Review on Micronutrient Fortification of Food and Its Impacts on Human Health

Gizachew Fitamo[1] Debebe Denbela[2] Babuskin Srinivasan[3] Ballekallu Chinna Eranna[4]
[1,2,3,4]College of Natural Sciences, Arba Minch University, Arba Minch, Ethiopia, East Africa

Abstract— Food fortification is the addition of essential vitamins and minerals (micronutrients) to foods during the manufacturing process to enhance the nutritional content of the end product for consumers. Food fortification has gained significant importance in the recent decades as a cost-effective and easy to implement intervention to address micronutrient deficiencies in the populations. Food fortification is the preferred public health intervention to combat nutrient deficiencies due to low nutrient intake in large segments of the population, high prevalence of micro-nutrient deficiency and well documented adverse health consequences. In this context, the present review tries to address the fortification strategies, challenges and limitations during fortification and the types of fortification. Some of the fortification programs that were carried out elsewhere in the world have also been described in the study.

Keywords: Food fortification, Micro nutrition, Human health, Impacts

I. Introduction

A. *Background*

Food fortification is the incorporation of essential vitamins and minerals (micronutrients) to foods during the manufacturing process to enhance the nutritional content of the end product for consumers. When fortified staple foods and condiments are appropriately produced, widely available, and regularly consumed by the population, a public health benefit is expected. Food fortification refers to the addition of micronutrients to processed foods and tends to have less immediate, however a much wider and sustained impact [1].

As defined by the World Health Organization (WHO) and the Food and Agricultural Organization of the United Nations, fortification refers to 'the practice of deliberately increasing the content of an essential micronutrient, that is, vitamins or minerals in a food, irrespective of whether the nutrients were originally in the food before processing or not, so as to provide a health benefit with minimal risk to health. Certain types of fortification are more accurately called enrichment in which micronutrients added to food are those that are lost during processing [2].

Vitamins and minerals are essential for growth and metabolism. The World Health Organization (WHO) estimates that more than 2 billion people are deficient in key vitamins and minerals, particularly vitamin A, iodine, iron and zinc. Most of these affected populations are from developing countries where multiple micronutrient (MMN) deficiencies coexist. The population groups most vulnerable to these micronutrient deficiencies are pregnant and lactating women and young children, given their increased demands. According to recent WHO estimates, globally about 190 million preschool children and 19.1 million pregnant women are vitamin A deficient [3].

Micro-nutrient deficiencies are major public health problems that affect all segments of the population both in developed and developing countries. A third of the global population and majority of Indians suffer from micro-nutrient deficiencies. Six decades ago India had recognized that iodine deficiency resulting in cretinism and goiter, Vitamin A deficiency leading to blindness in young children and iron and folic acid deficiency resulting in anemia with adverse health consequences. The country embarked on intervention programmers to combat these deficiencies through dietary diversification, micro-nutrient supplementation and food fortification [4]. Fortification is one of the most safe, effective and affordable tools to enhance the nutritional value of staple food products such as wheat, maize (corn), rice, vegetable oil and sugar. This process involves adding or replacing essential vitamins and minerals that may have been lost during processing, and has become well recognized for its benefits to public health. In many countries, staple food fortification is now mandatory, a movement that started to gain traction in the 1970s and took off in the early 2000s as more and more countries integrated it into their nutrition strategies. One of the earliest regions to adopt was the Middle East where, in 1978, Saudi Arabia was amongst the first countries to implement wheat flour fortification [5].Food fortification is regarded as one of the safest and most cost-effective strategies to combat micronutrient deficiencies worldwide .which account for 7.3% of the global burden of disease, with iron and vitamin A deficiencies included in the 15 leading causes of global disease burden. The populations most affected by micronutrient deficiencies are pregnant and lactating women and young children, given their increased demands. According to the World Health Organization (WHO) estimates every second pregnant woman and 40% of preschool children in the developing countries are anemic [6].

Many factors, including genetic make-up, dietary habits, lifestyle and the environment, influence a person's health status. Over the past decade dietary inadequacies of key vitamins and minerals have emerged as the most widespread and devastating nutritional deficiencies in the world. Vitamin A Deficiency (VAD), especially sub-clinical deficiency, affects about 285 million children under five years of age globally. An estimated two billion people are affected by Iron Deficiency Anaemia (IDA), with three point six billion being iron deficient [6].

Micronutrient (MN) deficiencies cause a considerable burden of disease for children in many countries. Dairy products or cereals are an important food component during adolescence. Fortification of dairy products or cereals with MN may be an effective strategy to overcome MN deficiencies, but their specific impact on health in this age group is poorly documented [7].

The main role of a fortifying food is to fill nutritional, sensory, biological, and physical gaps. Food-to-food fortification usually provides energy, proteins, fat, fiber, carbohydrates, phosphorus, iron, zinc, potassium, manganese, sodium, calcium, and vitamin C

B. Objectives of the Review

1) General Objective of the Study

The main objective of this study was to investigate micronutrient fortification of food and its impacts on human health.

2) Specific Objectives of the Study

- To distinguish the type of disease which affects the human being by lack of micro nutrients fortification
- To study micro nutrients fortification impacts on age difference.
- To list the types of fortified food.

II. Review of Literature

A. Historical trends and impacts of food fortification

For fixing the iodine deficiency that caused goiter which happened early in the 20th century, public health departments across several countries opted for the first time to food fortification. Indeed, the first fortified food was the iodized salt used to prevent goiter that was introduced in Switzerland and Michigan (United States) in 1923 and1924, respectively. In the same period, many vitamins were isolated and their molecular structures elucidated. As a result, it was possible to produce vitamins for fortifying foods at a large scale [9]. Many children worldwide suffer from nutritional deficiencies which can negatively affect their physical and mental development and increase susceptibility to infections. Moreover, undernutrition amplifies the effect of every disease including measles and malaria. Under nutrition (53%) causes as much mortality of children younger than 5 years via diseases like diarrhea (61%), malaria (57%), pneumonia (52%), and measles (45%; Black, Morris [10]

B. Global challenges of food fortification

1) Socioeconomic factors hindering the practice of food fortification

The major challenges of developing countries regarding food fortification rely on the lack of industrial concentration and socioeconomically large segments of levels of the population cannot afford expensive foods [14] .Major challenges to local-scale fortification programs include the initial cost of the mixing equipment, the price of the premix, achieving and maintaining an adequate standard of quality control, and sustaining monitoring and distribution systems.

2) Technical limitations to the practice of food fortification

Technical fortification challenges rely on (a) no appropriateness of fortification causing nutrients' loss, (b) sunlight exposure of fortified foods by retailers, (c) no regular monitoring and unreliable quality control procedures by companies. The most important challenge is to ensure a regulatory monitoring that aims at meeting fortified foods to national fortification standards [15]. Governments in developing countries may not have the resources to effectively monitor compliance, especially when there are many small processing companies operating. As [16] showed, financial inputs for monitoring have a proportional significant effect on the effectiveness of detection and enforcement of noncompliant and under fortified products.

3) Communication factors limiting the practice of food fortification

Apart from the socioeconomically and technical challenges, efforts must be done to inform consumers about the existence and importance of fortified foods for their well being [17]. Indeed, media are the most important source of nutrition information and fortification awareness. However, reliable information about food fortification is not widely available for instance some African countries. Under those circumstances, no fortified food has a price advantage because of the absence of a mandatory provision and low levels of awareness on the benefits of fortification.

4) From classical food fortification to food-to- food fortification

The unbalanced accessibility to staple foods is a major limit for poor populations who are actually the ones at the highest risk of micronutrient deficiency, to benefit of fortified foods [18]. It is then important to find a technique that uses the fortificant with a highly accessible (i.e., financially and physically) vehicle, already used by the target population. More and more, the aim of food fortification is to improve people health instead of deficiencies' prevention [19]. Thus, to overcome all these challenges, development of nutritious and cheap foods from locally available foods is important.

C. Practices and benefits of food-to-food fortification

1) Practices and benefits

Food-to-food fortification often uses foods that are available in the area of the target population to enhance nutrient intake. This approach consists of selecting and associating foods (a common staple and a fortifying food) in such a way to optimize the bioavailability of interesting micronutrients to consumers. For example, in Nigeria, ogi, fermented cereal-based dough produced mostly from maize, is fortified with baobab fruit powder (rich in vitamins A, C, E, and F; proteins; fiber; carbohydrates; iron; zinc; calcium; and potassium [20]. And tapioca made from cassava tubers is fortified with soybean flour (carbohydrates, fiber [21].

2) Step by step toward food- to -food fortification

For a successful fortification, the aim and the approach must be clearly defined before beginning the process. Obviously, the first thing to do is the identification of nutrients that lack and need to be provided. Then, the most appropriate fortificant has to be identified considering the food habits of the target population and [22] a vehicle food should meet four main features:(a) Its consumption must be common to a large population including the most vulnerable one, (b) its consumption must be regular in consistent quantity, (c) it should be centrally processed and (d) it must allow a nutrient premix to be added relatively easily using low-cost technology ,and in such away so as to ensure an even distribution within batches of the product [23]. When using the food-to-food approach, some agents can be added to improve its sensory properties [24].The step at which the fortificants added to the vehicle also impacts the physical properties of the fortified food. For example, in the case of gari fortified with soybean flour, the soybean flour is added to the gari before or after toasting [25]. Fortificant may also be added to some fermented food vehicle before or after fermentation.

D. Types of Food Fortification

Food fortification is "the practice of deliberately increasing the content of an essential micro-nutrient (vitamins or minerals) in a food stuff so as to improve the nutritional quality of the food supply and to provide a public health benefit with minimal risk to health[2]. The terms 'food enrichment' and 'replacement fortification' refer to the addition of micro-nutrients which are lost during processing of a food e.g., vitamin A from milk during preparation of low-fat milk. There are three major categories of food fortification: (a) fortification as a public health intervention to bridge the gap in nutrient intake across population groups; (b) targeted food fortification aimed at bridging the nutrient gaps in specific "at risk" population groups with nutrient deficiencies and (c) market driven fortification aimed at increasing product appeal without nutritional rationale.

E. *Flour fortification*

Flourwheat and maize, primarily is one of the most widely distributed and consumed staple food products. In fact, more than 600 million metric tons of wheat and maize flours are milled annually, and consumed as noodles, breads, pasta, and other flour products worldwide [26]. Wheat and maize flour are easily fortified with a wide range of micronutrients, meaning that there is huge potential for flour products to substantially improve global public health [27].

This is particularly the case in the Middle East and Africa, which have benefited from support from the public sector, including the World Health Organization (WHO) and NGOs such as Nutrition International (NI) [28].In fact, there are now 87 countries worldwide where it is mandatory to fortify at least one industrially milled cereal grain, such as maize or wheat. Of these, 86 countries fortify wheat flour alone, or in combination with other grains, suggesting that there is significant opportunity for the food industry and governments to address global malnutrition with this staple food product.

Fig. 1: Flour fortification

Fig. 2: Rice fortification

F. *Sugar fortification*

Although diets high in sugar have come into question over their impact on human health, sugar continues to be a widely consumed staple food for millions of individuals around the world. In countries that have mandated its fortification, sugar has proven to be one of the most cost-effective and safe food-based interventions to combat and control deficiencies, particularly in vitamin A. Conventional sugar fortification technology uses vitamin A beadlets that adhere to sugar crystals with the help of oil [28].

G. *Vegetable oils and margarine*

Oils and fats are key components of the human diet across the world, and provide energy, access to fat-soluble vitamins (vitamins A, D and E) and the essential fatty acids that are important for optimal growth and development. The consumption of vegetable oils, such as olive, palm and sunflower, is high throughout the world and continues to increase, particularly in developing countries and low socio-economic groups. These oils can also be fortified with fat-soluble vitamins to increase their nutritional offering, and become a richer source of vitamins A, D and E[29].

H. *Rice fortification*

Rice is the primary staple food crop of approximately half of the global population. It provides more than a fifth of the world's food calories and is a major food product, especially in Asia, where individuals consume around 150kg of milled rice per person per year. However, most of the nutritional value of rice is lost during milling of the kernels, meaning that it is not a rich source of the essential vitamins and minerals. In fact, hidden hunger is widespread in most countries that consume high levels of rice; even if its residents are consuming enough to address physical hunger requirements.

I. *Staple food fortification*

Fortification is one of the most safe, effective and affordable tools to enhance the nutritional value of staple food products such as wheat, maize (corn), rice, vegetable oil and sugar. This process involves adding or replacing essential vitamins and minerals that may have been lost during processing, and has become well recognized for its benefits to public health. In many countries, staple food fortification is now mandatory, a movement that started to gain traction in the 1970s and took off in the early 2000s as more and more countries integrated it into their nutrition strategies. One of the earliest regions to adopt was the Middle East where, in 1978, Saudi Arabia was amongst the first countries to implement wheat flour fortification [30].

J. Public Health Food Fortification

Involves identifying micro-nutrient deficiencies of public health importance and evolving and evaluating appropriate technologies for fortification of widely consumed food stuffs with these micro-nutrients. Food stuff that are to be fortified for public health intervention and the amount(s) of the nutrient(s) used for fortification should be chosen with care because the product may be widely used by large segments of population, who may continue to take the fortified food for long periods of time without adequate monitoring, supervision or evaluation. Initiating public health food fortification programmers is a long and sometimes very tedious process.

The current consumption levels of the highest consumption group and the gap between total intake in this group and the Tolerable Upper Limit (TUL) (Fig.3)

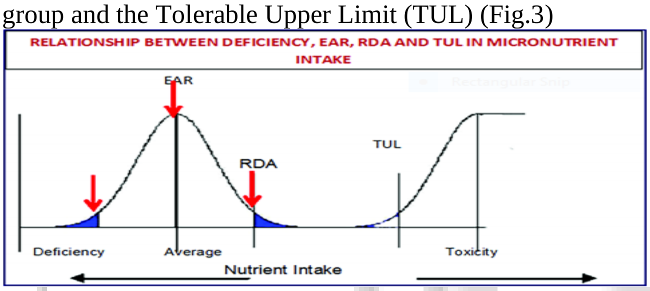

Fig. 3: Relationship between Estimated Average Requirements (EAR), Recommended Dietary Allowance (RDA) Tolerable Upper Limit (TUL). (REFERENCE)

A major public health problem due to micronutrient deficiency, across all segments of the population, which cannot be tackled through a food based approach. Adequate production, transport and marketing of the fortified food should be ensured before considering mandatory fortification.

K. 2.8 Fortification of Iodized Salt with Iron to Combat Anemia

Prevalence of anemia in India is the highest in the world (Fig. 6). The prevalence of anaemia is high, not only among under-nourished poor persons but also in normal and over-nourished individuals from middle and upper incomehouseholds. Low dietary intake of iron and folate are the major factors responsible for iron deficiency and folate deficiency and anaemia. In the last two decades there has been an increase in the reported prevalence of vitamin B_{12} deficiency as well. Given that iron deficiency is so wide spread, attempts have been made to fortify the universally consumed salt with iron. Salt also has the advantage that excessive consumption is not possible [31].

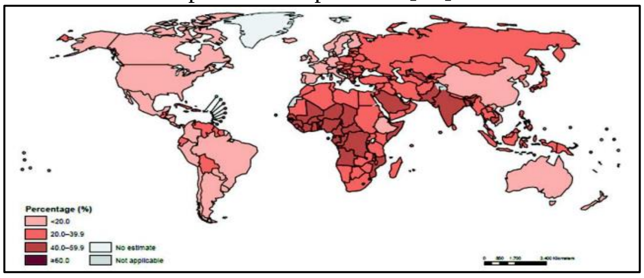

Fig. 4: Worldwide prevalence of anaemia in women aged 15-49 years (WHO 2011)

L. Adverse Consequences of Excessive Intake of Iron

In the last decade, potential adverse health consequences of excessive intake of iron have been documented. The difference between iron requirement in Indians (17 mg/day in men, 38 mg/day in pregnant women) and the tolerable upper limit of iron (TUL 45 mg/day) is low. If some segments of population who are currently consuming adequate iron and also begin to consume multiple food items that are fortified with iron, it is possible that TUL for iron may be exceeded. Experience with iron and folic acid (IFA) supplementation shows that minor gastrointestinal side effects are initially seen in 10% of persons who received iron supplements and because of this coverage under the programme was low. A similar situation can arise with the use of multiple food stuffs fortified with iron[4].

M. 2.9. Conceptual framework

In a study, the impact of micronutrient fortification strategies were analyzed- single, dual or multiple - on various outcomes shown as conceptual framework (Figure 7). These micronutrients were administered through one of the three food vehicles (staples, condiments or processed foods) to reach the population targeted. They have focused on a prior defined population groups of infants, children and adolescents under 18 years of age. The outcomes analyzed were broadly categorized into biochemical indicators, hematologic markers, anthropometric indicators, pregnancy outcomes, and relevant morbidity and mortality [3]. From the outcome of their study it has been concluded that

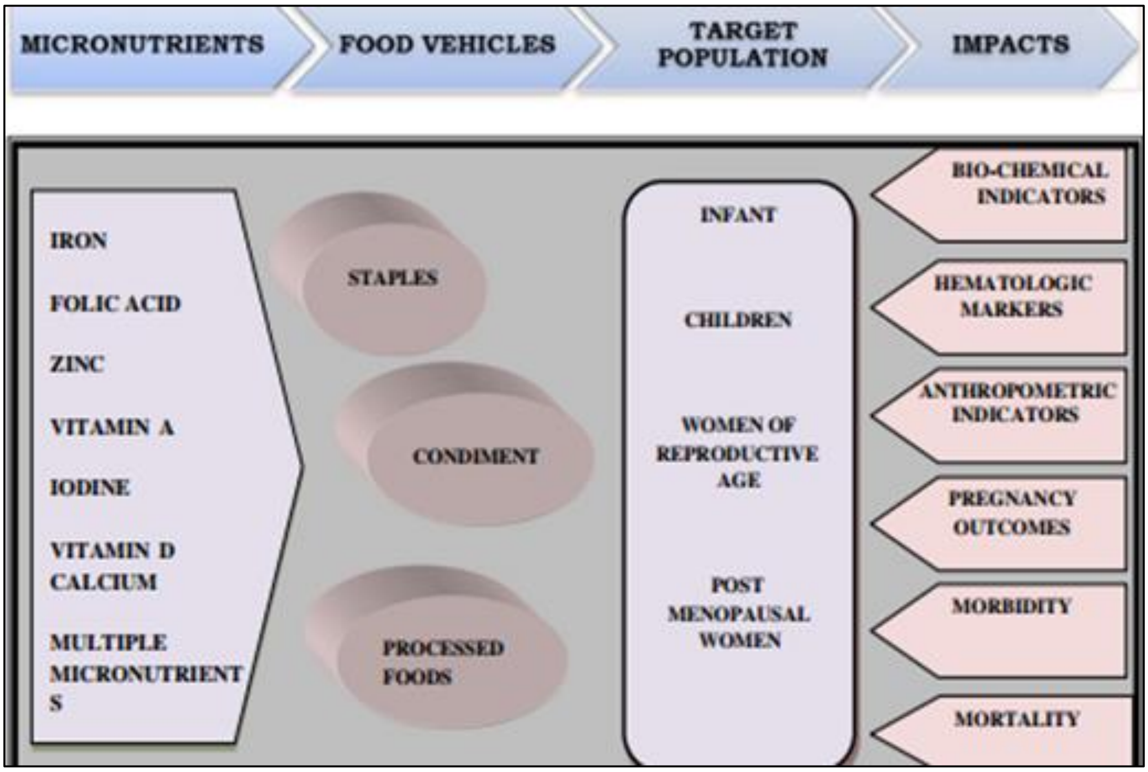

Fig. 5: Conceptual framework

III. Agricultural Interventions for Food Fortification

A. Bio fortification

Bio fortification is the development and dissemination of staple crop varieties that have been enhanced with micronutrients using plant breeding techniques. Naturally occurring variation exists in the germplasm of wheat, which provides options for incorporating higher levels of iron, zinc and β-carotene into wheat grains [32]. In1997-1998, the International Maize and Wheat Improvement Center in Mexico identified several wheat varieties with 25% to 30% higher grain and zinc concentrations than known varieties. Wild relatives of wheat have been found to contain a source of the highest iron and zinc concentration in the grains, although these accessions are often low yielding and have poor grain quality. In such cases, backcrossing to breed varieties would enhance the grain production and quality [33]. To date, bio fortified wheat seed is not available for consumption. However, other nutrient-rich crops, such as vitamin A-rich orange sweet potato, maize and cassava, and iron-rich beans are being planted and consumed by 400,000 farming families in Africa. Iron-rich pearl millet has also reached 30,000 Indian farming families. All bio fortified varieties of staple food crops currently being tested by Harvest Plus (wheat, rice, maize, pearl millet, sweet potatoes, beans and cassava) have been developed through conventional breeding methods and therefore technology of genetic engineering has not been used.

Crop Season	Available seed (tons)	Area planted for seed multiplication (acres)	Quantity of seed produced (tons)
2015-2016	1.0	25	30
2016-2017	30.0	600	720
2017-2018	720.0	14,400	17,280
2018-2019	17,280	345,600	414,720
2019-2020	414,720	Sufficient to plant 8.0 million acres	

Table 1: Seed multiplication scheme for bio fortified wheat variety.
Source: Harvest plus Pakistan

The achievement of bio fortification of staple crops in Africa has been successfully demonstrated, while breeding programmers are underway in several countries, including Pakistan, for genetically improving staple food crops. Although bio fortification is initially capital intensive and time consuming to reach the delivery stage, once it is achieved it is highly cost-effective and can be delivered on a large scale equitably. However, the degree to which bio fortification will be accepted and adopted in Pakistan is still unclear. Bio fortified wheat does not differ in appearance or taste from regular wheat varieties, but farmers will still need to be convinced to purchase the bio fortified wheat seed.

B. Fortification of edible oil with vitamin A

Strong programmatic evidence for the effect of fortifying staple foods with vitamin A comes from Central America, where sugar fortification has been implemented widely in several countries for several decades, beginning with Guatemala. An evaluation of the initial Guatemala programme showed that it was associated with a dramatic reduction in the prevalence of vitamin A deficiency among pre-school-aged children [34]. With respect to the vitamin A fortification of oil and oil products, a large and significant reduction in vitamin A deficiency prevalence was shown in an efficacy trial among pre-school-aged children in the

Philippines consuming fortified margarine daily over a period of six months [35].

C. Multiple Micro-nutrient Fortification

It is well documented that the diets of poorer segments of our population might be deficient in many micronutrients and several micro-nutrient deficiencies coexist in vulnerable segments of the population. In view of this, there have been efforts to fortify a variety of food stuffs with multiple micro-nutrients. In addition, micro-nutrient powders which could be added to home food prior to consumption have also been investigated [37]. A systematic review of these studies suggests that, though there may be some improvement in individual nutrient levels as shown by biochemical parameters after several months of consumption of fortified foods, such fortification may not reduce multiple micro-nutrient deficiencies, and there were no substantial health benefits [38]. In segments of the population who have adequate intake of one or more nutrients from food, the consumption of multiple food stuffs fortified with multiple nutrients, may result in a higher than required intake of some nutrients. Excessive intake of nutrients imbalance of intake between nutrients due to multiple micro-nutrient fortification of multiple food stuffs may have adverse health consequences.

In many countries, government leaders have established food fortification programs as one strategy to improve the nutrition status of their populations. To facilitate widespread coverage of adequately fortified foods, these leaders often enact legislation that requires food manufacturers to fortify their products with clearly defined levels of specific micronutrients.

IV. Conclusion

The best way to prevent micronutrient malnutrition is to ensure consumption of a balanced diet that is adequate in every nutrient. Studies on fortification of foods have shown promising results in the control and prevention of micronutrient deficiency among vulnerable populations, especially women and children. Food fortification is necessary for developed and developing countries to ensure essential nutrients in processed foods, improving their suitability for human nutrition. Micro-nutrient deficiencies, especially those of iodine, iron, folate, vitamin B_{12}, vitamin A and vitamin D are major public health problems in many segments of the population. Through fortification of appropriate food stuff, it is possible to achieve sustained improvement in the intake of these micro-nutrients and reduction in micro-nutrient deficiencies at the population level.

V. Recommendations

– Community education and promotion campaigns should be implemented in parallel to the primary fortification programs to increase awareness, acceptability and equity.
– Fortification is potentially an effective strategy but evidence from the developing world is scarce and future programs should need to assess the direct impact of fortification on morbidity and mortality.
– Fortification, though promising, is not the only answer to the global widespread nutritional deficiencies. A mix of many food-based approaches is needed to tackle under nutrition, especially in developing countries.

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