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Review Article

Advances in food fortification: Ensuring a healthier humanity, types, and analytical methods

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ABSTRACT

Food fortification is the practice of improving food products' nutritional value by adding necessary vitamins and minerals. This practice is typically implemented to address widespread deficiencies of these nutrients in the population and improve public health. Fortification can be achieved through various methods, including adding specific micronutrients to staple foods such as flour, oil, or salt, as well as through the addition of micronutrients to processed or packaged foods. The benefits of food fortification include reduced rates of malnutrition and related health problems, improved overall health and cognitive development, and increased productivity. Despite these benefits, there are also potential challenges to the implementation of food fortification programs, including the need for accurate monitoring and assessment to ensure the appropriate use of fortificants and to prevent over-fortification. Despite these challenges, food fortification remains a promising strategy for improving public health and reducing the burden of micronutrient deficiencies globally.

1. Introduction

The term "malnutrition" has no accepted definition. It has been used to identify nutrient imbalances, excesses, and deficiencies that adversely affect body composition, function, and clinical results.[1] An insufficient or unbalanced intake of the nutrients the body needs to operate correctly leads to malnutrition, a severe global health problem. It can happen in both wealthy and developing nations and affects people of all ages, but especially kids and expectant mothers. In addition to stunted growth, impaired immune systems, and an increased risk of infections, malnutrition can have a severe negative influence on a child's physical and cognitive development.[2] The strategies for preventing and treating malnutrition can vary depending on the underlying causes and the specific needs of the affected population. Some of the key strategies that can be used to address malnutrition include Increasing access to food: One of the most effective ways to prevent malnutrition is to ensure that people have access to a sufficient quantity and quality of food.[3] This can be achieved through a range of interventions, including food distribution programs, cash transfers, and initiatives to promote agricultural productivity. Promoting food fortification: In addition to increasing access to food, promoting good nutrition is also important. This can involve providing education and information on healthy eating habits, promoting breastfeeding, and providing micronutrient supplements such as iron, vitamin A, and iodine.[4] Addressing underlying health issues: Malnutrition can be caused by underlying health issues, such as infections or diseases that affect the ability of the body to absorb nutrients. Addressing these underlying health issues can help to prevent malnutrition. Access to clean water and

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sanitation is crucial for reducing malnutrition because it can help to lower the occurrence of waterborne infections that can interfere with nutrient absorption. Early childhood development investments: These investments can aid in the reduction of undernourishment and the promotion of normal growth and development in children. This can involve providing education and support to parents on nutrition and child-rearing practices, as well as investing in early childhood education and healthcare services. Helping vulnerable populations: For vulnerable populations, such as refugees, internally displaced people, people affected by armed conflict, and those affected by natural disasters, malnutrition poses a major concern. To prevent malnutrition and decrease its effects, these groups can get targeted assistance.[5] Overall, addressing malnutrition requires a comprehensive and coordinated approach that involves multiple stakeholders, including governments, civil society organizations, healthcare providers, and the private sector. Malnutrition can be prevented and treated by using a variety of interventions that target its underlying causes and cater to the individual needs of affected groups.[6] One of the key strategies for malnutrition are used worldwide is food fortification.

Food fortification is the process of enhancing the nutritional content of commonly consumed foods by combining vitamins and minerals.[7] It is an effective way to improve diets, avoid nutrient shortages, and keep prices under control. Mother and child malnutrition are the leading causes of death for children under five in low- and middle-income (LMIC) nations.[8,9] In LMICs, hidden hunger—or a continuous lack of essential vitamins and minerals in the diet—is an issue that is especially pervasive. Two groups of minerals that are frequently used are major minerals (macro-minerals) and trace minerals (micro-minerals). Iodine (I), zinc (Zn), selenium (Se), iron (Fe), manganese (Mn), copper (Cu), cobalt (Co), molybdenum (Mo), fluoride (F), chromium (Cr), and boron (B) are trace minerals. Calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), chloride (Cl), phosphorus (P), and Sulphur (S) are major[9]. The addition of nutrients necessitates close consideration of food laws, labelling, nutritional justification, cost, consumer acceptance, and a rigorous examination of technical and analytical constraints for compliance with label declarations.[10] Utilizing fortification or enrichment, restoration, standardization, and supplementation processes, more nutrients are added to food. Data on the per capita intake of food vehicles by various social and economic groups, in various ecological zones, preferably split down by age and physiological group, are used to determine the concentration of fortificants in such vehicles.[11] Deficits in iron, iodine, vitamin A, and zinc are said to affect mostly women and children in impoverished nations. Many impairments are brought on by these anomalies, including slowed brain growth and cognition, lower immunity to illness, adverse pregnancy outcomes, poor growth, reduced capacity for work, blindness, and even death.[12] Developing an efficient, practical, and cost-effective fortification programme is impossible without quality assurance, which ensures that food vehicles are adequately fortified and supplied to customers at the desired level of potency and quality. The justification for food fortification is crucial to understand since it serves two functions. By enriching a food with the nutrient that has been depleted, it can first restore nutrients that were lost during food preparation. Second, it can raise the amount of a particular nutrient in a diet. In both situations, fortification raises the consumption of a particular nutrient that was once considered inadequate.[13]

2. History

Fortification of food has been used successfully in the industrialized world for more than 80 years. In many nations, the prevalence of goiter, rickets, ariboflavinosis, and pellagra has decreased due to the consumption of foods fortified with iodine, vitamin D, vitamin B-2, and niacin.[14] However, the modern history of food fortification can be traced back to the early 20th century when scientists discovered that certain vitamins and minerals were essential for human health. In the 1920s, the United States began fortifying milk with vitamin D to prevent rickets, a bone disease caused by vitamin D deficiency. By the 1930s, many countries had followed suit, and milk fortification became a standard practice in the dairy industry. In the 1940s, the United States began fortifying flour with vitamins and minerals to prevent deficiencies in the population. By the end of the decade, most flour in the United States was fortified with thiamin, niacin, riboflavin, and iron.[15] The practice of flour fortification spread to other countries, and by the 1960s, many countries had implemented mandatory fortification programs for wheat flour. In the 1950s, iodine was added to salt in many countries to prevent iodine deficiency disorders such as goiter. Salt iodization became a standard practice in many parts of the world, and today, over 80% of the world's population consumes iodized salt.[16] In the 1960s, the United States began fortifying breakfast cereals with iron to address iron deficiency anemia. By the 1970s, most breakfast cereals in the United States were fortified with iron, and the practice spread to other countries. In the 1980s, many countries began fortifying milk and other dairy products with vitamin A to address vitamin A deficiency, which is a leading cause of blindness in children in developing countries. By the 1990s, vitamin A fortification had become a standard practice in many parts of the world.[17] More than 30 years ago, researchers began to understand how food fortification could help alleviate micronutrient deficits in impoverished nations.[18] Numerous national food fortification programmers have been put in place over the past 70 years in both industrialized and

developing countries, and they have considerably improved public health. The majority of the vitamins A, C, and D, thiamine, iron, and folate that Americans and Canadians consume comes from enhanced and/or fortified foods.[19] On a worldwide level, micronutrient deficiencies have been significantly reduced or, as with iodine, almost completely eliminated. In the last ten years, progress has quickened. Currently, there are salt iodization schemes in about 140 nations globally, at least one type of cereal grain fortification is required in 83 nations, 20 nations fortify edible oils, 9 nations fortify sugar, and numerous more nations fortify rice, milk, or sauces. With over one-quarter of iron intake in the US diet coming from fortified foods, a large portion of it from cereal goods, fortified foods are believed to be responsible for the country's present low levels of iron insufficiency[20] It has only recently been demonstrated, however, that widespread iron fortification of cereal flours may increase the iron status of national populations, despite multiple rigorous scientific research confirming the benefit of iron-fortified diets.[21]

3. Reasons for Implementing Food Fortification

The technique of incorporating vital vitamins and minerals into food products is known as food fortification. This is done to improve the food's nutritional value and treat dietary inadequacies among a community.[22] For preventing nutrients deficiencies by adding essentials nutrients to commonly consumed foods, such as iron, vitamin A, and folate among others and fortification can help prevent widespread nutrient. The chances of certain health issues, such as anemia, neural tube malformations, and stunned growth, can be reduced by fortifying diet to improve public health. In communities with limited availability to a variety of nutrient-rich foods, fortification can be an easy and affordable option to boost access to vital nutrients.[23]Food fortification can be used in combination with other public health initiatives, like education and supplementation programmes, to enhance nutrition and overall health results. The food fortification is a sustainable approach as it can be incorporated into the food supply chain, providing a long-term solution to nutrient deficiencies. Fortification can reach large populations, including those who are not reached by other nutrition interventions. Unlike supplements and other forms of direct supplementation, fortification does not require individuals to change their dietary habits or undergo medical procedures.[24]

4. Types of food Fortification[25,26]

There are several types of food fortification, including

1. Micronutrient fortification: This involves adding specific micronutrients such as iron, calcium, vitamin A, and vitamin D to food products to address nutrient deficiencies.
2. Mass fortification: This refers to the adding of essential micronutrients to widely consumed staple foods such as flour, oil, and salt.
3. Biofortification: This involves breeding crops to increase their nutrient content, resulting in more nutritious food products.
4. Selective fortification: This type of fortification targets specific populations, such as pregnant women and children, to address their unique nutrient needs.
5. Enrichment: This is the process of reintroducing nutrients that were removed from food during processing.
6. Industrial fortification: This depends on supplying one or more nutrients when producing the final food product.

5. Methods of Food Fortification

Food fortification is the practice of enhancing the nutritional value of staple foods by adding necessary micronutrients. The methods of food fortification include: Dry blending involves adding the micronutrient powders or granules to the dry ingredients of the food and then thoroughly mixing them before the final product is produced. This method is commonly used for cereal-based products, such as flour, maize meal, or rice. The micronutrient powders are often blended with a carrier, such as sugar or maltodextrin, to improve dispersion and prevent caking. This method is relatively inexpensive and can be used for large-scale fortification programs. However, it is not suitable for all types of foods, as it can cause changes in the taste, texture, or appearance of the final product.[27] Spray drying is a process in which a solution containing the micronutrients is sprayed onto the food and then dried to preserve the nutrients. This method is commonly used for liquid foods, such as milk, and can also be used for dry foods, such as cereal-based products. The spray drying process can be more expensive than dry blending, but it can be useful for fortifying foods that are difficult to blend with other ingredients, such as liquids or powders with small particle sizes. Liquid fortification involves adding the micronutrients to liquids, such as oil, sugar syrup, or milk, and then mixing them into the food. This method is commonly used for oil-based products, such as margarine, and for liquid foods, such as milk. The advantage of liquid fortification is that it can be easily controlled and monitored, and it does not affect the taste, texture, or appearance of the food. However, it can be more expensive than dry blending, and the micronutrients can be lost during cooking or storage. Injection molding is a process in which micronutrients are injected into solid foods, such as bread or pasta. This method is more expensive than dry blending, but it can be useful for fortifying foods that are difficult to blend with other ingredients, such as those with a high moisture content. The injection molding process can also be used to

create fortified products with a uniform distribution of the micronutrients. Seed coating involves coating seeds with a mixture of micronutrients before planting. This method is commonly used for staple crops, such as maize, rice, and wheat, and can improve the nutritional content of the crops grown from the treated seeds. Seed coating can be a cost-effective method of fortification, as it does not require additional processing or storage. Food premixes are mixtures of micronutrients that are manufactured and sold to food processors to be added to their products during production. The precise control of the number of micronutrients added to the food is made possible by this technology, which is frequently utilized for large-scale fortification initiative. The food premixes can be blended with other ingredients, such as sugar or maltodextrin, to improve dispersion and prevent caking.[13]

6. Constituents Included in Food Fortification

There are various constituents used for the food fortification in various countries and it is important to know the nutritional importance of every constituents.[28] There are mainly two types micronutrients and macronutrients. Iron, Vitamin A, Vitamin D, Folic acid, Iodine, Zinc, Calcium are the various micronutrients elements. Carbohydrates, Proteins, and Fats are various macronutrients are used for the food fortification for maintaining human health and well-being.[29] Iron is added to foods such as flour, breakfast cereals, and pasta to combat iron-deficiency anemia, which can lead to fatigue, weakness, and reduced work capacity. Iron is essential for the production of hemoglobin, which carries oxygen in the blood, and myoglobin, which helps muscles store oxygen. Vitamin A is added to foods such as oil, milk, and cereal flour to prevent vitamin A deficiency, which can lead to blindness, night blindness, and increased susceptibility to infections. It is essential for maintaining healthy vision, skin, and immune function.[30] Vitamin D is essential for the absorption of calcium and phosphorus, which are important for strong bones and teeth. Vitamin D also supports the immune system and regulates calcium and phosphorus levels in the body. Adding vitamin D to foods such as milk, breakfast cereals, and orange juice can promote strong bones and teeth and support the immune system. Folic acid is essential for cell division and the formation of genetic material. It is also important for the production of red blood cells. Adding folic acid to flour, bread, and cornmeal can prevent neural tube defects in newborns, which can lead to spina bifida and anencephaly.[31] Iodine is essential for the proper functioning of the thyroid gland and the synthesis of thyroid hormones. A lack of iodine can result in goiter and other thyroid problems. Adding iodine to salt can help prevent these problems. Zinc is essential for many functions in the body, including immune function, wound healing, and growth and development. Adding zinc to foods such as cereal flour and breakfast cereals can support these functions. Calcium is essential for strong bones and teeth, muscle and nerve function, and blood clotting. Adding calcium to foods such as orange juice, tofu, and soy milk can help support these functions.[32] Protein is an essential macronutrient that is used to build and repair body tissues. Adding protein to foods such as breakfast cereals and energy bars can help increase the overall protein content of the food product. Fiber is a form of carbohydrate that aids in digestion and can reduce the risk of a number of health issues, including heart disease, obesity, and type 2 diabetes. Adding fiber to foods such as bread and breakfast cereals can increase the overall fiber content of the food product.[33] Healthy Fats For heart health and general well-being, lipids like omega-3 fatty acids and mono- and polyunsaturated fats are crucial. Adding healthy fats to foods such as spreads, dressings, and snack bars can help increase the overall healthy fat content of the food product. These fortificants are used to prevent deficiencies in essential nutrients, which can lead to various health problems. It is important to note that excessive intake of these micronutrients can also have adverse effects, so it is crucial to follow recommended daily allowances.[34]

7. Regulations

In many countries, food fortification is regulated by government agencies to ensure the safety and efficacy of fortified foods.[35] The % of malnutrition of certain developed and developing countries are shown in Figure 1 . Food fortification regulation in India is carried out by the Food Safety and Standards Authority of India (FSSAI), which is the main regulatory body for food products in the country.[36] The FSSAI has established standards for food fortification in India through the Food Safety and Standards (Fortification of Foods) Regulations, 2018. These regulations set standards for the fortification of staple foods such as rice, wheat flour, and edible oils with essential micronutrients like iron, folic acid, and vitamin A. The regulations also prescribe the methods for fortification, including the type of micronutrient, the minimum and maximum levels of fortification, and the methods of quality control and monitoring.[37] To ensure that fortification is carried out effectively, the regulations require food manufacturers to obtain a license from the FSSAI and to comply with the standards set by the authority. In addition, the FSSAI also carries out regular monitoring and enforcement activities to ensure that the fortification regulations are being followed by manufacturers. This may include regular testing of food products for compliance with the fortification standards and imposing penalties on manufacturers who violate the regulations. In summary, the FSSAI plays a crucial role in regulating food fortification in India, and its regulations ensure that the public has access to fortified food products that provide essential nutrients and contribute to improving public health.[38] In India,

according to the latest data from the National Family Health Survey (NFHS-5), conducted in 2019-20, the prevalence of malnutrition in India is 38.40%.[39]

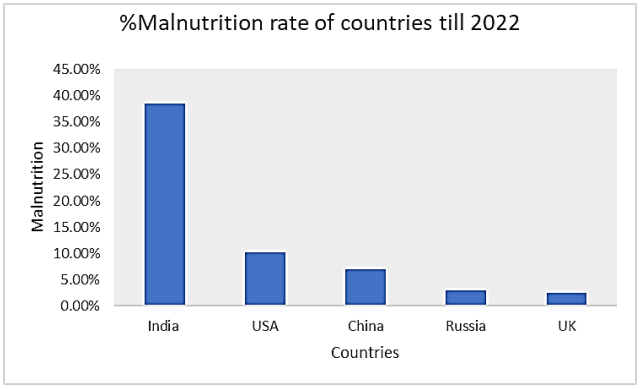

Figure 1: % of malnutrition rate of few countries

In USA the regulation is carried out by USDA. According to the latest data from the United States Department of Agriculture (USDA), the prevalence of food insecurity in the United States in 2020 was 9.7%, which translates to approximately 34.0 million people. Lack of constant access to enough food for a full, healthy life is referred to as food insecurity.[40] In terms of malnutrition specifically, data from the Centers for Disease Control and Prevention (CDC) indicate that around 10% of the US population has some form of malnutrition, which can include both overnutrition (e.g., obesity) and undernutrition (e.g., micronutrient deficiencies). However, the prevalence of specific types of malnutrition can vary significantly by age, gender, race/ethnicity, and other factors.[41] For example, according to data from the National Health and Nutrition Examination Survey (NHANES) for the period 2013-2016, the prevalence of overweight and obesity among adults aged 20 years and older was 71.6%. Among children and adolescents aged 2-19 years, the prevalence of obesity was 19.3%.[42]

Malnutrition in China is a significant public health problem, affecting millions of people, particularly children and rural residents. According to a report by the World Health Organization (WHO), the prevalence of underweight children under the age of five in China was 2.4% in 2019, while the prevalence of stunted growth was 6.4%.[43] However, malnutrition in China can take many forms, including undernutrition, micronutrient deficiencies, and obesity. In recent years, there has been a rise in the prevalence of overweight and obesity among adults, particularly in urban areas. In 2019, the prevalence of overweight and obesity among adults in China was 34.3%.[44] The causes of malnutrition in China are complex and varied, but they are often linked to poverty, limited access to healthcare, and a lack of education. In rural areas, malnutrition is often due to a lack of access to nutritious food, while in urban areas, it can be due to a shift towards a more Westernized diet and a sedentary lifestyle.[45] The Chinese government has implemented several measures to address malnutrition, including the National Nutrition Plan (2017-2030), which aims to improve nutrition and reduce malnutrition. The government has also implemented various programs to address micronutrient deficiencies, such as the National Iodine Deficiency Disorders Control Program and the National Nutrition Improvement Plan for Rural Compulsory Education Students.[46]

Malnutrition in Russia is a significant public health problem, particularly in certain population groups. According to a report by the World Health Organization (WHO), the prevalence of underweight children under the age of five in Russia was 2.2% in 2019, while the prevalence of stunted growth was 4.6%.[47] However, malnutrition in Russia can take many forms, including undernutrition, micronutrient deficiencies, and obesity. In recent years, there has been a rise in the prevalence of overweight and obesity among adults, particularly in urban areas. In 2016, the prevalence of overweight and obesity among adults in Russia was 59.5%.[48] The Russian government has implemented several measures to address malnutrition, including the National Nutrition Strategy (2010-2020), which aims to improve nutrition and reduce malnutrition. The government has also implemented various programs to address micronutrient deficiencies, such as the National Program on Micronutrient Deficiencies Prevention and Control (2017-2022). Despite these efforts, malnutrition remains a significant challenge in Russia, particularly in rural areas and among vulnerable populations.[49]

Malnutrition in the UK is a significant public health issue, particularly among certain population groups. According to a report by the British Association for Parenteral and Enteral Nutrition (BAPEN), an estimated 3 million people in the UK are at risk of malnutrition, with around 1.3 million over the age of 65.[50] The prevalence of malnutrition varies depending on the population group. In hospital, the prevalence of malnutrition among adults ranges from 20-30%, while in care homes, it can be as high as 42%. Among people living in their own homes, the prevalence of malnutrition is estimated to be around 10%.[51] The UK government has implemented several initiatives to address malnutrition, including the Malnutrition Task Force, which aims to raise awareness of malnutrition and improve the identification and management of malnutrition in healthcare settings. The government has also launched several programs to improve nutrition in specific population groups, such as the Healthy Start scheme, which provides vouchers for pregnant women and families with young children to purchase healthy foods.[52]

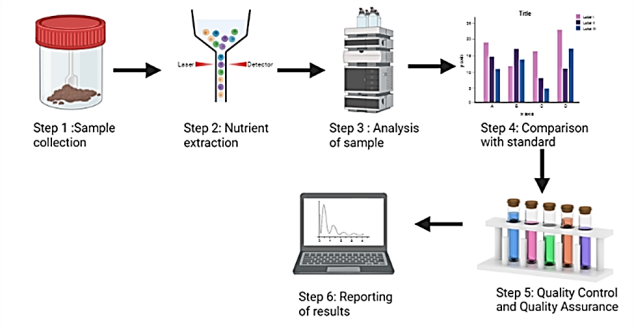

Figure 2: Steps for analysis of food fortification [53,54]

8. Analytical methods for fortified foods

The analysis of food fortification involves the measurement of the levels of essential vitamins and minerals in fortified foods to ensure that they meet established standards and are safe and effective for consumption. There are following steps are included for the analysis i.e. given in Figure 2**.** The initial step includes Sample Collection it is a representative sample of the fortified food is collected and prepared for analysis. This may involve grinding or homogenizing the sample to ensure an accurate measurement of its nutrient content. The second step include nutrition extraction in it the vitamins and minerals in the food sample are extracted and prepared for analysis. This may involve using various chemical or physical methods to isolate the nutrients. The third steps include Analysis of nutrient content in it the extracted nutrients are analyzed using laboratory techniques, such as high-performance liquid chromatography (HPLC), inductively coupled plasma-mass spectrometry (ICP-MS), or atomic absorption spectroscopy. These methods allow for the precise measurement of the levels of essential vitamins and minerals in the food sample. The fourth step include comparison with standards in it the results of the analysis are compared with established standards for food fortification to ensure that the food meets the required nutrient levels. The fifth step include Quality control and quality assurance in it To ensure the accuracy and reliability of the analysis, a variety of quality control and quality assurance measures are employed, such as the use of internal and external quality control materials, blind duplicates, and the performance of standard operating procedures (SOPs).The final and last step include reporting of results in it the results of the analysis are reported to the appropriate government agencies, as well as to the manufacturer of the food, who can use the results to improve their fortification processes and ensure that they are meeting the required standards. It's important to note that the analysis of food fortification can be a complex process that requires specialized knowledge and laboratory facilities. Laboratories conducting these analyses must meet specific quality requirements and are subject to regular audits and inspections to ensure the accuracy and reliability of their results.

9. Future scope of food fortification

Food fortification has the potential to make a significant impact on public health by addressing nutrient deficiencies and reducing the risk of diet-related diseases. However, there is still much to be done to ensure that the benefits of food fortification are realized on a global scale. Some of the future directions and areas of focus for food fortification include Expansion of fortification programs, Targeted fortification, Monitoring and evaluation, Innovative fortification technologies, Consumer education and awareness. Overall, the future of food fortification holds great promise for improving public health and reducing the burden of nutrient deficiencies and diet-related diseases. Continued investment in research and development, as well as partnerships between governments, the food industry, and public health organizations, will be critical to realizing the full potential of food fortification as a tool for improving global health.

10. Conclusion

In conclusion, food fortification is an important strategy for improving public health by addressing nutrient deficiencies and reducing the risk of diet-related diseases. Food fortification can assist healthy growth and development by incorporating necessary vitamins and minerals into foods to increase the diets' overall nutritional quality. Food fortification can assist healthy growth and development by incorporating necessary vitamins and minerals into foods to increase the diets' overall nutritional quality. Effective food fortification programs require a strong commitment from governments, the food industry, and public health organizations to ensure that fortified foods are widely available and accessible to those who need them.

11. Source of Funding

None.

12. Conflict of Interest

None.

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