The Fortification of food products with micronutrients to address their deficiencies is a concept which has been introduced over a hundred years from now. Yet the problem of malnutrition still persists in the 21st century. Micronutrient deficiencies are a problem which disproportionately affect vulnerable groups like women, children and low income families. Fortifying foods with required micro nutrients is a legitimate solution that employs highly effective strategies to combat deficiencies in these essential nutrients. Food fortification has been a vital part of missions to face micronutrient deficiencies worldwide especially in developing countries

Food Fortification to combat micronutrient deficiencies- a review

ABSTRACT-

The Fortification of food products with micronutrients to address their deficiencies is a concept which has been introduced over a hundred years from now. Yet the problem of malnutrition still persists in the 21st century. Micronutrientdeficiencies are a problem which disproportionately affect vulnerable groups like women, children andlow income families.Fortifying foods with required micro nutrients is a legitimate solution that employs highly effective strategies to combat deficiencies in these essential nutrients. Foodfortification has been a vital part of missions to face micronutrient deficiencies worldwide especially in developing countries. In this review paper we have started with how fortification works as a viable solution in the current scenario worldwide. A historical overview has been provided. All over the world there are many programs where specific foods are mandated to be fortified with certain micronutrients in fixed amounts to make sure of proper nutritional access to affected socio-economic groups.We used data available from various research articles,government reports andpolicies to assess the current situation of fortification programs especially in regard to government stanceand commitment through policies in India. Various potential advantages and risks of fortification have been analysedfrom available research.

Key words:Fortification, micronutrient deficiencies, policies,nutrients,vitamin,minerals,FSSAI,WHO.

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1.INTRODUCTION-

Our diet requires proper nutrients for normal growth,development,health, and functioning of the body[1]. But proper nutrition continues to be beyond reached of a large segment of population especially in developing countries. Deficiencies of micronutrients can cause various disorders likeimpaired physical development and cognitive disabilities, increased risk of functional impairment, perinatal complications, increase in morbidity and mortality [2].WHO acknowledges that there are more than 2 billion individuals around the world that suffer from various micronutrient deficiencies.In this number of 2 billion people experiencing these micronutrient deficiencies, one-third belong toIndia [3]. Providing required nutrients helps to prevent many diseases, preventing deficiencies and optimal functioning of the body [4]. Inthis situation foodfortification comes across as a viable solution. It is increasingly used and is aimed at all age groups and is often used to minimize micronutrient deficiencies.Food fortification involves adding nutrients or bioactive ingredients to foods [5]. All over the world people suffers from various types of malnutrition but people from low-income groups are most affected, especially in developing countries like India. Fortification, as a strategy to diversify and complement the diet, provides the required nutritional needs in a cost-effective manner.For every USD invested in fortification it brings returns on average USD 17 of benefits by reducing burden on healthcare from micronutrient deficiencies [6].It has beenpracticed from a long time in the developed countries to combat these micronutrient deficiencies. Fortification in the United States commenced in 1924 by introducing iodine into salt to decrease the prevalence of goitre, a prevalent condition during that era stemming from micronutrient shortages.Developing countries are too

fast catching up on fortification programme. 29 countries from the developing world began expanding or they are already in expanded stages of development of a wide variety of vitamin A fortified foods [7]. Manyfoodssuch as milk, oils, rice,wheat flour, double-fortified salt are mandated to be fortified in many countries [3]. Currently, over 100 developing countries have salt iodization programs in progress [7]. Food products all over are now being fortified to become richer in micronutrients like iron,vitamins, and zincetc [8]. Thus due to these circumstances Fortification has attracted more attention in developing countries leading to more rapid advances than anticipated by experts previously.The appeal of fortification is being reflected in government policies around the world too. Government of India has suggested fortification in 5-year plans to combat nutrients deficiencies along with implementing other schemes.

2.PRINCIPLE OFFORTIFICATION:

Fortification, which involves the process of enhancing the nutritional content of frequently consumed food items with micronutrients, has been widely acknowledged as a well-established, secure, and economically efficient strategy to improve dietary quality and safeguard against nutritional deficits[9]. The benefits of fortification to public health have been demonstrated over time by the scientific community. They include helping to control micronutrient deficiencies, improving nutritional status and food intake, and thus improving dietary habits and lifestyle[10].Food fortification aims to tackle a proven deficiency of one or more micronutrients within the broader population, or a particular demographic group[11].Required nutrients can be provided in food to accomplish any of these: fortification; restoration of nutrients lost during processing; the nutritional similarity of substitute foods; and guaranteeing a special purpose food has the right nutrient makeup[12].

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3.HISTORY

The idea of adding nutrients to staple foods is not new; it has been used to address micronutrient deficits for more than 70 years in Europe and North America[13].In Switzerland and USA during the early 1920s, the fortification of salt with iodine was initiated to address prevalence of goitre due to deficiencies[14].In 1918, Denmark launched margarine supplemented with vitamin A. Additionally, vitamin A-enriched milk and vitamin B and iron-fortified flour were introduced in advanced nations during the 1930s [15].Due to the prevalence of rickets in youngsters, in the United States, vitamin D fortification of milk was initiated in 1932. Additionally, in 1941, B vitamins were added to flour and bread [15]. In 1991, the British Medical Research Council demonstrated that most cases of infant spina bifida and anencephaly (two serious, disabling, and often fatal neural tube defects in newborns) could be prevented if pregnant women took folic acid (vitamin B9) even before becoming pregnant [16] promoting the fortification of folic acid in diets.

4.TYPES OF FORTIFICATION:

For the selection of a suitable and successful fortification method for a country we take into multiple factors such as type of deficiency,its extent, the demographic groups that are most impacted, dietary patterns, government policies and initiatives, infrastructure, food processing and production capabilities. Following are major types of fortifications-

4.1.Biofortification- Micro nutrient deficiency is commonly caused by the insufficient availability of essential minerals in crops grown in the regions with poor bioavailability, coupled with limited consumption of these crops and a lack of fish or other nutrient-rich foodsin the region [17]. One solution to address the issue of inadequate minerals in crops grown is to breed and genetically modify plants to enhance their nutrient content and absorption. This method is known as Biofortification [18]. It also involves Agronomic biofortification where mineral fertilizers are made bioavailable by applying them on field and crops [19]. One of popular examples of biofortification in crops is of Orange sweet potato being fortified with vitamin A to address deficiencies [20].” Golden rice” is another prominent examples which is a genetically

modified crop having twice the normal iron level and a large amount of beta-carotene[21].In biofortification approach staple foods are targeted.

4.2.Industrial fortification- It entails fortification of processed products such as rice, flour, sauces, butter, and oils [21]. For example, a large amount of B1, B2, and B3 are lost during refining, which occurs in grain processing. This loss can be restored through fortification of processed food with the missing ingredients in smaller amounts. Industrial fortification is often mandated by governments, as in the case of salt fortified with iodine, which is mandatory in over 130 countries [22].This solution is the most optimal means of reaching a vast number of people. The implementation of this strategic approach to boost the nutritional value of foods on a large-scale has a crucial role in tackling prevalent nutrient deficiencies among populations. Industrial fortification extends beyond just one food item and covers a vast array of products, including cereals, flours, oils, dairy, and more. Health authorities typically regulate and monitor it to ensure that the added nutrients meet specified standards. This practice acts as an economical and effective way to enhance the overall nutritional value of staple foods.

4.3.Point of usefortification- It is a combination of supplements with fortification which involves micronutrients packets or tablets added during cooking or eating at home to reach populations at risk of micronutrient [21]. The effectiveness of various products, such as tablets, powders, and spreads that contain micronutrients, is currently being studied to determine their ability to improve micronutrient intake. The WHO suggested in 2016 that theaddition of micronutrient powders (MNPs) in complementary foods at the moment of consumption was a crucial tacticfor increasing micronutrient consumption [23].MNPs do not affect the taste or colour of food.

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5.FORTIFIED FOODS:

5.1.Milk: In India, vitaminD and Aare provided inmilk. Even though India leads the world in milk production, a lamentable issue persists, wherein milk, despite its prolific production, continues to elude affordability for individuals with lower incomes. This disparity can be attributed to the ever-increasing demand for milk along with still limitedsupply. Unlike some other countries, milk in India is not homogenized, leading to noticeable separation upon storage, with higher fat content in the upper layers. To ensure consistent distribution of added vitamin A and D in milk, it would be necessary to homogenize it [24].

5.2.Flour: Fortification of flour is found in 1942. Fortified flours containing various vitamins have been used to address nutritional deficiencies and combat diseases. For instance, vitamin A-fortified rice has been employed to enhance the vitamin A and ironlevels. Additionally, B vitamins have been added to maize flour, helping to eliminate pellagra and beriberi inmany nations. Furthermore, vitamin B12, when fortified in flourand subsequently baked into bread, maintains its high bioavailability, thereby contributing to the reduction of vitamin deficiency when consumer [25].

5.3.Sugar: Sugar is provided with vitamin D and A reducedeficiencies of micronutrients [26]. Thepractice, often carried out in collaboration with governments and public health agencies, ensures that a widely consumed product like sugar becomes a vehicle for delivering vital nutrients to the masses,particularly in regions where nutrient deficiencies are prevalent.

5.4.Salt: In Switzerland and the United State of America, Salt iodization was initiated during 1920s[14].Salt is used in every home. The lack of iodine results in hypothyroidism, goitre, cretinism, intellectual disabilities, decreased fertility, and is a factor contributing to elevated rates of prenatal and infant mortality. So salt is fortified with iodine [27].

5.5.Oil: Oil is fortified with vitamin A, which is essential for the growth and development of bones and soft tissues. It also plays a role in protein synthesis, bone cell differentiation, and the creation and

maintenance of tooth enamel and healthy gums. Vitamin A deficiencies can manifest as skin changes, night blindness, and corneal ulceration. Fortification of oil with vitamin A helps to combat these deficiencies [28].

5.6.Yogurt: Yogurt is fortified with selenium. It is crucial for humans as well as animals because it is vital micronutrient. It serves as a key element in glutathione peroxidase, a renowned antioxidant that mitigates cellular oxidative damage. Additionally, selenium has an essential role in facilitating the synthesis of the active form of thyroid hormone [29].

5.7.Rice: Rice is fortified with calcium. It is necessary for the development, functioning, and upkeep of human body [30]. Concerns about bone health are widespread in the public. Each year, roughly 9 million individuals worldwide experience fractures caused by osteoporosis [31]. Inadequate calcium levels can result in diminished blood clotting abilities, dental weakness, and various other symptoms [32].Calcium, in the form of calcium carbonate, tricalcium phosphate and calcium lysinate is added to foods like rice for the purpose of fortification [33].

5.8.Corn flour: Corn flour fortified with folate. As of now many countries around the world have mandated incorporation of folic acid into a variety of cereals, such as corn flour to decrease the deficiencies of megaloblastic anaemia [34].

Table 1. Fortified foods to address micronutrient deficiencies.

Serial number	Micronutrient	Deficiency disorder	Fortified in foods	Reference
1.	Vitamin A	Night blindness	Orange,sweetpotato,cassava,maize,wheatflour,edibleoils,rice	[35,36,37,38,25,39]
2.	Vitamin B complexes	Pellagra,Beriberi,Anaemia,Cardiovasculardiseases,Alzheimer'sdisease,neural tube defects	Rice,maida,corn flour	[34,35,40,41,42,]
3.	Iron	Anaemia,pregnancycomplications,retarded growth.	Milk,rice,pearlmillet,beans,biscuits	[39.42,43,44,45,46,47]
4.	Zinc	Retarded growth and development,susceptibility to infections ,Alopecia,Obesity	Rice,wheat,cornflour,infantformulas,pearlmillet,beans banana	[39,48,49]
5.	Iodine	Goiter,Hypothyroidism, reduced fertility,mental retardation	Salt,oils	[50,51,52]
6.	Vitamin D	osteoporosis ,osteomalacia and rickets	Margarine,milk and other dairy products	[53,54]
7.	Vitamin C	Scurvy	Baby food,mik,beverages	[55,56,57]
8	Calcium	Osteoporosis	Wheat flour,potatochips,milk	[35,58,59,60]
9.	Selenium	Cardiomyopathy,osteoarthropathy,increased risk of cancer	Yogurt,salt,milk,babyfood,corn and wheat flour	[57,61]
10.	Fatty acids	Scaly dermatitis, alopecia, mental retardation in children and thrombocytopenia	Bread,oil,butter,meat,jelly,Dahi	[62,63]
11.	Protein	Organ failure,impaired mental health,oedema,mararasmus,kwashiorkor	Mushroom,Sausages and meat products	[64,65,66]

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6. Fortification in Indian context of legislation and policies

India recently became the most populated nation on earth surpassing China,ensuring food security for such a massive population is a challenging situation for any government. This is seen by government focus on fortificationthrough implementing new schemes and working under already existing schemesto meet nutrient needs of this growing population.

6.1 Regulations

In 2016, FSSAI introduced food fortification regulations to fortify vitamin B-12, folic acid along with iron in staple foods in order todecrease the occurrence of deficiencies all over the country. Further FSSAI in the year 2018 implemented food safety and standards regulations for fortified food products. These standards set mandatory levels of fortification of essential micronutrients in staple foods of Indian diet.

To differentiate fortified products and promote them in market a fortified logo was also launched indicating that the food product is fortified.The logo features an “F+” symbol, where “F” stands for “fortified” and is enclosed within a square symbolizing fullness. The plus sign signifies the addition of essential minerals and vitamins to meet daily nutritional needs.The ring signifies robust health and safeguards for a vibrant and active life. Foodbusinesses can apply for the logo by completing a straightforward form on the FFRC website, enabling them to easily share details about the fortified products they offer, making customers aware about the food product [3].

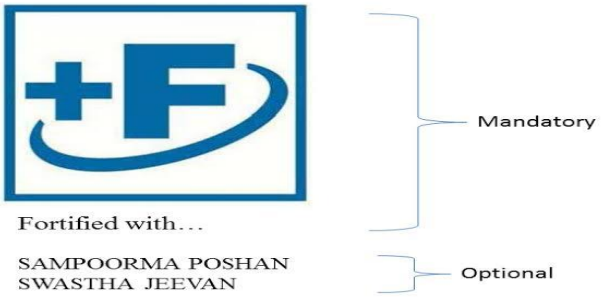

Figure1. Fortified logo

Recently a third amendment was made to the standards laid down earlier.From 22nd September, 2021 this amendment is in effect.

Table 2. Fortification standards for salt, milk and oil as per Food Safety and Standards (Fortification of Foods) Regulations, Food Safety and Standards Authority of India, 2018

Serial number	Component	Level of nutrients	Source
1.	Iodine in salt	a)20–30 ppm (on the basis of dry weight) at the manufacturing level b)15-30 ppm(on dry weight basis)at distribution channel including retail level	Potassium Iodate
2.	Iodine in double fortified salt	15-30 ppm(on the basis of dry weight)	Potassium Iodate

3.	Iron in double fortified salt	850-1100 ppm	Ferrous fumarate or Ferrous sulphate
4.	Vitamin A in milk	270–450 mg RE	Retinyl palmitate or Retinyl acetate
5.	Vitamin D in milk	5–7.5 mg	Cholecalciferol or Ergocalciferol (From plant source only)
6.	Vitamin A in oil	6–9.9 mg RE per g of oil	Retinyl acetate or Retinyl palmitate
7.	Vitamin D in oil	0.11–0.16 mg RE per g of oil	Cholecalciferol or Ergocalciferol (From plant source only)

Table 3. Fortification standards for Atta, Maida and rice as per Food Safety and Standards (Fortification of Foods) Regulations, FSSAI 2018

Serial number	Nutrient added	Level of Fortification
1.	Iron- a)Ferroussulphate or Ferrous citrate Ferrous lactate or Ferric pyrophosphate or electrolytic iron or Ferrous BisGlycinate or Ferrous fumarate ; Or (a)Ferric pyrophosphate(in case of rice) Or b)Sodium Iron (III) Ethylene diamine tetra Acetate trihydrate	28 mg- 42.5 mg 14 mg- 21.25 mg
2.	Folic acid	75 µg- 125 µg
3.	Vitamin B12	0.75 µg- 1.25 µg
4.	Zinc – zinc sulphate (zinc oxide in case of rice)	10–15 mg
5.	Vitamin-A – retinyl acetate or retinyl palmitate(retinyl palmitate in case of rice)	500–750 mg RE
6.	Thiamine– thiamine hydrochloride or thiamine mononitrate	1–1.5 mg
7.	Riboflavin – riboflavin or riboflavin 5′ -phosphate sodium	1.25–1.75 mg
8.	Niacine – nicotinamide or nicotinic acid	12.5–20 mg

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9.	Pyridoxine–pyridoxine hydrochloride	1.5–2.5 mg

The schedule III of Food Safety and Standards (Fortification of Foods) Regulations, FSSAI 2018 in the 3rd version has also included standards for fortified processed foods like bakery wards,cereal processed foods (pasta,noodles,cereal breakfasts) and juices.

6.2.Government schemes to promote fortification

Along with these regulations various government schemes are being implemented to reach fortification goals. They include

6.2.1.Fortification in Mid-Day Meal -The Mid Day Meal (MDM) Scheme strives to enhance the nutritional status of children attending government, municipal, and government-supported schools up to the 8thstandard. A recent directive mandates the inclusion of Double Fortified Salt, fortified wheat flour, and fortified edible oil in the MDM scheme. States like Tripura and Tamil Nadu are now supplying double fortified salt in diet through MDM.Maharashtra supplies fortified wheat flour in its three districts and Haryana introduced fortified rice and flour in Ambala [3].

6.2.2.The Integrated Child Development Scheme (ICDS)-The Integrated Child Development Scheme (ICDS) provides complementary nutrition in the form of Take-Home Rations (THR) for pregnant women, breastfeeding mothers and children along with hot meals for children aged 3-6 [3].

6.2.3. National Nutrition Mission- It was initiated by the Prime Minister's Office in 2018, introducing staple food fortification as a cost-efficient method to combat vitamin and mineral deficiencies. The National Nutrition Mission is also known as the Poshan Abhiyan. The mission adopts a multi-sectoral approach, involving various government departments and agencies, to tackle the complex problem of malnutrition.

6.2.4. Fortification in Public Distribution System (PDS)-It is the main channel for the government to ensure food security in the country, and it reaches 67% of the population, making it ideal for fortification programs for staple foods..Many states are providing fortified rice,wheat flour,oils and double-fortified salts using these channels [3].

6.2.5.Eat Right India Initiatives – The Eat Right India Initiatives were launched with the aim of comprehensively transforming the country's food system to guarantee the availability of safe, nutritious, and sustainable food for every Indian. It strengthens government efforts, key players in food industry, area experts, civil society organizations, professionals, along with playing a role in development of organizations and people[67].

6.2.6.National Iodine deficiency disorders control programme (NIDDCP)- Thisprogram helps to promote iodine fortification in salt along with its adoption by the general population [68]. It is an important public health initiative in India dedicated to combating iodine deficiency disorders (IDD) and ensuring the overall well-being of its population. The program also emphasizes awareness and education, urging the consumption of iodized salt to prevent IDD.

6.2.7. Sabla Scheme- It is a central government program designed for the holistic advancement of adolescents aged 11 to 18 and presents an excellent opportunity for introducing fortified staple foods. This intervention could effectively combat micronutrient deficiencies during the crucial adolescent phase, which precedes motherhood. The nutritional aspect of the program strives to enhance the health and nutritional well-being of these girls by supplying additional nutrients through fortification.

7. FORTIFICATION TARGETED AT CHILDREN

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Micronutrient deficiencies exert a significant impact on the well-being of children across numerous nations, impeding both their physical and mental growth, and increasing morbidity and mortality rates [6]. The presence of various micronutrients in food is crucial for sustaining important cellular and molecular functions, allowing proper growth and development. The susceptibility of children under the age of 5 to these deficiencies is heightened due to their rapid growth and developmental processes, necessitating an increased intake of micronutrients [2]. This vulnerability of children is evident from rates of malnutrition in children especially in some of poorest nations of world[69].

On a global scale, an alarming 43% of children under 5 years old suffer from anemia [70] and in India among preschool children 58.4 have anaemia[3]. In the context of low- and middle-income countries (LMICs), an estimated 29% of children under 5 years old encounter a deficiency in vitamin A [71].In India 35.7% of children under the age of 5 are under weight[3].

This is a very concerning issue for any nation. From a public health point of view, proper nutrition is important to achieve optimal physical and mental development between the ages of 5 and 15, to ensure they reap full educational benefits during the school years [72].

Large-scale fortification involves enhancing the nutritional content of commonly consumed foods, which are staples in our diet like wheat, flour, rice, salt, sugar, oil, and milk, during central processing. This is done to boost their nutritional value due to their widespread consumption in target populations. However, for small children these methods may not be as effective due to low consumption of staple foods in children in comparison to adults and these programmes not satisfactorily targeting at children[73]. Hence,fortification programmes need to increase their focus on children considering their unique needs.In addition, it is important that young people entering working life and women of childbearing age pass on optimal nutritional status to their future children. Ensuring adequate energy and nutrient-dense diets can improve the health of this population in developing countries. Ultimately, this approach may be a viable way to break the cycle of malnutrition [74].

This targeted fortification focuses on adding micronutrients to foods specifically formulated for subgroups like infants, children over 6 months, and institutional programs catering to school- and preschool-aged children [69]. In this direction ,experts have advocated for even fortifying human milk fed by mothers to infants[75]. Current strategies to improve the situation of malnutrition in children include home fortification with micronutrient powders (MNPs), large-scale fortification, targeted fortification, and lipid-based nutrient supplementation (LNS).

Among these one of important ways to reach children is through fortification of marketed infant formulas and supplements with micronutrients like iron. MNPs have been found to reduce anaemia and promote better health and growth in children[76].In 2018 alone MNPs have been delivered to 18 million children across 54 countries[77].Micronutrient supplementation is the provision of single micronutrients like iron,vitamin B9,vitamin A, vitamin B12, vitamin D, iodine and zinc in the form of capsules, tablets or syrup. A multi-micronutrient (MMN) supplement is defined as a single dose with at least three different types of micronutrients[69].A study on young children in North India has shown that regular consumption of fortified milk reduced the occurence of diarrhea by 18% , a 7% reduction in days with high fever, a 15% reduction in days with severe illness and 26 % reduction in occurrence of pneumonia[78].

8.ADVANTAGES OFFOOD FORTIFICATION:

The advantages of food fortification are far-reaching, contributing significantly to public health and nutrition. It is a cost-efficient approach to enhance the nutritional well-being of a population [79].Micronutrients have consistently been rated as the most cost-effective development intervention in reviews like the Copenhagen Consensus, offering substantial returns at a minimal cost[80].Food fortification is a strategic public health approach that effectively reaches larger vulnerable population segments through established food distribution systems, all without necessitating significant alterations in current consumption habits. It's a cost-efficient method to enhance nutrient intake in the population, and

fortified foods help maintain consistent nutrient stores within the body [15]. Staple foods grown in specific regions may be lacking in essential nutrients due to factors like soil conditions or natural dietary limitations. Incorporating micronutrients into condiments and staple foods can effectively prevent widespread malnutrition related diseases on a significant scale [10]. Thescientific community has consistently shown that fortification offers notable benefits to public health. It aids in correcting and preventing micronutrient deficiencies within a population, leading to improved nutritional well-being, dietary intake, and ultimately fostering healthier dietary habits and way of living [10]. Moreover, the ability to customize fortification to target specific regional needs, alongside the preservation of taste and texture, ensures easier acceptance by consumers. As a result, fortification leads to better public health outcomes, reducing the incidence of nutrition-related diseases and promoting overall well-being, making it an essential strategy for improving nutrition on a large scale.

9. DISADVANTAGES OF FOOD FORTIFICATION:

Although food fortification has its advantages, it is not without its drawbacks and complexities. Fortification is insufficient in addressing micronutrient deficiencies when a largepartamongthe targeted demographics lacks access to foods which are fortified due to poverty or location, when deficiencies are severe, or when infections increase the body's need for micronutrients. Furthermore, safety, technology, and cost-related factors can limit the effectiveness of food fortification interventions. Therefore, successful planning for such programs necessitates not only evaluating their potential impact on the population's nutrition but also assessing their feasibility in specific circumstances.

Additionally, appropriate legislation is essential to oversee these interventions [81]. Overloading the body with excessive amounts of vitamins and minerals can carry many dangers and lead to adverse health consequences. Foodfortification with various micronutrients can potentially lead to unwanted interactions with individuals using prescription medications. This fortification may cause instances of reduced absorption, treatment ineffectiveness, and an elevated risk of mortality [82]. The effective regulation and consistent monitoring of fortification processes to maintain correct nutrient levels can be a challenge.

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9.CONCLUSION-

Though various staple foods have been fortified and many mandates on fortification of foods through government channels have been passed and seen considerable success in addressing micronutrient deficiencies, a significant population still suffers from many micronutrient deficiencies. Stronger lobbying and laws are required to push mandatory fortification of food products as in the case of iodine fortification of salt all over the world.

In addition to these, there are many risk factors associated with fortified foods. Many times, fortification is not accessible or available equally to all sections of society. More research and investments are required in this field to properly address these problems so that fortification programs achieve their true potential and to ensure a malnutrition-free world. Addressing these concerns and ensuring responsible implementation of fortification initiatives is essential for optimizing benefits while mitigating drawbacks.

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