Micronutrient Deficiencies in the Developing World: An Evaluation of Delivery Methods

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Abstract— Malnutrition is a serious problem in developing countries, particularly among children under five and women of childbearing age. Expectant and nursing mothers are especially vulnerable to micronutrient deficiencies. Effects of micronutrient deficiencies such as weakened immune systems, overall morbidity, and stunted childhood growth are reversible in the critical age group of 0 to 5. Providing children with the essential nutrients lacking in their diets during infancy is essential as it can lead to long-lasting health benefits. Many solutions have been researched and implemented to increase micronutrient intake in the diets of people in developing nations. Implementation of the solutions have ranged from national policies such as the mandatory fortification of certain food products and educating rural communities about improving nutrition levels, to the in-home application of micronutrient fortification powders. The spectrum of solutions has strengths and weaknesses; however, few, if any solutions have been successful at decreasing nutrient deficiencies on a macro scale. This article presents a comprehensive review of academic studies detailing different methods of delivering nutrients to individuals in developing countries. The results of this review are categorized and synthesized into a framework describing the approach, range and success of different strategies to help vulnerable groups meet their micronutrient needs. Understanding this framework will help in identifying gaps in current efforts to address micronutrient deficiencies and improve the current integration techniques into settings with insufficient resources to satisfy dietary needs of populations.

Keywords—nutrition; global health; micronutrient deficiencies; agronomy; animal source foods; fortification; supplementation

I. INTRODUCTION

Due to the lack of sustainable solutions, as of 2016, 2 billion people, about one-third of the world’s population, are iron deficient, and 250 million school aged children are vitamin A deficient [1]. Iron deficiencies are the leading cause of anemia, and stunted childhood growth are reversible in the critical age group of 0 to 5. Providing children with the essential nutrients lacking in their diets during infancy is essential as it can lead to long-lasting health benefits. Many solutions have been researched and implemented to increase micronutrient intake in the diets of people in developing nations. Implementation of the solutions have ranged from national policies such as the mandatory fortification of certain food products and educating rural communities about improving nutrition levels, to the in-home application of micronutrient fortification powders. The spectrum of solutions has strengths and weaknesses; however, few, if any solutions have been successful at decreasing nutrient deficiencies on a macro scale. This article presents a comprehensive review of academic studies detailing different methods of delivering nutrients to individuals in developing countries. The results of this review are categorized and synthesized into a framework describing the approach, range and success of different strategies to help vulnerable groups meet their micronutrient needs. Understanding this framework will help in identifying gaps in current efforts to address micronutrient deficiencies and improve the current integration techniques into settings with insufficient resources to satisfy dietary needs of populations.

From the 1930s to 1980s, protein and carbohydrates were the primary focus of efforts to reduce malnutrition as nutrition deficiencies were linked to a lack of energy [6]. However, studies conducted in the 1980s revealed that while populations in the developing world received adequate protein and carbohydrates, they were deficient in micronutrients [7] [8] [9]. Consequently, the focus of efforts to reduce malnutrition shifted to vitamin A, iodine, iron, and zinc, the most commonly recognized micronutrients lacking in the diets of individuals in developing countries. Most approaches implemented from the 1980s to the present day have proven to be successful in specific regions for short intervals of time. However, few, if any have had long lasting impacts on a scale widespread as the deficiencies themselves. The three primary approaches to alleviate micronutrient malnutrition are rooted in agriculture, nutrient fortification, and nutrient supplementation. Agriculture-based approaches involve enhancing soil fertility through agronomy, dietary diversification, or the promotion of animal source foods (ASFs). Fortification-based approaches involve deliberately increasing the micronutrient content of foods through biofortification (genetically modifying crops) or mass fortification (enhancing the micronutrient content of food staples such as salt). Supplementation-based approaches deliver additives to food to enhance its nutritional content. All three approaches have had respective successes and failures; however, no single approach has proven to be a universal remedy in championing a solution to micronutrient deficiencies.
supplementation-based approaches that have been used to treat micronutrient deficiencies in developing countries. The strengths and weaknesses of the different approaches are juxtaposed to reveal systematic gaps and opportunities in the way micronutrient deficiencies are currently being combatted. This article aims to inform development professionals interested in creating nutrition solutions that are effective and sustainable. Each section within the review individually explains the three focal approaches’ methods, strengths, and weaknesses. After an evaluation of the approaches, the culminating section provides insight on which approach proves to be the most feasible for the developing world through a comparative analysis of the beneficial aspects of all three.

II. AGRICULTURE-BASED APPROACHES

Nearly all micronutrients are consumed through food. Therefore, agriculture-based approaches aim to enhance micronutrient intake through the enhancement of the soil surrounding plants (agronomy), the selection of crops based on nutritional value (crop rotations and cultivar selections), and the promotion of ASFs. Crop rotations, cultivar selections, and ASFs involve a diversification of diets of individuals in the developing world, allowing for a higher micronutrient intake with a lower consumption, which proves to be cost-effective for consumers.

A. Agronomy

Approaches involving agronomy—the science of soil management—primarily employ fertilizers in order to increase the nutrient uptake in plants [11]. A popular approach is to fortify fertilizers with macronutrients that act as carrier molecules for micronutrients by facilitating their absorption through the roots. An increased absorption of micronutrients by plants leads to a higher micronutrient density in crops, which can potentially increase the micronutrient intake in diets of individuals in the developing world. Fortified fertilizers can also be applied at the foliar level by spraying liquid fertilizer on the leaves. Fortifying traditional fertilizers has a high acceptability rate, as shown in the Anatolia region in Turkey [12]. Furthermore, they have also proven to increase the micronutrient density in crops. However, fortified fertilizers must be tailored to specific regions due to varying soil types, which inhibits a large-scale implementation strategy. Implementation must also be coupled with extensive education programs, requiring resources from government authorities. Further research must also be conducted to establish a link between the application of fortified fertilizers and improved intake of micronutrients [11]. Until then, industrial efforts to ameliorate the micronutrient density have yet to be successfully defined as an approach to ameliorate micronutrient malnutrition.

Another approach researched which employs the same path of increasing micronutrient density in crops to alleviate malnutrition is the use of biofertilizers—microorganisms in symbiotic relationships with certain plants which increase the micronutrients absorbed by the plant. However, the focus of approaches involving biofertilizers is usually on delivering macronutrients and increasing crop yields, sometimes at the expense of micronutrient absorption. For example, Azolla, a biofertilizer used to increase nitrogen delivery in crops like O. sativa (rice), precipitates zinc into an insoluble compound that is unable to be absorbed by plants [13]. Further research is needed that investigates how biofertilizers can balance the delivery of macronutrients that increase crop yields and the delivery of micronutrients required for human nutrition. Once the research culminates in positive outcomes, implementation strategies can be discussed, which introduce further challenges due to the extensive education requirements, the cost of initial research, and the variety of soil types which restricts large-scale implementation.

B. Crop Rotations and Cultivar Selections

Crop rotations involve changing the crops grown on soil to ensure that the soil’s chemical and physical fertility are retained [11]. For instance, a rotation of T. aestivum (wheat) and O. sativa achieved an increase in soil concentrations of iron, copper, manganese, and zinc [14]. This increases the availability of micronutrients for absorption by crops. On the other hand, cultivar selections involve selecting which crops to grow based on the higher micronutrient content in grain. In a trial conducted on Prince Edward Island, legumes such as G. max (soybean) had almost three times the iron concentration of H. vulgare (barley), prompting the promotion of growing more legumes [15]. Coupling crop rotations and cultivar selections ensures that the soil retain optimal concentrations of micronutrients and that the crops grown will have higher in-grain micronutrient concentrations.

Crop rotations and cultivar selections promote a diversification of diets of individuals in the developing world, a micronutrient deficiency solution which requires minimal intake of food. Furthermore, since no infrastructure is required to implement rotations and cultivar selections, it is cost-effective for farmers to initiate in rural and peri-urban areas. However, education on the approaches must be given to farmers as different regions in the world have different soil types and requirements. Another important challenge to consider is the lack of research linking the rotation of crops to human nutrition, as crop rotations are usually employed to increase the yield of crops, rather than, their micronutrient density. While the education given to farmers in regards to cultivar selections can be thorough, the sustainability of the selections depends largely on how the recommended crops align with the cultures of the region. For instance, it was recommended that farmers in southern India grow T. aestivum rather than O. sativa due to the former’s higher zinc availability [16]. However, since O. sativa is a staple food, the cultivar selection was not successful as the population was not willing to switch from one staple food to another. Thus, researchers investigating the diversification of diets characteristic of individuals in developing countries must take into account the staple food of the region as well as the rigidity of individuals’ diets.

C. Animal Source Foods

While cultivar selections involve enhancing plant source foods for an increase in micronutrient intake, the coupling of plant source foods with ASFs increases the nutritional quality of diets without increasing the quantity of food eaten [17]. For instance, milk added to a Kenyan biscuit, which provides only 20% of the daily energy requirement for a child, fulfills 38% of the calcium, vitamin B12, and riboflavin daily requirements. ASF approaches have also implemented local fisheries and coupons...
for ASFs such as meat and eggs [18]. These approaches are accessible to rural as well as peri-urban areas. In terms of dietary diversification, ASFs have been more successful than enhancing plant source foods.

ASF-based approaches also help farmers in countries such as Thailand by reducing the oversupply of ASFs and increasing their standard of living [18]. However, infrastructure must be set up in order to establish a sustainable link to the supply, distribution, and consumption of ASFs, which is expensive to maintain [19]. Thus, the promotion of ASFs must be implemented in conjunction with either government programs such as the National Milk Campaign Board in Thailand and the VAC program in Vietnam, or non-governmental organizations, such as the Participatory Livestock Development Project headlined by the Asian Development Bank [20]. The large implementation scope for the promotion of ASFs also requires time, which proves ASFs to be unfit approaches in severe circumstances where micronutrient addition needs to be immediate.

III. FORTIFICATION-BASED APPROACHES

Fortification involves the deliberate increase of the micronutrient content of common foods through either biofortification or mass fortification approaches. Biofortification involves increasing either the micronutrient concentration or the bioavailability of micronutrients in crops through genetics. The bioavailability of micronutrients refers to the micronutrient amount available for absorption in the body during metabolism. Mass fortification (or industrial fortification) involves increasing the micronutrient composition in industrially-processed foods such as cereals and milk. Since fortification-based approaches focus on both the concentration and the bioavailability of micronutrients in food, the micronutrient absorption rate is higher than that of agriculture-based approaches.

A. Biofortification

Biofortification approaches involve enhancing the genetic traits of plants to increase the concentration and bioavailability of micronutrients in grain. A popular biofortification approach to alleviate micronutrient malnourishment is genetically modifying staple foods based on traits favorable to consumers [21]. Genetically modified crops such as BioCassava Plus and Golden Rice have been introduced in Sub-Saharan African markets to increase the intake of micronutrients with enhanced bioavailabilities [22] [23]. Research has also been conducted on selecting physical genetic traits for crops based on consumer preference, such as the introduction of orange-fleshed sweet potatoes—a rich source for vitamin A [24]. Sub-Saharan African populations prefer a higher dry mass (the amount of solid mass in the vegetable) as larger servings are available after the water in the sweet potatoes was boiled out, thus increasing the availability of micronutrients and the affordability to the consumer. The BioCassava Plus program currently provides genetically modified cassava leaves—a staple in much of Sub-Saharan Africa—with enhanced vitamin A, iron, and zinc concentrations. A different approach to the biofortification of crops is through facilitators—substances which facilitate the absorption of micronutrients during metabolism [25]. For instance, diets in the developing world include a high amount of phytic acid, which inhibits iron absorption [26] [27]. Thus, approaches to increase iron absorption have also fortified crops with vitamin C, a facilitator which can increase iron absorption in the body.

The implementation of genetically modified crops is unfavorable since the intended consumer base does not have to significantly change their dietary regimen (their staple foods) and their purchasing habits (the markets they usually visit). However, implementation on a wide scale is hindered by the lack of access to rural farmers who harvest crops for a community rather than purchase crops at a market [19]. The initial investment on research processes such as TILLING (Targeting Induced Local Lesions in Genomes), which determines what crops and traits are suitable for breeding, also render the implementation of biofortification undesirable because an investor must be found [28]. After the research has been conducted, the approvals required to implement biofortified crops renders the approach incompatible with severe micronutrient deficiencies which require immediate solutions. While the implementation of biofortification has its strengths and weaknesses, the effectiveness of the approach to increase micronutrient intake in diets of individuals requires further, long-term research. Preliminary results have shown an increased absorption of micronutrients such as iron, but the long-term sustainability of programs has yet to be evaluated [24]. Establishing this link will facilitate the approval and initial investment phases of biofortification approaches.

B. Mass fortification

Mass fortification approaches increase the nutritional quality of commonly-eaten processed foods such as salt and milk powders. The scale of mass fortification requires either large non-governmental organizations (NGOs) or the government itself to intervene. NGOs introduce fortified products which are regulated internally. In Sub-Saharan African markets, milk powders such as Guigoz for children are fortified with vitamin C in order to facilitate iron absorption [29]. Furthermore, cooking oils fortified with vitamin A such as Enrichi have been introduced in West African markets by Helen Keller International with 70% of the population having access to the fortified oil [30]. The distribution channels previously established by NGOs can be employed to distribute the fortified products, which increases the affordability of the product to the investors.

Furthermore, the introduction of these fortified products into peri-urban markets requires a relatively lower amount of education to the target audiences in comparison to agriculture-based approaches. However, the extensive infrastructure to link the production, distribution, and consumption of fortified products must be maintained in order to ensure that the consumers receive a constant supply of micronutrients [19]. While NGO distribution networks in peri-urban markets have been established, the distribution of fortified products to rural areas presents a challenge. Furthermore, due to the initial investments on research and regulation, the affordability of the product to the consumer decreases. Thus the effectiveness of the product is dependent on the purchasing power of the consumer base, especially in the case of rural populations who depend heavily on agriculture as a primary source of employment. Once
these obstacles are overcome, implementing mass fortification can potentially be a desirable intermediate approach to alleviate micronutrient malnutrition.

Government interventions approaches usually involve a nation-wide fortification policy, such as the universal salt iodization policy in India [31]. In various states, the prevalence of goiters (a side effect of an iodine deficiency) has been reduced significantly in certain areas [5]. Since the fortified product in question is salt, a staple food, the consumption of the iodized salt was accepted by consumers due to the affordability, ease of access, and the lack of significant change in their dietary habits. Similar to NGOs, the government employs the same distribution channels established by oligopolies in the market. The established brand name, consumer base, and market share facilitate the nation-wide implementation of the policy. However, government policies usually mandate the fortification of one micronutrient instead of a spread of micronutrients due to the side-effects on the physical quality of the product. In India, when the fortification of iodized salt with iron was researched, the salt had turned orange due to moisture present in the salt [25] [32], which dissuaded consumers from purchasing the fortified product. Another issue with government-mandated policies is the regulation of the fortified products in the market. While most companies comply with fortification guidelines, the lack of constant regulation leads to vendors selling non-fortified, more cost-effective products to rural populations [31]. The uneven distribution of the fortified products can also lead to a non-uniform success rate for nation-wide policies, highlighting the logistical challenges of large scale programs like mass fortification [5]. Challenges must be addressed prior to implementation, with the regulation of the policy requiring time, rendering mass fortification inapt for immediate action.

IV. SUPPLEMENTATION-BASED APPROACHES

Supplementation-based approaches provide dietary supplements such as micronutrient powders (MNPs) and nutritious pastes which are taken in conjunction with regular meals, thus supplements do not enhance commonly-eaten foods, but rather, the meal consumed by an individual [6] [10]. Supplementation-based approaches presented here can be divided into two stages: short-term research trials and sustainable long-term ventures.

Trials conducted to evaluate the effectiveness of MNPs containing iron and vitamin A on school-going children in Ghana [33], China [34], and Indonesia [35] showed decreasing mortality rates. In China, a decrease of approximately 34% was observed. Furthermore, children given supplements with multiple micronutrients had increased growth rates in comparison to children supplemented with just one or two micronutrients. MNPs optimized with facilitators for micronutrient absorption such as vitamin C and phytase have increased iron absorption fivefold and increased the BMIs of wasted adults (BMI<18.5) [36] [37]. The link between the implementation of dietary supplementation and improved health has been established, but these results are relevant primarily in trials. They do not account for the dietary supplements being sold on the market instead of being given to the target audiences. Thus, they do not establish a daily dietary regimen through which micronutrient malnourishment can be alleviated. While dietary regimens are recommended by researchers during the trial, the participants’ lack of adherence causes the results of the trials to be inconsistent [38]. For instance, while supplementation with vitamin A caused a decrease in morbidity levels in Chinese children, Ghanaian children did not exhibit the same health benefits [33]. Establishing a daily dietary regimen is one of the various specs which must be addressed prior to implementation on a larger scale. Another potential side-effect of supplementation is diarrhea, which can hinder the consumer’s willingness to consume the product. Conducting more trials on the side effects of supplementation based will be useful in establishing more sustainable products.

Since trials have provided positive results of dietary supplements, ventures involving the distribution of supplements have been undertaken in developing countries. In 2008, Sight and Life began the MixMe initiative at the Kakuma Refugee Kamp in Kenya, providing MNPs with vitamin A, iron, iodine, and zinc to the refugees [38]. As of 2013, MixMe has spread its distribution to 90 million per annum, a sign of acceptance as well as use of the MNPs [39]. Sprinkles, another MNP, was introduced in countries with limited access to food such as Vietnam and Bangladesh [40]. In Cambodia, a trial on the effectiveness of Sprinkles revealed that it had reduced anemia in children by 20.6% on average [41]. Along with other supplements such as Nutributter, Sprinkles helps child growth and reduction of child mortality [33]. The cost-effectiveness of a Sprinkles sachet and the ease of access to consumers has allowed the MNP to reach sustainability. While Sprinkles has established a business model to sustain the distribution of the MNP, MixMe’s distribution is still dependent on funds which can falter, as evident by the interruption of supplementation programs on the Thailand-Burma border [42]. Thus, a source of revenue must be established in order ensure that the ventures attain sustainability. Another issue which must be addressed during research is the adherence to recommended dietary regimens, which determine the effectiveness of supplements. The purchasing power of the consumer base is an important factor in determining whether the target audiences will receive daily doses. Thus, the pricing of the product must be scaled to the consumer base’s income. This proves difficult when the cost of setting up the infrastructure for the supplement’s production and distribution is high, especially since the distribution network must be set up for the new supplement through extensive education about the product and its benefits [19]. Supplementation-based approaches are apt for immediate, severe micronutrient deficiencies; however, the challenges presented make it difficult for them to achieve sustainability in the long run.

V. DISCUSSION

A. Scale

Each of the three approaches have been tested at a wide range of scales varying from research to government implementation, all with different levels of success. Agricultural approaches often require time and extensive education programs, so they are better implemented in situations where immediacy is not required. Rural regions prove to be the most sustainable for agricultural approaches since crops are a main source of food. Agricultural approaches can be coupled with biofortification as
a long-term approach since distributing biofortified seeds to farmers does not require extensive education; however, the distribution channels to rural farmers must be established, which requires infrastructure and funding. Furthermore, biofortified crops require a set of approvals from local authorities before they can be implemented, so the preparation work often offsets the advantages. Mass fortification has worked well due to high acceptability and the scope of integration involved, such as India’s universal salt iodization policy [43]. Mass fortification does require infrastructure and funding, but is more affordable to target audiences since they do not have to buy any additional products. Established distribution channels facilitate mass fortification making the approach accessible and desirable for widespread implementation. Lastly, supplementation approaches are most apt for areas in which immediate action is required. However, extensive infrastructure is necessary and there are challenges involved with building a brand name to educate target audiences.

The scales on which the approaches discussed have been implemented and researched are summarized in Fig. 2. While approaches based on mass fortification and supplementation have been implemented, approaches based on diet diversification (agriculture- and biofortification-based approaches) are still primarily in the research phase. Since dietary diversification is more of a long-term approach to alleviate micronutrient malnourishment, extensive research is required to ensure that the approaches are sustainable, culturally-aligned, and effective.

B. Lifecycle

The advantages and disadvantages of the approaches to alleviate iron, iodine, zinc, and vitamin A deficiencies as explained in the above section are in part due to the varying lifecycle stages of each approach. Agriculture-based approaches, like crop rotation and cultivar selection, are well-established basics of farming that are used across the world not only for increased nutritional content but also to increase crop yields. Chemical and biofertilizers, are similarly used on nearly all farms. The methods of use and the benefits associated with the use of fertilizers are widespread knowledge, but new fertilizers are continually created for specific niches within agriculture, such as the delivery of micronutrients. Fertilizers used to address micronutrient deficiencies are an established way to increase the concentration of micronutrients in plants, but further research must be done to understand if and how these fertilizers affect human micronutrient intake. While supplementation continues to be researched in regards to the exact micronutrients and their respective concentrations, aid organizations and private companies have already developed both supplementation programs and commercially available micronutrient supplements. Supplementation directly and immediately impacts the intended audience’s micronutrient intake and its effect on the prevalence of micronutrient deficiencies is measurable across specific areas in distinct intervals of time. Supplementation programs now work to scale these results so that the approach can reach a more widespread audience in the long term. The major hindrance to the scalability of supplementation is the need for consistent adherence to a dosage regimen. Since the scale for supplementation approaches is usually nation-wide, the funding required for production and distribution is a challenge to overcome when looking for investors.

Mass fortification approaches are an established and successful part of most developed country food processing industries; however, because such approaches require a high level of infrastructure and government involvement, they are difficult to implement in developing countries. Mass fortification is not a viable solution unless proper regulations and distribution channels are in place to process and disseminate the fortified products. Mass fortification is successfully established in areas and countries with high levels of infrastructure for food processing and distribution. Without established food processing programs and dissemination channels, mass fortification has a limited impact on correcting micronutrient deficiencies. Biofortification is an early stage approach to combat micronutrient deficiencies that is still undergoing preliminary testing to fully understand its ability to impact human diets. Research has been conducted on how to ameliorate the bioavailability of micronutrients in various crops, such as the BioCassava Plus program. However, few, if any, initial trials have been conducted studying the acceptance and effectiveness of biofortified crops.

C. Systemic Gaps and Opportunities

The agriculture-, fortification-, and supplementation-based approaches have their respective systemic gaps and opportunities. Agriculture-based approaches have been researched as beneficial practices for micronutrition. However, conclusive studies have not been conducted linking the use of fertilizers, biofertilizers, agricultural practices, and ASFs to improved absorption of micronutrients. A lack of conclusive literature also hinders the implementation of biofortification-based approaches, as much of the literature present discusses the research behind biofortified crops rather than the effects on micronutrient malnourishment. The opportunities involving agriculture-based and biofortification-based approaches entail a diversification of food consumed by the target groups through cultivar selections, animal source foods, and biofortification. The distribution network and infrastructure required to implement the diversification is limited, but the education given to farmers to employ the new approaches must be comprehensive, which requires both time and educators. Thus,
food diversification is a more long-term goal due to the extensive resources required and the wide-spread implementation strategies involved.

Mass fortification-based approaches require fewer education and distribution requirements as they usually employ existing brand names which have their own consumer base and distribution networks. However, the rigorous regulation and research involved while implementing mass fortification-based approaches require extensive infrastructure and a constant source of funding. While fortification policies and products have been implemented in developing nations such as India, their effectiveness have been limited due to the affordability to consumers and the availability of non-fortified and more cost-effective competitive products. Furthermore, due to the scope of implementation involved, mass fortification-based approaches cannot be implemented immediately. The approach suitable for immediate implementation is supplementation-based, as it requires the least amount of approvals from local authorities. However, supplementation-based approaches are not generally designed for longevity as they require a constant source of funding, regulation of micronutrient content, a new distribution network, and education to the target groups. The Sprinkles Global Health Initiative found this opportunity in the short-term and designed their product for longevity to create a multinational initiative present in several developing countries. While their commercial success can be measured through their expansion, the effectiveness of the MNPs must be further studied as the literature evaluating their effects on morbidity and mortality are rather limited, which prevents an accurate analysis of the effectiveness of the product. While supplementation-based approaches fare well in immediate and severe deficiencies, the comprehensive review of the literature recommends dietary diversification as the long-term solution to micronutrient deficiencies, which is best accomplished through approaches which focus on animal source foods and biofortification as they allow consumers to maintain their daily dietary routine. Developing a sustainable model which will couple the two approaches will be a leap in bridging the micronutrient gap in the developing world.

The traits of each approach based on severity of micronutrient deficiencies, education requirements, infrastructure needed, funding, and scale have been summarized into a flowchart in Fig. 3. The flowchart synthesizes the information provided by the sources cited in this article in order that researchers and innovators can gauge which approach is most suitable to their situation. While supplementation-based strategies are most promising in the short-term, severe deficiencies require infrastructure and education prior to implementation. In the long run, approaches which collaborate on agriculture- and biofortification-based approaches work best as they require minimal change in individuals’ diets: they can consume their staple foods. Furthermore, due to women’s interests in horticulture in many developing countries, approaches based in agriculture can provide employment through business-centric farming, which is more self-sustainable in terms of funding.

VI. CONCLUSION

Despite major efforts to alleviate micronutrient malnutrition, there is still a prevalence of micronutrient deficiencies in the developing world. The approaches discussed in this review have their strengths and weaknesses, but few, if any, have proven to be effective long-term solutions. The literature cited recommends combining agricultural efforts with biofortification-based approaches as it increases the micronutrient intake as well as the micronutrient bioavailability. Agriculture-based approaches also provide employment opportunities for women interested in horticulture [44]. Since these women take care of their families and their livestock, they think beyond grain yield in terms of cultivar selection, and the nutritional value of the foods is a key factor in their decisions. Combining the indigenous knowledge with biofortification-based approaches can potentially lead to agriculture-based
approaches which increase the micronutrient intake in individuals in developing nations as well as the cultural acclimation of the approaches.

Few, if any, fortification- and supplementation-based approaches introduced in several developing nations have taken into account the chemical inhibitors and facilitators which influence the absorption of the key micronutrients. Further research must be conducted to produce a guideline on introducing micronutrients into diets of individuals of the developing world while not significantly altering their current diets. Finding a balance between dietary diversification and rigidity of their current diets is essential in order to provide a long-term solution. Several trials have proven to increase micronutrient absorption and the betterment of health in participants from introducing fortified products and dietary supplements. However, few, if any, long-term sustainable business-centric solutions have been implemented at a national level. If a business-centric model employing agriculture- and biofortification-based approaches can be introduced into the developing world, nations can benefit through increased employment, health benefits, and research opportunities.

VII. REFERENCES


