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Review Article

Role of Staple Food Fortification in Combating Micronutrient Deficiency

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ABSTRACT

Micronutrient deficiencies, often referred to as "hidden hunger," result from a dearth of vital nutrients and minerals in the diet, causing malnutrition. The mortality rate of children under the age of five is high in India, with more than half of these deaths linked to deficiencies in iron, zinc, iodine, and folic acid. During pregnancy and lactation, elevated levels of calcium and other essential minerals in the bloodstream are required to ensure adequate nutrition. Should the dietary intake of calcium fall short of meeting this increased demand, it could jeopardize the health of both the mother and child. Fortification has emerged as an established, cost-effective, and sustainable method for delivering vital nutrients to a large population and involves an intentional increase in the content of specific vitamins and minerals in staple foods or food products to boost their nutritional quality. This not only prevents deficiencies but also restores nutrients that may be lost during food processing, contributing to improved public health outcomes with minimal risks. This review highlights the importance of fortifying staple foods with micronutrients to improve nutrient absorption. Regular consumption of these food products ensures a steady supply of micronutrients, thus improving overall health.

Keywords: Fortification, Malnutrition, Micronutrients, Staple food.

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INTRODUCTION

Nutrients- Macro and micronutrients with RDA specified by WHO or ICMR

Nutrition is an essential human necessity that underpins a healthy existence. It is vital to maintain an appropriate diet from the earliest stages of life to promote adequate growth, development, and overall activity. The health and nutritional well-being of a population are significantly affected by food consumption, which is intricately connected to its production and distribution. However, foods also contain non-nutrient phytochemicals that positively contribute to health. Consequently, it is imperative to prioritize nutrition in the context of food rather than solely focusing on nutrients, as individuals consume food. This perspective has evolved from a nutrient-centric approach to one that emphasizes food to achieve optimal nutritional health. Dietary guidelines serve as a means of translating scientific insights regarding nutrients into concrete dietary recommendations, reflecting recommended dietary allowances in terms of diets that should be adopted by the population. These guidelines advocate nutritionally sufficient diets and healthy lifestyles throughout all stages of life, from conception to old age. Recommended Dietary Allowances (RDA) are technical guidelines that concentrate on specific nutrients, and the Indian Council of Medical Research (ICMR) is tasked with periodic revisions in nutrient requirements and Recommended Dietary Allowances (RDAs).[1,2] This process offers essential guidance to the population and aids in the formulation of policies concerning nutrient requirements that align with the goal of maintaining a healthy population. The average daily requirements for essential nutrients, referred to as Recommended Dietary Allowance (RDA), Recommended Nutrient Intake (RNI), Recommended Daily Amounts of Nutrients, or Safe Intakes of Nutrients, are determined based on the latest scientific evidence. These values were set at levels deemed adequate to satisfy the physiological needs of nearly all healthy individuals within a defined population group. In 2007, a partnership involving the UNU, WHO, FAO, and various other organizations created nutrient-based dietary standards. This collaboration established that Nutrient Intake Values (NIV) should include both the Average Nutrient Requirement (ANR) and Upper Nutrient Limit (UNI). The ANR plus two Standard Deviations (2SD), which accounts for 98% of the population, is associated with terms such as Recommended Dietary Intake (RDI), Recommended Dietary Allowance (RDA), and Reference Nutrient Intake (RNI).[3-5] The issue of severe Iodine Deficiency

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Disease (IDD), which is an environmental concern, has seen significant improvements following the widespread adoption of iodized salt. Nevertheless, milder manifestations of IDD continue to exist in numerous regions owing to shortcomings in its implementation. Additionally, the presence of goitrogen in certain foods may exacerbate the situation, as many individuals experience sub-clinical malnutrition related to IDD.[6] Numerous individuals are affected by subclinical malnutrition in each overt case of nutritional deficiency.[7-10]

Statistics of Nutritional deficiency in India and across the world

Malnutrition is the world's major but least addressed developmental challenges. The human and economic costs associated with it are enormous, with women, children, and economically deprived groups, being the most affected.[11] According to the Joint Child Malnutrition Estimates (JME) report of 2023, globally, 148 million children under five years were reported to be stunted, 45 million children with severe malnutrition, and 37 million children overweight.[12] The JME report reveals the need to make significant progress in attaining the WHO global nutrition target of 2025 and the Sustainable Development Goal 2 target of creating a world free of hunger by 2030.[13,14] Concern Worldwide and Welthungerhilfe (Ireland's largest aid and Germany's humanitarian agency respectively) prepared a tool called the Global Hunger Index (GHI), which measures and provides a comparison of hunger levels in different regions and countries. The tool helps identify regions where hunger levels are high and requires effective strategies to address the situation. The Global Hunger Index (GHI) score for each nation is determined using a formula that integrates undernourishment, child stunting, wasting, and mortality, the four indicators that collectively reflect the complex nature of hunger.[15,16] India contributes to one third of the global burden of undernutrition. According to the 2024 GHI report, India ranks 105th out of the 127 countries, with 13.7% of the population being undernourished due to caloric deficiencies and poor nutrition; 35.5% of children under five are stunted, indicating chronic undernutrition; 18.7% of children under five are wasted, denoting acute undernutrition. Additionally, 2.9% of children do not survive beyond 5 years, because of insufficient nutrition and unhealthy living conditions.[15-17] Considering India's vast population, it is crucial to prioritize efforts aimed at combating all types of malnutrition. Such initiatives are not only vital for India's own well-being but also play a pivotal role in helping achieve global objectives.

One of the most prevalent forms of malnutrition worldwide is micronutrient deficiency, which stems from insufficient consumption of vital nutrients such as iron, calcium, zinc, vitamins, iodine, and folate, among others. Each of these nutrient deficiencies causes distinct health implications and the combined shortage of these and other micronutrients significantly contributes to widespread illness and death rates globally.[18]

Impact of micronutrient deficiency in India

India has a variety of cuisines unique to each region of the country. The diversity of cuisine is strongly linked to region, climatic conditions and local agricultural practices,[19,20] Economic factors play a crucial part in an individual's nutritional status and overall health. The influence of economic factors on global food consumption patterns extends beyond what might be anticipated from examining dietary trends in industrialized countries alone.[21] As urbanization spreads and incomes rise, societies undergo a 'nutrition transition', in which diets rich in carbohydrates and fiber are replaced by diets rich in sugars and saturated fats. These shifts in dietary patterns have resulted in increased incidences of type 2 diabetes mellitus, obesity, cardiovascular diseases, metabolic syndrome, and colorectal cancer. This is a result of decreased intake of fibre rich food, increased consumption of meat products and heavily seasoned food, and declining levels of physical activity.[22-24] India is currently in a transition stage from a traditional diet rich in fibre and whole grains to western style diets high in processed foods loaded with calories. Urbanization, economic progress, aggressive marketing and availability of packaged or ready-to-eat foods have increased the consumption of junk foods.[25-27] In India, the prevalence of obesity, especially among children, along with micronutrient deficiencies, is always high, and this situation is largely attributed to the country's cereal-based dietary habits.[28,29]

In 2016, nutritional deficiencies were responsible for 0.5% of all deaths in India.[30] The National Family Health Survey-5 (NFHS-5) indicated a high prevalence of anaemia in India, with approximately 52 to 61% of women, pregnant and breastfeeding women being affected. The prevalence of anemia had increased between NFHS-4 and NFHS-5, rising from 53% in 2015-16 to 57% in 2019-21 among women, and from 23% in 2015-16 to 25% in 2019-21 among men.[31] The data indicated that between 2015-16 and 2019-21, the prevalence of anaemia among children aged 6-59 months increased from 59% to 67%, with rural children being disproportionately affected. The 2019 Comprehensive National Nutrition Survey of Children (CNNSC) in India had identified zinc deficiency in 19% of pre-school children and 32% of adolescents, while folate deficiency was present in 23% of pre-school children and 37% of adolescents.[32] Deficiencies in vitamins A, B12, and D ranged from 14% to 31% among preschoolers and adolescents. A community based cross-sectional study conducted in rural areas across eight Indian states reported a 0.8% prevalence of Bitot's spots, 67% prevalence of anaemia among preschoolers, 69% among adolescents, and a 3.9% prevalence of IDD.[33]

In India, elderly individuals often do not consume enough micronutrients, likely due to the substandard quality of their diets. Reports indicate that the percentage of those who do not meet the RDA is 48% for magnesium, 81% for copper, 89% for chromium, 33% for vitamin B1, and 88% for niacin. Nutritional

deficiencies were found to be more prevalent among older adults from lower socioeconomic backgrounds.[34-36]

Research on the micronutrient levels among rural Indians has shown that 42.3% suffer from vitamin B12 deficiency, with no notable difference between genders, although women aged 45-54 years exhibit a higher deficiency rate.[37] In urban areas, 35.5% of individuals were found to be deficient in vitamin B12. The likelihood of having adequate zinc levels was 11%, while that of vitamin B2 and vitamin B1 was 37% and 58% respectively. Those with insufficient micronutrient levels faced an increased risk of iron-deficiency anemia and folate deficiency. Among healthy urban Indians, men were more prone to inadequate levels of vitamins A, B2, C, and zinc compared to women.[38]

In India, micronutrient deficiencies are largely due to poor eating habits and insufficient diets.[39] Most Indian states have diets that fall short of essential nutrients, with the consumption of riboflavin, fiber, potassium, and vitamin A being less than 50% of the RDA.[40] Indian diets are mainly based on cereal grains. However, grans like rice and wheat typically contain low levels of iron, calcium, vitamin A, riboflavin, and folic acid.[41,42] It is concerning that 54-70% of households consume less than the RDI, of green leafy vegetables, and dairy products.[43]

In India, eating habits are influenced by cultural and religious traditions. Vegetarians tend to eat more legumes, pulses, and vegetables while consuming less fat compared to those who eat meat. However, vegetarian diets often lack enough vitamin B12, omega-3 fatty acids, zinc, and other minerals. Moreover, vegetarians experience poorer absorption of zinc and iron than non-vegetarians, which can lead to deficiencies. Additionally, diets aimed at weight loss, combined with unhealthy eating habits such as increased junk food consumption, frequent unhealthy snacking, higher intake of processed foods, and cereal based diets, have also resulted in micronutrient deficiencies.

Multi micronutrient Deficiencies

Worldwide, approximately two billion people are deficient in one or more micronutrients. It is estimated that more than 50% of children under five years suffer from iron, zinc, or vitamin A deficiency. Additionally, over 66% of non-pregnant women of childbearing age are lacking in at least one micronutrient, including iron, zinc, and folate (vitamin B9).[44,45] A lack of vitamin A can worsen severe diseases and illnesses, leading to higher maternal and child mortality rates.[45] Zinc is crucial for growth and healing, and its deficiency can hinder development, increase vulnerability to diseases and infections, all of which are linked to higher mortality rates in mothers and newborns.[46-48] The nutritional requirements of an expectant woman is significant not only for her wellbeing but also for her child's development and it is vital to monitor and address micronutrient deficiencies in the initial trimesters, to ensure healthy development.[49,50] In India, deficiencies in more than one nutrient have been identified in 2.9% of pregnant women who were tested for selenium, zinc, copper, iodine, vitamin B12, and ferritin.[40] Iron, folic acid, and vitamin B12 are also essential for hematopoiesis. Research conducted in India found that adolescents with anemia lacked vitamin B12 but not folate.[41] A community-based study in northern India revealed that deficiencies in iron, folate, and vitamin B12 were found in 67.7%, 26.3%, and 74.1% of pregnant women, respectively, with 16.2% experiencing simultaneous deficiencies in these micronutrients.[42] Another study indicated that women with folate deficiency had twice the prevalence of vitamin B12 deficiency.[51-56]

In India, pervasive poverty continues to pose a major obstacle, affecting the nutritional status nationwide. Although the economy has grown, a wide segment of the population still struggles with limited access to nutritious food, and worsening malnutrition. Rural regions are particularly at risk because of scarce resources and low agricultural output. Ongoing poverty results in a lack of dietary variety, especially impacting children and women. Malnutrition, including stunting and being underweight, remains a critical issue that impedes both physical and mental development.[57] To tackle these problems, government programs such as the National Food Security Act aim to improve food access for at-risk groups.[58] However, the intricate mix of economic inequality, social factors, and regional differences highlights the complex nature of the problem, necessitating ongoing, comprehensive efforts to reduce poverty and enhance nutritional outcomes for India's diverse population. In rural India, the challenge of providing nutritious diets is significant as limited financial resources, along with traditional eating habits, often restrict access to nutrient rich foods. The expenses of essential food items, particularly fruits, vegetables, and protein sources, can be excessively high for many rural families. Agricultural practices that mainly focus on staple crops lead to a lack of dietary diversity.[59] Moreover, a lack of awareness of importance of balanced nutrition and its long-term benefits further exacerbates this issue. Government efforts to promote sustainable farming, income generation, and nutritional education are vital for addressing these challenges. Incorporating local and traditional food sources into dietary guidelines can make nutritional options culturally acceptable and economically viable. Overall, a comprehensive approach involving economic empowerment, education, and cultural sensitivity is crucial to make nutritious diets more affordable in rural India.

Food fortification - A sustainable solution for malnutrition

The Codex General Principles for the Addition of Essential Nutrients to Foods (CAC/GL 9-1987), provide guidelines government agencies on the scientific principles involved in nutrient enrichment of foods.[60] These guidelines form the basis for a logical and secure method for enriching food products with essential nutrients. Adding micronutrients, such as trace

elements, to basic food items during processing or providing fortified supplements can assist in addressing malnutrition in developing countries.[61] Enhancing the nutritional value of food through fortification is essential for enhancing consumer health and well-being, while reducing health risks.

Food fortification plays a vital role in promoting public health by addressing several key aspects. It aids in disease prevention by reducing health issues caused by micronutrient deficiencies in the general population and specific vulnerable groups. By enhancing the nutritional content of commonly consumed foods, fortification helps improve overall health and reduce nutrient deficiencies.[62] It is also a cost-effective strategy for combating micronutrient malnutrition.[63,64] Fortification enables focused intervention to target specific subpopulations vulnerable to certain nutrient deficiencies by adding nutrients to the foods that they regularly eat.[62] It is easy for consumers to incorporate into their diets without requiring special education, although awareness about its benefits can still be promoted.[62] Additionally, food fortification has better reach than direct supplementation, enabling it to serve a larger and varied population.[65] Importantly, fortification is inconspicuous, and fortified foods appear no different from their non-fortified counterparts.[66] Additionally, the impact of food fortification on health outcomes is significantly influenced by various factors, such as the extent of fortification, bioavailability of added nutrients, and amount of fortified food consumed.

Types of food fortification

The World Health Organization (WHO) and Food and Agriculture Organization (FAO) have outlined three kinds of food fortification,[67,68] depending on the specific group being targeted. Mass fortification is typically required for the general population. Target fortification is created for a specific group of people and may be mandatory or optional, depending on the gravity of the public health problem it intends to address. Finally, market-driven fortification permits food manufacturers to voluntarily fortify their products for sale, within the regulations established by the authorities.

Several researchers have classified food fortification techniques using varying terminologies; however, the ultimate objective remains consistent. In general, it is categorized into the following categories.[69-72]

Classical food fortification is a technique used to improve the nutrient value of basic foods, seasonings, or condiments through the addition of important vitamins and minerals. Man-made micronutrients can be added to these foods for fortification. In numerous developing nations, foods such as fats, oils, salt, sugar, milk, and cereal flour are essential for traditional food fortification. One simple and effective way to deliver nutrients is by fortifying flour, as it allows for the easy mixing of powdered nutrients. Fortifying rice flour with zinc, iron, and folate leads to quick absorption, improving micronutrient levels and the growth rate of children under five in developing nations. Recently, classical fortification has shifted from preventing diseases to enhancing health of the population. Nevertheless, traditional methods of fortifying food face difficulties in developing nations because of the need for advancements in various areas such as the economy, regulations, transportation, markets, and monitoring systems throughout the food production to consumption process.[71,73-77]

Large Scale Food Fortification (LSFF) /Industrial fortification

This technique enables the incorporation of various nutrients to staple foods such as flour, salt, sugar, and oil. The loss of nutrients like vitamins in refined flour during grain processing can be recovered by adding smaller amounts of these nutrients to the processed food. Industrial or large-scale fortification can be classified as either required, mandated by the government (such as iodized salt and fortified flour), or optional, initiated by food producers to enhance nutrients while adhering to government mandated regulations. Complying with mandatory regulations, more than 130 countries have enforced iodized salt production. Likewise, mandatory fortification of cereal flours with iron, folic acid, Vitamins A and D and calcium, and sugar fortification with vitamin A are being implemented in numerous countries, resulting in significant health advantages for consumers. Additionally, voluntary fortification programs have led to increased regulations and a strong authorization system in India.[70,78-81]

Mandatory fortification involves the government-mandated addition of micronutrients to staple foods, aimed at addressing widespread nutritional deficiencies within the population. This approach typically achieves extensive coverage and ensures more equitable access, particularly among low-income and nutritionally vulnerable groups, especially when integrated with public distribution systems and welfare programs. Conversely, voluntary fortification is initiated by manufacturers and serves as a market-driven enhancement, which can foster product innovation but predominantly reaches urban and higher-income consumers, thereby limiting its capacity to mitigate deficiencies on a large scale. Although both strategies contribute to enhanced micronutrient intake, mandatory programs generally exhibit greater efficacy in improving public health outcomes due to consistent exposure and standardized nutrient levels. Voluntary fortification alone is often inadequate to meet national nutrition targets unless supplemented by mandatory measures, comprehensive monitoring, and coordinated public health policies.[79]

Biofortification

Biofortification is a modern method used in agriculture to enhance nutritional content, particularly essential micronutrients including minerals and vitamins, using innovative biotechnology techniques. Orange sweet potatoes are a well-known example

of biofortified food products that have been found to combat vitamin A deficiency and are high in organic acids and β-carotene. Various methods to enhance the nutritional value of crops, including traditional breeding, agricultural practices, and genetic modifications, have been examined in previous studies. Soil fertilization with organic salts immediately after planting has proven to be an effective way to boost iron absorption rates in Indian pearl millets. Pre-transplant biofortification was used in a similar manner to increase selenium levels in lettuce and sweet basil. Similarly, fortifying maize with vitamin A led to a significant increase in vitamin A levels in children in Zambia, whereas the selenium fortification initiative in Finland helped reduce selenium deficiency.[82-88]

Food to Food Fortification (FtFF)

This method entails integrating one or more foods rich in micronutrients into other foods to improve their nutritional content or increase the bioavailability, aiming to meet the dietary needs of populations with limited access to these nutrients. FtFF typically provides energy, fat, proteins, fiber, carbohydrates, minerals (such as phosphorus, iron, zinc, potassium, manganese, sodium, and calcium), and Vitamin C. Kruger examined the impact of FtFF using cowpea leaves and orange sweet potatoes, combined with traditional micronutrient fortification and fermentation, on the Caco-2 cellular absorption of zinc and iron from ready to eat maize porridges. The results of the study were encouraging.[89] In a different study, baobab fruit powder, which is rich in proteins, fiber, minerals, vitamins, and carbohydrates, was used as a fortificant and added to fermented maize dough.[90] FtFF can be effectively employed as an additional strategy alongside household methods by utilizing locally available nutrient dense staple foods, with everyday meals. These food blending or compositing techniques are notably safe and hold potential for standardization, making them suitable for commercialization. A recent example of FtFF includes the addition of *Moringa oleifera* leaf powder in bread and cheese, *Ocimum basilicum* leaf powder in cookies and rice cakes, *Mentha spicata* leaf powder in fruit bars, *Lepidium sativum* seed flour in cookies, and *Amaranthus* leaf powder in wheat noodles.[91-97]

Point-of-use/home fortification

Refers to the practice of adding micronutrient powders or supplements to cooked meals just before consumption. This is done to improve the nutritional value of meals meant for infants and children. In 2012, the WHO updated this term to 'point-of-use' to encompass various settings like schools and refugee camps, where interventions could be effective. By 2016, WHO recommended using Micronutrient Powders (MNPs), which are small sachets containing a blend of powdered vitamins and minerals. They could be easily mixed into food without altering its taste or appearance to elevate iron levels and reduce anemia in children aged 6 to 24 months.[98,99]

Methods of fortification

The incorporation of nutrients can be done by various methods.

Dry blending entails mixing micronutrient powders or granules with the dry components of food, ensuring thorough integration before the final product is produced. This technique is frequently applied to cereal-based items like flour, maize meal, and rice.[100]

Liquid blending is addition of micronutrients to oil, sugar syrup, or milk, which are then mixed into the food. This method offers the benefit of being easily controlled and monitored without altering the taste, texture, or appearance of food. However, it is costlier than dry blending, and there is a risk of micronutrient loss during cooking or storage.

Spray drying involves spraying a micronutrient solution onto food and drying it to retain the nutrients and can be used for both solid and liquid foods. It is beneficial for fortifying foods such as liquids or powders with fine particles, that are challenging to mix with other ingredients.

Injection molding is a technique where micronutrients are injected into solid foods like bread or pasta. Although it is more expensive than dry blending, it can distribute the micronutrients uniformly and can be used for fortifying foods with high moisture content.

Seed coating is done for staple crops like maize, rice, and wheat, to boost the nutritional value of the resulting crops. It involves applying a micronutrient mixture to seeds before planting and is a cost-effective fortification method as it does not require additional processing or storage.

Food premixes are ready blends of micronutrients produced and sold to food processing units for inclusion in their products. This technology allows for precise control over the micronutrient content added to food and is frequently used in large-scale fortification projects.[101]

Staple food fortification - perceived benefits

Enriching staple foods is a secure and cost-effective approach, supported by evidence, to guarantee essential micronutrients reach all individuals, particularly the most vulnerable. Smoothly blending essential nutrients into everyday foods has been a successful practice in the Association of Southeast Asian Nations (ASEAN) region. This includes fortifying flour and cereals with multiple micronutrients, enriching cooking oil with vitamins, and incorporating iodine into salt. Consuming sufficient micronutrients can help prevent infections, as well as nutritional deficiencies such as anaemia and neural tube defects. Fortified flour containing folic acid, and oil fortified with vitamin A, when consumed by pregnant and nursing mothers, has been shown to positively impact infant health. This occurs indirectly through the enhancement of breast milk quality, particularly in the case of oil. Fortified foods enhance the mothers' wellbeing,

consequently improving their ability to care for their children. This is particularly relevant for individuals with lower incomes who are unable to purchase supplements, and whose sources of vitamins and minerals primarily come from fortified foods.

Mandatory food fortification offers numerous advantages, such as boosting immunity, reducing stunting, enhancing pregnancy outcomes and offspring health, and promoting cognitive development in children and teenagers. This, in turn, fosters economic development and supports progress towards achieving Sustainable Development Goals. Ongoing access and intake of essential micronutrients are advantageous for overall well-being. Currently, it is crucial to prioritize this, especially since populations depend on shelf-stable foods, many of which contain fortified ingredients.[102,103]

Status of food fortification in India

Food fortification was initiated in the 1950s in India with the addition of vitamins and minerals to vegetable oil and cooking salt, to prevent nutritional deficiencies in the prevalent population. After an interval of 60 years, with global evidence obtained, the government began fortifying staples like rice and wheat in the 2000s. The Food Safety and Standards Authority of India (FSSAI), the nation's food regulator, has set standards for fortifying rice, wheat flour, edible oil, double fortified salt (fortified with iron and iodine), and milk. Additionally, the Food Fortification Resource Centre was established, which created the '+F' logo and supported food producers in building capacity. The Centre also introduced new requirements for using fortified staples in Mid-Day Meal (MDM) and Integrated Child Development Schemes (ICDS). The requirement that salt be iodized for human use was established in 1997 and subsequently confirmed in 2005 following years of agitation and promotion. Although the law requiring salt iodization was abolished in 2000, enabling the sale of non-iodized salt to be sold, it was updated and made mandatory again in 2005.[104-106] To address iodine and iron deficiencies, the double-fortified salt program was first introduced to schoolchildren in Tamil Nadu and has now spread to other Indian states. It is currently available in several states via the Public Distribution System (PDS), including Gujarat and Madhya Pradesh. This subsidized salt is currently available to more than 12 million individuals in 20 regions at a very low cost. Additionally, India has aggressively marketed to the public the advantages of double-fortified salt.[107]

In India, several state-level initiatives have been implemented to strengthen vegetable oils and wheat flour. Small-scale rice fortification initiatives have also been implemented in the Indian states of Andhra Pradesh and Odisha. A centrally supported pilot program called "Fortification of Rice and Its Distribution under Public Distribution System (PDS)" was initiated by the Ministry of Consumer Affairs, Food, and Public Distribution. It ran for three years, starting in 2019 and ending in 2020, and combined rice at the milling stage. Under the POSHAN Abhiyan (2018), wheat fortification was started in 12 states with the goal of enhancing the nutritional status of children, adolescents, expectant and nursing mothers. Additionally, the National Dairy Development Board of India (NDDB) started fortifying milk with vitamin D in 2017.

The mid-day meal scheme, initially introduced in 1995 as the National Programme of Nutritional Support to Primary Education, was rebranded as PM-POSHAN (Pradhan Mantri Poshan Shakti Nirman) in September 2021. This initiative aimed to improve children's nutritional levels while encouraging higher enrollment, retention, and regular school attendance. In 2018, the Ministry of Health and Family Welfare in collaboration with UNICEF launched the Anemia Mukt Bharat initiative under the ambit of National Nutrition Mission. This program sought to decrease incidence of anemia among women and children, representing a strategic effort to address the anemia crisis in the nation, alongside POSHAN Abhiyan, which was also launched that year. The Eat Right India Initiatives, linked to the National Health Policy 2017, were also introduced with focus on promotive and preventive programs like POSHAN Abhiyan and Anaemia Mukt Bharat. This project aimed to extensively transform the country's food system, ensuring that all Indians have access to safe, nutritious, and sustainable food.[108-110]

India has implemented significant revisions to its food fortification regulations, specifically impacting Schedule-I and Schedule-III of the Food Safety and Standards (Fortification of Foods) Regulations, 2018. These revisions, effective from August 27, 2021, with a compliance deadline of March 1, 2022, included modifications to the iron content, new guidelines for fortified milk powder, and the reclassification of fortified raw rice as fortified rice. Furthermore, Schedule-III now sets standards for fortified processed foods such as cereal products, bakery products, and fruit juices.[111]

Although food fortification holds promise in India, it has yet to penetrate most markets and it is estimated that 40-60% of fortified food production fails to reach or be consumed by the most vulnerable groups, such as people belonging to low-income brackets. Apart from cost issues, other factors that contribute to the low consumption among vulnerable populations include the limited adoption of fortified foods by certain states, inefficiencies in supply chain management, and the absence of private distribution networks in rural areas. For consumers, the cost of fortified foods is not a major obstacle, because fortification increases the retail price by only 3-7%. Although price is not the main issue, awareness is generally low. In addition, cultural practices and "food aesthetics" pose challenges that decrease the acceptance of these foods.61 Additionally, obtaining funding for equipment necessary for food fortification poses a considerable challenge. The cost of processing machinery are often prohibitive for small milling businesses. Prospective buyers frequently

encounter difficulties in securing affordable financing, leaving the financial sustainability of these producers in doubt.[112,113]

Implementation of staple food fortification with suggestions

Malnutrition is a complex challenge, and the Indian government might focus its efforts in three key areas: First, attention should be directed towards the food system. Beyond addressing food security and sovereignty issues, it is essential for both central and state governments to establish a robust regulatory and policy framework that encourages healthier eating habits among the population.[103] Additionally, investing in biofortification is a highly cost-effective approach for governments to combat malnutrition and increase the availability of vital nutrients. Monitoring the situation after a successful implementation is crucial. Emphasizing nutritional economics is important, highlighting the necessity for a proactive financing mechanism to supplement existing funding sources. Nutritional disparities are present both within communities and across states, necessitating a data-driven approach to resource allocation that promotes evidence-based and cost-effective outcomes. Besides investing in human resources, it is vital for both the central and state governments to set up cost-effective nutritional facilities to ensure that high-quality nutrition care is accessible to everyone. Supporting community-based initiatives such as Village Health Nutrition Day is essential for strengthening the health system as they aid in delivering healthcare services and sensitizing the public on topics related to health and sanitation, food and nutrition, family planning, maternal and child health. In India, researchers have developed numerous innovative methods and techniques that are not yet fully utilized or available for commercial use. Cost-effective and advanced technologies promise to improve the production of high-quality fortified foods.[104]

Dietary diversification is another method that can be considered for combating malnutrition. This approach entails the expansion of the variety of foods consumed to enhance the overall nutritional quality of the diet. Unlike interventions that emphasize supplementation or fortification, this approach leverages existing food systems to address micronutrient deficiencies through natural food sources. By incorporating a broader range of fruits, vegetables, whole grains, and animal products, individuals can naturally acquire essential vitamins and minerals that may be deficient in more restricted diets.[114]

Micronutrient supplementation also serves as an effective short-term strategy for the prevention and management of micronutrient deficiencies in specific at-risk populations. This method entails the administration of either a single micronutrient, such as iodine, iron, folic acid, Vitamin A, Vitamin B12, Vitamin D, or zinc, or a combination of multiple micronutrients, delivered in the form of capsules, tablets, drops, or syrup.[115]

CONCLUSION

Multi-micronutrient deficiencies are common, especially among pregnant women and children, impacting health outcomes while poverty and access to nutritious diets remain significant challenges in rural India. Food fortification is a cost-effective and sustainable solution to address malnutrition and offers numerous benefits, such as boosting immunity, reducing stunting, and improving cognitive development. In India, food fortification initiatives have been implemented, with standards set by the FSSAI for fortifying staples. However, challenges remain in reaching vulnerable populations and ensuring affordability and awareness. Suggestions for addressing malnutrition in India include focusing on the food system, investing in biofortification, emphasizing nutrition economics, supporting community-based initiatives, and utilizing cost-effective and advanced technologies for fortified food production.

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ABBREVIATIONS

ANR: Average Nutrient Requirement; **CNNSC:** Comprehensive National Nutrition Survey of Children; **DFS:** Double Fortified Salt; **EAR:** Estimated Average Requirement; **FAO:** Food and Agriculture Organization; **FtFF:** Food-to-Food Fortification; **GHI:** Global Hunger Index; **ICDS:** Integrated Child Development Schemes; **ICMR:** Indian Council of Medical Research; **IDD:** Iodine Deficiency Disease; **LSFF:** Large-Scale Food Fortification; **MDM:** Mid-Day Meal; **NFHS:** National Family Health Survey; **NIV:** Nutrient Intake Values; **RDA:** Recommended Dietary Allowance; **RDI:** Recommended Dietary Intake; **RNI:** Reference Nutrient Intake; **UNI:** Upper Nutrient Limit; **UNU:** United Nations University; **WHO:** World Health Organization.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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AUTHOR CONTRIBUTIONS

All the authors contributed to the conception and design of the study. Material preparation, data collection and analysis were performed by Sindhu Abraham, Sharon Furtado, Amruthavarshini, and Suman. The manuscript was drafted by

Sindhu Abraham and Amruthavarshini and reviewed by Sharon Furtado.

SUMMARY

Staple food fortification is a cost-effective, sustainable strategy to combat widespread micronutrient deficiencies, or "hidden hunger," which causes significant malnutrition and mortality, especially in children and women in India. Fortification, which involves intentionally adding vitamins and minerals to staple foods, enhances nutritional quality and promotes public health. Despite India's mandatory fortification efforts, challenges like low consumption among vulnerable groups, poor supply chain management, and low public awareness persist

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