reduction in VAD could not be attributed to NPPNB[46]. According to Kapil and Sachdev[16], the decline in the prevalence of clinical VAD antecedes effective implementation of the vitamin A supplementation programme and can be attributed to a significant reduction in under-nutrition and overall improvement in dietary intake of young children over the last four decades.

Food fortification policies in India for common micronutrient deficiencies (MNDs): Fortification, as an intervention strategy for MNDs, is a century-old technology[47]. The earliest evidence of food fortification dates back to the 1920s when Switzerland in 1923 and the USA (Michigan) in 1924 began fortifying salt with iodine[47]. In India, food fortification started in the 1950s, when vanaspati was mandated to be fortified with vitamin A, a policy that continues to date[48]. USI was adopted in 1986[27]. Some other early governmental programmes and policies regarding fortification include notification of standards for voluntary wheat flour fortification in the 1970s, introduction of a scheme regarding fortification of milk with vitamin A in the 1980s and distribution of fortified rice through mid-day meal scheme in some States since the 2000s[48]. Food Safety and Standards Authority of India (FSSAI) in 2016, 2017 and further in 2018 notified standards for fortification of multiple key micronutrients in various staple foods[49-51]. The FSSAI in 2020 intensified its efforts towards fortification by issuing a draft regulation for mandating fortification of packaged milk and edible oil with vitamin A and vitamin D[52]. In fact, Prime Minister Modi, in his Independence Day speech (15th August 2021), announced that rice provided under various government schemes will be fortified by 2024[25].

MNDs not fully covered under national programmes: Not all MNDs in India (such as vitamin B12, zinc and vitamin C) are being targeted by national programmes[5]. Vitamin D deficiency, despite scientific reports about its widespread prevalence in the country, was not being addressed until recently[11]. Since India is a tropical country and receives adequate sunlight, vitamin D deficiency was not widely recognized as a public health concern[11]. It was only in 2020 that the GoI proposed mandatory fortification of packaged milk and edible oil with vitamin D[52]. The situation is similar for vitamin B12, and in the future, we may get similar reports for many other micronutrients[5]. The bigger question, therefore, is 'are we going to go for supplementation or fortification-based interventions for all other micronutrients eventually?'

Emerging concerns

There is an ongoing paradigm shift from reductionism to holism in nutrient science, which may eventually change the way we perceive nutrition and health and hence mandate an overhaul in nutrition-based public health policies.

No national representative data on MNDs: India's micronutrient intervention programmes are not founded on any nationally representative data on the prevalence of major MNDs[5]. Most of the data on MNDs in the past decade have been published by independent researchers based on small samples[5]. Governmental intervention programmes and advocacy are based on the data that are either one to two decades old or not nationally representative[5,53]. Experts have been warning against universal intervention without adequate data, especially because of high inter-community differences in the prevalence of MNDs[54].

Lack of community-specific standards: Owing to the variations in genetics, environment, socio-demography, habitual diet, culinary practice and food patterns, the nutritional requirements of various populations are bound to be different[55]. For example, while per capita calcium intake in many developing countries is much less (500 mg/day) as compared to their western counterparts (1 g/day), these do not show any apparent ill effects of low calcium intake[56,57]. Long-term studies have demonstrated that low calcium intake does not affect calcium balance in these populations; rather there is a tendency to maintain a positive calcium balance[56,57]. Positive calcium balance, despite low calcium intake, can also be due to the body's physiological response to calcium deficiency through measures such as bone calcium reabsorption[58]. Besides calcium, experts have also critiqued the cut-offs of haemoglobin for Indian populations, which may have been fixed higher based on western standards[59]. This implies that a common recommended daily allowance (RDA) for different communities may lead to a higher cut-off than required, hence overestimating the prevalence of the deficiency in some populations.

MND gaps are perceived but may not exist: The fact that nutrient requirements vary considerably among healthy individuals is increasingly being recognized and appreciated. 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[60]. In fact, intake of nutrients as per the RDA levels comes with a risk of excess intake[60]. Therefore, the estimated average requirement (EAR) (which is the median of the distribution of nutrient intake in the population) is being recommended as the unit of the nutrient requirement to assess the nutritional requirement of populations[60].

While the RDA is the nutrient requirement used for healthy individuals, the EAR is used for evaluating the nutrient intake of populations[60]. RDA is prescribed to avert inadequacy in the intake of specific nutrients by a particular gender group at a particular life stage[60]. However, diet plans for healthy populations should be made on the basis of the EAR and not the RDA. Such plans should target a 50 per cent (and in some cases 30-40%) risk of the inadequacy of nutrient intake, and not zero per cent[60].

Often, the inadequacy in micronutrient intake is calculated by comparing the dietary intake levels with RDA or similar values[61]. Such calculations based on RDA give inflated figures *viz-a-viz* inadequacy in the intake of micronutrients[61]. There is a realization in the scientific community that the estimates of the prevalence of risk of dietary inadequacy based on the RDA might be unfairly high. Experts are of opinion that EAR-based calculations give a more realistic estimate of gaps in micronutrient intake and should be preferred over RDA for calculating nutrient requirements at the population level[60,61]. Consequently, the notion that inadequacy in micronutrient intake in many Indian populations is too big to be bridged by food alone should also be re-examined.

Effectiveness of supplementation and fortification based on the prevalence of deficiency/disorder: It has been demonstrated that some MND interventions have not been as effective as expected in curbing the deficiencies. For instance, although IFA supplementation programmes have been successful in elevating ferritin levels to an extent among the beneficiaries, their effectiveness in controlling anaemia in the Indian population has been a matter of debate[17,39,43]. Moreover, an increased level of serum ferritin can also be a result of the high prevalence of infections and morbidity in low-income group communities of India and therefore cannot reliably assess the iron status in an individual[62]. Furthermore, experiences of iron fortification programmes from across the world are far from unanimous in endorsing iron fortification as an effective public health intervention for anaemia[63,64].

Bridge gap measures turned permanent: Another important sociopolitical phenomenon that is making experts increasingly wary is what is being called '*programmatic permanence*'[65]. Most of the supplementation and fortification programmes were initiated five decades ago to reduce the high levels of MNDs in the Indian population[5]. Latest data from various sources have indicated a decline in the prevalence of some of the MNDs in the general population (like iodine deficiency) and huge variations in the prevalence of other MNDs (like folate deficiency)[6,32]. Yet, old universal programmes have continued with reinforcements from time to time, giving a permanent colour to what ought to be temporary measures[65]. This has induced a debate on universal supplementation and fortification in the scientific community[54,65]. Many experts are of the opinion that supplementation and fortification-based interventional programmes should be seen as short- or medium-term desperate measures to bring extensively prevalent and extreme levels of deficiencies under check, but not as a permanent public health policy[21,46,65]. Moreover, universal intervention programmes should be revised in favour of targeted measures towards those at risk, which eventually should be phased out in favour of diet-based interventions[20,21,65].

Overlapping programmes of supplementation and fortification: The GoI has recently recommended fortification of several food products with various micronutrients (*e.g.* iron, folic acid, *etc.*); however, there are existing supplementation policies and national programmes for some of these micronutrients that are already functional across the country[49-51,65]. In the absence of any considered decision on the continuation of supplementation when fortification is scaled up, it appears that both supplementation and fortification programmes will run simultaneously in the foreseeable future[65]. This raises two important questions: (*i*) what are the measures in place to check the overconsumption of micronutrients and (*ii*) is it prudent to invest resources in overlapping programmes? Experts have cautioned that both supplementation and fortification should be exercised prudently, especially because a large proportion of the Indian population is illiterate and ignorant, leading to a possibility of overdose[46].

Supra-physiological doses and toxicity: The imminent risk of micronutrient overdose due to supplementation and fortification has led to concerns regarding micronutrient toxicity[60,66,67]. The last two decades have seen an explosion in scientific literature associating supra-physiological levels of various micronutrients with chronic disorders[68-71]. For instance, high folate levels have been associated with an increased risk for cardiovascular disorders in some cases and certain cancers[68,69]; similarly, high levels of vitamin B12 have been associated with lung cancers[70]. Vitamin A overdose has been implicated in adverse bone health and an increase in respiratory tract infections[54,71].

Talking about metals and trace elements, higher concentrations of iron in human tissue has been associated with severe health conditions such as liver and heart diseases, diabetes, certain cancers, dysfunction of the immune system and abnormalities in endocrine systems[72,73]. Copper toxicity, though rare in humans, can cause liver damage[73]. Manganese overdose, on the other hand, can cause Parkinson-type syndrome[73,74]. Furthermore, zinc toxicity can result in copper deficiency and altered iron function in the body[73]. It is also linked with reduced high-density lipoprotein levels and poor immune function[73].

These associations show how overlapping and poorly monitored universal supplementation and fortification programmes can prove to be not just counterproductive but also perilous in the long run. MND alleviation is an important public health goal; however, the question is, how are we going to realize that goal imprudently or sustainably?

Although nothing can be said conclusively based on the available literature, one pertinent observation that deserves space in scientific discourses is the concomitant upsurge in supplementation/fortification-based public programmes and the prevalence of major chronic health disorders all across the world[75]. There can be many plausible explanations for this observed concomitance; in fact, it can also be coincidental. However, the use of nutrient supplements or fortified foods can also have a causal relationship with several chronic disorders and hence is worthy of a scientific inquiry.

The fallacy of reductionism and lack of holism: The biomedical model of health, which has also been borrowed by nutrition science from modern medicine, is loosely based on Newtonian physics and Cartesian reductionism[76].

Nutrition science, in concordance with medical science, is also being understood using the philosophy of reductionism[75]. Food is thought to be the sum total of the nutrients and bioactive compounds that it contains; therefore, the nutrient composition of food takes precedence over the whole food matrix; level of food processing and the way nutrients present in the food interact with each other[75,77]. While the composition determines the availability of nutrients in the diet, other stated factors determine the bio-availability of those nutrients[77]. For example, it is well documented that apple as a whole (with intact matrix and minimal processing) has the least insulinaemic response and better satiety than apple puree or apple juice; apple puree in turn has a lower insulinaemic response and better satiety than apple juice[78]. In this example, while the initial nutrient composition of the whole apple, apple puree and apple juice is the same, their final health potentials are different. Moreover, such interactions are physiologically complex and obligate[79]. This point can further be explicated by the example of the interaction between zinc and iron in the human body. Iron and zinc deficiencies often coexist and baseline zinc deficiency hinders iron absorption in the gut; however, they interact negatively if consumed together in high doses[79]. Therefore, consumption of zinc-rich food alternated by iron-rich food with a time gap is a better strategy to address iron and zinc deficiencies[79].

Following the principle of reductionism, most of the researchers in nutrition science so far have tried to explore the relationship between a nutrient and a disorder[80]. Although such studies may have played an important role in designing micronutrient interventions for a number of disorders, they have not fully addressed how nutrient interventions for one disorder may in turn affect the functioning of other organs or the human body as a whole[80]. Supplementation or fortification-based public health interventions can be viewed as the products of reductionism in nutrition. Micronutrient supplementation and fortification to ease the burden of MNDs have become the norm; however, how these supplements interact with other physiological and metabolic pathways and also with other dietary components in the human body over prolonged use have not been studied adequately. A recent debate pertaining to zinc supplementation and black fungus disease can substantiate this point[81]. Owing to its popularity as an immune booster, a dramatic increase in intake of zinc supplements during the COVID-19 pandemic has been documented[81]. Successively, as the incidence of black fungus disease increased in India, a section of health professionals implicated indiscriminate use of zinc supplements for this[81,82]. Whether or not zinc supplements played any role in the aetiology of black fungus disease, the debate certainly highlights the lack of consensus or clarity among health researchers on how a micronutrient supplement may affect the pathways other than those for which they are conventionally studied.

Possible Way Forward

There is a need for strategies that not only combat the hidden epidemic of MNDs but also help us address other forms of malnutrition and related non-communicable diseases (NCDs) as one continuum. As established by a new body of evidence, supplementation can bridge the deficiency for a relatively shorter duration, while diet-based interventions are more helpful and sustainable in the long term[21]. For instance, it has been demonstrated that vitamin A supplement raises the serum retinol level to normal only for a few months, whereas adequate vitamin A intake through diet affects the stores and therefore sustainably increases serum retinol level to normal[53].

By implication, supplementation and fortification-based strategies are more or less like shortcuts to address widely prevalent MNDs, while there is no alternative to wholesome, nutritious food[21]. One of the most widely discussed food-based approaches and arguably the ideal solution to combat MNDs is dietary diversification and modification[21,83].

Understanding dietary diversity: Dietary diversity (DD) is defined as the consumption of a number of different foods or food groups over a given reference period and is a well-recognized element of a high-quality diet[84]. DD in terms of both composition and amount has been found to be essential for optimal growth and development as well as long-term health[85,86]. There are several methods to measure DD, the simplest being a count of the number of distinct foods or food groups consumed over a reference period ranging from 1 to 3 (sometimes up to 7 to 15) days[87]. The number of different food items consumed over a reference period is used to calculate Food Variety Score (FVS), whereas the number of distinct food groups consumed over a reference period is used to calculate DD score (DDS)[87]. Studies have indicated that both DDS and FVS are valid proxy indicators of nutrient adequacy, DDS being better of the two[87,88].

Greater DD has been shown to be associated with both increased energy and micronutrient intake[89]. A study by Hoddinott and Yohannes[90] in 10 countries found a positive correlation between household DD and household per capita availability of dietary energy. Numerous studies since then have confirmed this association[91,92]. Similar associations have been confirmed between DD and micronutrients intake[89]. DD has also been shown to be associated with increased micronutrients among children[85], adolescents[93], women of childbearing age[94], pregnant women[95] and elderly[88]. Apart from energy and micronutrients, recent studies have shown an association of DD with reduced risk of type 2 diabetes mellitus[96], cardiovascular disease[97], certain cancers[98] and an overall longer and healthy life[86]. DD has also been found to be positively associated with a bio-diverse gastrointestinal microbiome[99].

Despite its importance for human health, DD has reduced drastically among major populations of the world in the last 50 years[99]. As per the Food and Agricultural Organization, farmers across the world have stopped cultivating many local crop varieties in favour of high-yielding varities, leading to the loss of 75 per cent of plant genetic diversity[100]. Further, local livestock breeds are also reducing at the rate of six per month in favour of high production varieties[100]. Furthermore, only 12 plants and five animal species reportedly contribute to 75 per cent of food worldwide[100]. Thus, there is an urgent need to revive shrinking DD, not just to combat MNDs but also to achieve higher health and ecological goals.

Where does India stand viz-a-viz dietary diversity (DD)?: National-level studies have revealed a poor state of DD across India. The percentage of people consuming adequate DD in different Indian States varied from seven to less than one per cent[101]. Moreover, only 1.7 per cent of women in the reproductive age group were consuming food with adequate DD[101]. As per the NFHS-5[24], only 11.3 per cent of children in the 6-23 months age group were consuming minimum acceptable diet (MAD), which is a combination of DD and minimum meal frequency. In fact, a careful analysis of government food and social security measures such as public distribution system reveals that ensuring calorie intake has remained the main focus while DD had received less attention until recently[102]. Nevertheless, the inclusion of dietary diversification as a key nutrition intervention under *POSHAN Abhiyaan* is rather heartening[22].

A number of tribal populations of India that are heavily dependent on their traditional sources of food, on the contrary, have been found to be doing better in terms of DD as well as nutritional status than other populations. For instance, Longvah *et al*[103] in their study among Chakhesang tribe of Nagaland found a lower prevalence of undernutrition, anaemia and VAD among young children than the national average. They attributed the better nutritional status of the tribe to the diverse food list of the tribe containing 635 items, many of which are not identified scientifically[103]. Regular intake of diverse food groups in sufficient quantity can provide a wide variety of nutrients in the right amount[21]. Again, it is pertinent to understand that diversification of the diet of a community should be achieved by promoting local and traditional foods rather than introducing exotic crops. Realizing the importance of traditional and unconventional foods, government institutions such as the ICMR-National Institute of Nutrition (NIN) and the Indian Institute of Millets Research, Hyderabad, have been studying and characterizing the nutritive value/nutrient composition of such food items[104,105].

Dietary diversification and modification as an intervention for MNDs: Dietary diversification and modification involve working with communities to appraise and modify the pattern of their food production and consumption in a way that enhances the availability, accessibility, affordability and acceptability of food[83]. This approach also involves diversification and modification in indigenous methods of food processing and preparation so that nutrient bio-availability and overall satiety of the food can be improved[83]. This approach achieves multiple goals at once. It combats multiple MNDs without the risk of antagonistic interactions between the nutrients, which is not possible by using single nutrient supplementation or fortification-based approaches, and also addresses other nutrition-related issues such as under- and over-nutrition as well as NCDs[106,107].

The deficiency of nutrients can also be caused by their inefficient absorption, or poor bio-availability (due to nutrient interactions) despite adequate intake[44,106]. As stated earlier, dietary diversification and modification can be effective in reducing antagonistic interactions among nutrients and increase their bio-availability[44,106]. For instance, plant-based diets can be supplemented with flesh food (like dried whole fish) to increase the absorption of non-heme protein and zinc[106]. Soaking can reduce hexa- and penta-inositol phosphate (IP-6 and IP-5) content of maize and legumes[106]. Fermentation can be used to enhance vitamin B content, improve iron and zinc bioavailability and reduce IP-5 and IP-6 levels[106]. Germination of cereals can also increase nutrient density and reduce phytate content[106].

To implement dietary diversification, foods are categorized into food groups based on similarities in their nutrient compositions, and people are encouraged to consume foods from varied food groups[21]. ICMR-NIN has recently published values of key micronutrients in various food groups per 100 g edible portion[60]. This report acknowledges that the nutrient requirements of different groups of individuals (with different lifestyles) are bound to be different[60]. Hence, separate dietary recommendations for different groups of people (such as moderately active men, sedentary men, moderately active women, sedentary women and pregnant women) have also been published[60].

Non-nutritional benefits of dietary diversification: Apart from nutritional benefits, dietary diversification also has non-nutritional benefits. Community-based dietary diversification approach brings indigenous and traditional food practices to the centre of the discourse[83]. Since this approach is often based on locally available indigenous food sources and takes into account indigenous food practices, it is culturally acceptable, ecologically viable, and feasible as well as sustainable[83,108]. Furthermore, it validates traditional food and culinary practices and hence integrates itself with local identity[83] and also boosts local production and processing of traditional crops[83,107]. The DD approach including training and skill development at community levels will further help in income generation as well as empowerment of women[83,107].

How dietary diversification can achieve multiple goals at once can be more clearly understood through the example of coarse cereals of India. Coarse cereals (jowar, bajra, maize and ragi) are fundamentally rich in iron and calcium and were once consumed in large quantities throughout the country; however, their consumption and thus production have reduced considerably over the last three decades[109]. Some recent studies have attributed reduced consumption of iron-rich coarse cereals as one of the factors contributing to a fall in iron content in the average Indian diet[109]. By implication, it can be argued that the prevalence of anaemia in India can be reduced by improving the availability and intake of coarse cereals[110]. Taneja *et al*[111] also endorse the consumption of indigenous iron-rich foods, such as coarse cereals, jaggery products *(gur-chana, tilbugga)* and Bengal gram, as the most desirable and sustainable measures against iron deficiency. Prioritizing DD and re-incorporating coarse cereals in the Indian diet can not only help in reducing iron deficiency but also of other micronutrients, improve fibre intake and aid in preventing metabolic disease and hence enhance the overall quality of the diet[112].

Strategies to implement dietary diversification:

<u>Home and school nutrition gardens</u>: One of the pragmatic and undemanding approaches towards DD is setting up and promoting home and school nutrition gardens[113,114]. Rural households usually have

both the adequate space and the agricultural skills to establish a kitchen garden[114]. Studies from various parts of India have demonstrated the positive impact of home/kitchen gardens on DD, food security, MND and overall nutritional and financial status of households[113,115,116]. Furthermore, school nutrition gardens can improve nutritional status and food preferences among children[117]. School gardens have been found to increase the consumption of fruits and vegetables among students and bring positive health and nutrition-related behavioural change[118]. Moreover, school gardens have been found to improve physical activity among students[119].

Nutrition-sensitive agriculture: Conventional farming, which usually involves growing staple food crops, focuses on food security, productivity and profitability which results in disconnection between agricultural output and human nutrition[120]. This can reduce and perpetuate nutritional imbalances including MNDs[120]. Nutrition-sensitive agriculture, on the other hand, involves the promotion of production diversity, micronutrient-rich crops and rearing of dairy and small animals, leading to nutrition security[120]. Evidence suggests that nutrition-sensitive agriculture can improve DD and nutrition outcomes[121]. Nutrition-sensitive agricultural programmes have been found to be more effective when they involve social and behaviour change communication (SBCC) and interventions for women's empowerment[121]. Further, for successful implementation of such programmes, ecological, cultural, economic and food environment factors should also be taken into account[121].

Behaviour change communication: Experts have argued that besides affordability, consumers' attitudes towards food (in a market-driven ecosystem) might also be a factor behind poor DD[21]. It has been observed that in the past few decades, expenditure on non-food items by an average Indian has increased while on food items has decreased[122]. Not undermining the issue of affordability, the trend indicates that there is a need to bring back the emphasis on food[21]. Behaviour change communication can bring about much required dietary modification and hence diversification. Interventions, especially those that involve changes in the fundamental components of daily life such as food and diet, should have an inbuilt behaviour change communication component. This will ensure not only better acceptability but also long-term sustainability.

Helen Keller International's (HKI) Homestead Food Production (HFP) programmes: With objectives such as increasing DD and reducing MNDs, the HKI has been running its HFP programmes coupled with nutrition education in many Asian countries since the 1990s[123]. In one of its major interventions, HKI implemented HFP (which integrated animal husbandry and nutrition education with ongoing home gardening) among around 30,000 households of Bangladesh, Cambodia, Nepal and the Philippines between 2003 and 2007[123]. Evaluation of the programme showed a significant improvement in DD, a decline in anaemia, better nutrition status and improved income among intervention households compared to their own baseline data as well as those households that were not covered under the programme[123]. Experiences of HKI's HFP clearly demonstrates the importance of DD, which is linked with better nutritional status as also a lower prevalence of MNDs. It also shows that an idea, as simple as a home garden coupled with nutrition education and behaviour change, can prove to be a game-changer.

Farming System for Nutrition (FSN) Study: The FSN study under the programme 'Leveraging Agriculture for Nutrition in South Asia' demonstrates how nutrition-sensitive agriculture can contribute to DD and better nutritional status[120]. To explore the feasibility of nutrition-sensitive agriculture, the FSN study was undertaken during 2013-2014 and 2017-2018 at two agro-ecologically different regions of India: Koraput district of Odisha State and Wardha district of Maharashtra[120]. During the baseline assessment, populations in the studied areas were found to be undernourished and dependent on cereal-dominated diets. As a part of the intervention, crop diversification was promoted at the farm level (whereby cultivation of nutrient-dense cereals and pulses were encouraged), nutrition gardens were promoted at households and capacity building initiatives (in terms of nutrition awareness) were taken up at local levels[120]. By the end line assessment, an improvement in production and consumption of nutrient food, household dietary diversity and awareness regarding balanced diet and health as well as nutrition-sensitive agriculture was noted[120]. The FSN study shows that the practice of nutrition-sensitive agriculture can substantially improve DD and in turn the nutritional status of smallholder farmers.

Need for multi-disciplinary centre for food: As effective as it may sound, designing a viable DD and modification-based intervention at the national level can be a herculean task. For DD to be successful, multiple factors need to be considered. These include in-depth knowledge of community-specific dietary patterns, food production and culinary practices, food beliefs, taboos; nutrient composition of food items; the impact of food processing and cooking practices on nutrient composition; availability and affordability of food items in different seasons of the year; agricultural practices and availability of micronutrients in soil and knowledge of local economy, markets, and awareness and education level of the community[83]. To design and implement such a programme, a multi-disciplinary team of experts in domains such as nutrition, public health and epidemiology, anthropology, psychology, economy, agriculture, food processing and behaviour change communication would be needed. In fact, the notion of 'cross-sectoral convergence' propounded by *POSHAN Abhiyaan* captures the importance of a multi-disciplinary approach in combating malnutrition in a true sense[22]. Therefore, to sustainably address the issue of MNDs (and other nutrition-related challenges), multi-disciplinary centres for food at national and State levels should be supported where experts from different domains can combine their respective disciplinary expertise to formulate food-based interventions. The existing Home Science colleges, Agricultural Universities, *Krishi Vigyan Kendra* of Indian Council of Agricultural Research and Medical Colleges can collaborate to nucleate such centres. A multi-disciplinary centre for food would further institutionalize this notion and can prove to be a game-changer in our battle against MNDs as well as malnutrition.

Overall, India needs to promote holistic food-based approaches around DD and behaviour change communication to not just address population-based MNDs but also promote healthier lives as a long-term and sustainable strategy.

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