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Current approaches in food fortification for overcoming micronutrient deficiencies

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Abstract: The widespread recognition of the importance of micronutrient deficiencies to global health, and the potential to address such deficiencies relatively cheaply through fortification or supplementation, has led to several efforts to support traditional interventions. The role of food fortification in virtually eliminating micro nutrient deficiency is widely acknowledged and recognized. WHO identifies fortification (micro nutrient intervention) as among the most cost effective of all health interventions, but it requires well developed , efficiently monitored and properly regulated pharmaceutical and food processing sectors. Food fortification would be especially beneficial in conjunction with the farming of increasingly micronutrient-laden foods, biofortification, and ,biotechnology. These various established alternatives to fortification are examined for their potential and their limitations, with particular attention to industrial fortification that would work wonders for the health of India's people.

Key words: Biofortification, Biotechnology, Micronutrient deficiencies, Food fortification

Introduction

The overt effects of micronutrient malnutrition, such as blindness, anemia and goiter, have been known for many centuries. In more recent years, scientific research has revealed that the impact of micronutrient deficiencies (MND) extends far beyond these effects, positioning their elimination as a global priority. Vast populations with MND in developing countries are unable to achieve their full mental and physical potential due to stunted growth, low physical work capacity, reduced IQ and lower resistance to infection. Elimination of these deficiencies is essential not only to improve health but also for sustained economic growth and national development. Micronutrients are required in small quantities and responsible for vital functions of the human body. Logically, they should be addressed easily and on a priority basis. The facts are, however, contrary. As a result, micronutrient malnutrition has been a persistent problem in India, and as the recent data suggest, some forms of micronutrient malnutrition are reaching their peak in the present century.

Magnitude of micronutrient malnutrition: Thirty percent of the world's population is affected by vitamin A, iron or iodine deficiency. About 700 million persons suffer from clinical forms of these deficiencies and another two billion from sub-clinical forms. The intake of micronutrients in daily diet is far from satisfactory and largely less than 50% RDA is consumed by over 70% of Indian population (NNMB and NIN, 2002.). Every day, more than 6,000 children below the age of five die in India. More than half of these deaths are caused by malnutrition-mainly the lack of vitamin A, iron, iodine, zinc and folic acid. About 57% of preschoolers and their mothers have subclinical vitamin A deficiency (WHO, 2007).

Anemia prevalence among children under five years is 69% and among women it is over 55% in a recently concluded national study (National Family Health Survey 2005-2006, International Institute of Population Science: Mumbai, 2007.)

Apart from these three major public health problems, deficiencies of other micronutrients increases the risk of disease and death. IDA affects 60 % of women of reproductive age and is an important cause of maternal mortality. It reduces physical work capacity and productivity in adults and impairs learning ability and scholastic achievement in children. Both iron and iodine deficiencies have a negative impact on psychomotor development of children, which may be permanent if not corrected early in life. Thus micronutrient malnutrition poses a serious threat to national health. (brahmam et al., 2000).

Micronutrient deficiencies and potential interventions: It is now recognized that micronutrient deficiencies are persistent public health problems that require direct intervention during the process of economic development

Combating poor nutrition in India –current approaches in food fortification: India is a country historically plagued by malnutrition. Even today, sixty-four hundred million Indians, 64% of the population of India are chronically malnourished (Kurtz, 2008).Many advances have been made in India over the past several decades. The Green Revolution has been successfully implemented to allow India to produce almost all of the staple grains its people need (Swaminathan, 2002). The problem of malnutrition however, is based in the quality of food instead of the quantity. the industrial fortification of food provides an important tool in the battle against malnutrition and over-nutrition. Through fortification, small quantities of essential micronutrients are added to a food product after harvesting and before it is sold to the consumer. This includes the addition of iodine to salt and the addition of small quantities of iron, zinc, folic acid, and vitamin B to processed grain. Fortification of food is routine practice in industrialized countries (CBHI, 1993), and it would accomplish much for India's urban poor to reduce the incidences of malnutrition.

Supplementation: Periodic provision of supplements (often in the form of tablets) can address deficiencies of micronutrients that are stored in the body, such as VA and iron. The total annual cost of iron tablet supplementation in India to reach 27 million women and 128 million children at risk is only $5.2 million. Furthermore, while certain populations are easy to reach through existing institutions (*e.g.* Schoolchildren through schools), it is often difficult to accomplish full coverage of those most at risk—poor women and very young children. Thus, supplementation has often been most effective when delivered together with other maternal and child health interventions.

Promotion of dietary diversification: Education is an important element in ensuring that improvements in income result in better maternal and child health. However, dietary diversification is constrained by resource availability for poor households and seasonal availability of fruits and vegetables. Increased production of fruits and vegetables for household use reduces resources available for other income-earning or food-production activities. This type of effort is also relatively expensive and difficult to sustain on any large scale (Tontisirin, 2002).

Food fortification -

Background and history of fortification: Nutrient supplementation of foods was mentioned for the first time in the year 400 B.C. by the Persian physician Melanpus, who suggested adding iron filings to wine to increase soldiers' "potency." In 1831 the French physician Boussingault urged adding iodine to salt to prevent goitre. However, it was between the First and Second World Wars (1924-1944) that supplementation was established as a measure either to correct or prevent nutritional deficiencies in populations or to restore nutrients lost during food processing. Thus, during this period the adding of iodine to salt, vitamins A and D to margarine, vitamin D to milk, and vitamins B1, B2, niacin, and iron to flours and bread was established (Darnton-Hill and Nalubola, 2002; Venkatesh *et al*., 2004).

General principles for food fortification: There are a number of general principles that must be considered in introducing a food fortification regime. In 1995, the FAO convened a technical consultation on food fortification, focusing on technology and quality control. The consultation agreed that, ideally, fortified food should:

- Be commonly consumed by the target population
- Have constant consumption patterns with a low risk of excess consumption
- Have good stability during storage
- Be relatively low in cost
- Be centrally processed with minimal stratification of the fortificant
- Have no interaction between the fortificant and the carrier food
- Be contained in most meals, with the availability unrelated to socio-economic status
- Be linked to energy intake.

In addition, the Codex Alimentarius Commission has adopted the General Principles for the Addition of Essential Nutrients to Foods which state:

- The essential nutrient should not result in an adverse effect on the metabolism of any other nutrient
- Addition of essential nutrients should not be used to mislead or deceive the consumer as to the nutritional benefit of the food
- Methods of controlling, measuring and/or enforcing the levels of added essential nutrients in foods should be available
- Food standards, regulations or guidelines for fortification should identify the effectual nutrients which are to be required, and the levels at which they should be present in the food to achieve their intended purpose.

Evaluations revealed that the biologic impact of these interventions was unsatisfactory. Inadequate allocation of funds (10% of the actual needs) necessary to cover the enormous number of beneficiaries was one of the important obstacles. Consequently, the allocation of supplies to different provinces was far short of the requirements (10-30%). As a result of poor orientation, the functionaries were not adhering to the guidelines, leading to woefully inadequate (1-20%) and irregular coverage. There was no proper monitoring or supervision to make midcourse corrections to improve the functioning. The community was not informed of the purpose and details of each intervention. Hence, it did not utilize the resources completely and remained passive recipients. The community was not aware of the dietary approaches to prevent micronutrient disorders owing to absence of nutrition education (Vijayaraghavan, 2000).

Industrial fortification: The marketed supply of a widely consumed staple food can be fortified by adding micronutrients at the processing stage, and historically this is how micronutrient deficiencies have been addressed in the developed world (FAO, 1995). While industrial fortification efforts are becoming more widespread in developing countries, such efforts are limited by their continuing costs and by the imperfect coverage of the target population, particularly the rural poor and young children. Where mandatory, fortification costs are most often borne by food processors, such as flour millers, and they may resist this imposition. Such mandates also may be impossible to enforce where food processing is carried out by many small and widely dispersed firms. Industrial fortification will only apply to marketed supplies and therefore may not reach those among the poor who obtain food outside of commercialized channels. Given these limitations, it is clear that industrial fortification of food cannot provide a complete solution to the problem of micronutrient deficiencies in the medium term. It is in this context that a role emerges for biofortification as a complementary strategy. Currently, food fortification encompasses a broader concept, and might be done for several reasons. The first is to restore nutrients lost during food processing, a process known as enrichment. In this case, the amount of nutrients added is approximately equal to the natural content in the food before processing. A second reason is to add nutrients that may not be present naturally in food, a process known as fortification. In this case, the amount of nutrient added may be higher than that present before processing. Fortification also standardizes the contents of nutrients that show variable concentrations. A typical example is the addition of vitamin C to

Table - 1: India country profile

Population	1,168,714,600
Children-under-5 mortality rate:	79 per 1000
Vitamin A deficiency, in children 6 to 59 months old:	57%
Iodine deficiency:	33%
Prevalence of anemia, in children 6 to 59 months old:	69%
Prevalence of anemia, in women:	62%

Micronutrient malnutrition in India: Let us say "no" to it now. Indian J Community Med. 2008;33:9-10)

orange juice to standardize vitamin C concentration and compensate for changes due to seasonal and processing variations. Finally, for technological purposes, a preservative or colouring agents are added to processed foods.

Biofortification: Improving the nutritional value of staple food crops has usually been a secondary concern for high-income consumers, who have access to improved nutrition through dietary diversification. As a consequence, the scientific improvement of staple food crops has focused on improving yield and productivity (Morris and Sands, 2006). Market forces have tended to reward higher yield far more than higher nutrient content, and crop breeders have often felt they must sacrifice the latter to get the former. This is one reason most efforts to fortify foods with micronutrients have taken place off the farm in the downstream processing and formulation of food products and often through regulatory interventions that go beyond market forces. With higher incomes, chronic diseases resulting from consumption of fats and sugars become more important health risks. It appears that this transition is occurring more rapidly in countries now in the middle income range (Popkin, 2001), and thus, both established policies and new types of intervention may be needed to address this "dual burden" of over- and under-nutrition in developing countries

The established interventions have all been limited in scope, due to the recurrent budget costs and limited coverage in rural areas. The relatively lower cost associated with building nutrients directly into the seeds of crops makes biofortification a potentially cost-effective and sustainable intervention. This is an important motivation for biofortification. Several studies have documented the relative cost-effectiveness of biofortification. Robertson and Unnevehr (2002) compared golden rice with wheat fortification in developing Asia, and found that cost per retinol activity equivalent delivered was comparable for golden rice with low beta-carotene levels. Its cost-effectiveness would be substantially greater with the higher levels of beta carotene achieved in subsequent research (Dawe and Unnevehr, 2007). These results reflect the fact that it is fundamentally cheaper to build nutrients into the crop than it is to incur the costs of fortification indefinitely into the future.

Biofortified crops presumably will need to meet an equal safety standard to conventional fortification in terms of providing nutrients that are effective in alleviating deficiencies but not harmful to any subpopulation. Yet unlike industrial fortification, variations in the nutrient content of a biofortified crop could be more difficult to control, since they will depend on the agricultural practices of farmers in differing production environments. Information on the impact of different cultivation methods, weather, and preparations could thus become essential to making comparable safety determinations for biofortified crops (Qaim *et al*., 2007).

Biotechnology -

Conventional plant breeding: This allows crop scientists to make significant improvement in the nutritional, eating quality, and agronomic traits of major subsistence food crops. Conventional breeding is limited, however, because it can only use the genetic variability already available and observable in the crop being improved, or occasionally in the wild varieties that can cross with the crop. Furthermore, conventional breeders usually have to trade away yield and sometimes grain quality to obtain higher levels of nutrition. One example is quality protein maize (QPM), which has taken decades of conventional plant breeding work to develop into varieties acceptable to farmers. However, multiple gains are at times possible, as with iron and zinc in rice and wheat, where the characteristics that lead to more iron and zinc in the plant can also lead, by some accounts, to higher yield. Other biofortified crops, such as the orange-fleshed sweet potatoes (OFSP) promoted through the harvest plus program in Africa, have been successfully selected and developed for both nutrient and (at least rainy season) yield traits.

Tissue cultures: Modern tissue culture techniques can allow scientists to reproduce plants from a single cell. These techniques are now used extensively to produce disease-free planting material of clonally propagated crops such as bananas. When tissue culture is combined with embryo rescue techniques, plant breeders can use the genes from wild and weedy relatives of a crop, which would normally not cross with the cultivated crop. This allows breeders to increase genetic variability of the cultivated crop and then bring in valuable traits of the wild and weedy relatives. These techniques have allowed scientists to cross Asian and African rice varieties and develop nerica rice varieties with agronomic traits, such as higher yield and resistance to water stresses, that have met with growing success in Africa. Tissue culture is an important tool for propagation of roots and tubers, such as potatoes and cassava, and both of these crops are part of current biofortification research.

Mutation breeding: Mutation breeding has been used extensively in developed and developing countries to develop grain varieties with improved grain quality and in some cases higher yield and other traits. This technique makes use of the greater genetic variability that can be created by inducing mutations with chemical treatments or irradiation. The FAO/International Atomic Energy Agency (IAEA) website contains more than 2,500 varieties that have been developed through mutation breeding (Mutant varieties database). Of these, 1,568 are in Asia, 695 in Europe, and 165 in Europe. Most of the European and US mutants are flowers, but most in Asia are basic food crops such as wheat, rice, maize, and soybeans. According to their website, FAO/IAEA include biofortification as one

Table - 2: Micronutrient deficiencies and their estimated impacts

Micronutrient	Estimated impact and efforts to address
Iodine	Associated with brain damage. Easily mitigated with iodized salt. While incidence has declined dramatically in recent years due to the universal adoption of salt iodization starting in 1993, WHO estimates that 54 countries still have some iodine deficiency.
Vitamin A	Associated with blindness and increased risk of disease and death for small children and pregnant women. Can be addressed through supplements, which are now estimated to reach children at least once a year in 40 countries. The UN Standing Committee on Nutrition (UN/SCN) estimates that 140 million children and 7 million pregnant women are VA deficient, primarily in Africa and South/Southeast Asia. In 1998, WHO, UNICEF, Canadian International Development Agency, USAID, and the Micronutrient Initiative launched the VA Global Initiative. This provides support to countries in delivering VA supplements.
Iron	Associated with maternal death, impaired physical and cognitive development, increased risk of morbidity in children, and reduced work productivity in adults. Can be addressed through fortification of wheat products. WHO estimates 2 billion people are anemic, and this is frequently exacerbated by infectious diseases. Malaria, HIV/AIDS, hookworm infestation, schistosomiasis, and tuberculosis contribute to a high prevalence of anemia in some areas. Efforts to increase iron intake must be accompanied by efforts to control infectious disease.
Zinc	Associated with reduced immune status in neonates and children. Preliminary research shows that additional zinc can reduce incidence of diarrhea and pneumonia in children and improves maternal health. One estimate shows zinc as close to iron deficiency in contribution to the global burden of disease. Can be provided through supplements.
Folate	Deficiency associated with increased risk of maternal death and complications in birth; also associated with neural tube defects in infants and with an estimated 200,000 severe birth defects every year. Can be addressed through fortification of wheat products.

Note. Data from Shekar *et al.* (2006); UNICEF/MI (2004) and World Health Organization (2004).

of the objectives of their mutagenesis program, but there do not seem to be any applicable results yet. Varieties produced using mutagenesis can be grown and certified as organic crops in the US, whereas transgenic crops developed using recombinant DNA (rDNA) technology cannot.

Molecular breeding: Also called marker-assisted breeding, this is a powerful tool of modern biotechnology that encounters little cultural or regulatory resistance and has been embraced so far even by organic growers because it relies on biological breeding processes rather than engineered gene insertions to change the DNA of plants. This technique is expanding rapidly with the development of genomics, which is the study of the location and function of genes, and with the rapid decline in costs of screening plant tissue. Once scientists have identified the location of a gene for a desirable trait, they build a probe that attaches itself only to a DNA fragment, a so-called marker, unique to that gene. They then can use this marker as a way to monitor and speed up their efforts to move this trait into relatives of the plant using conventional breeding. For example, since the marker can be detected in the tissue of new seedlings, the presence or absence of the desired trait can be determined without having to wait for a plant to mature, often reducing by years the length of a typical crop-development process. If molecular breeding reduces the number of generations required to develop a pureline variety by three generations, this can save three years of research time.

Use of molecular breeding has increased dramatically both by private seed companies and government plant breeders in developed countries, and it is gradually spreading to developing countries (Pray, 2006). Using this technique, plant breeders also can stack into one variety several different genes that code for different traits. Asian government scientists have been working with the International Maize and Wheat Improvement Center (CIMMYT) to stack into maize a number of traits such as QPM, disease resistance, and drought tolerance (Pray, 2006). This technique has also been used to find recessive traits in plants that cannot be located by conventional breeding or other techniques.

Genetic engineering: Genetic engineering, or rDNA, is a technique that offers still greater speed and reach because it moves specific genes with desired traits from a source organism—one which does not have to be a related organism—directly into the living DNA of a target organism. The *transgenic* trait is added without normal biological reproduction, but once in the plant it becomes inheritable through normal reproduction (BMA, 2004). Scientists first developed this technique in the laboratory in 1973 and have been using it to transform agricultural crop plants since the 1980s. Once a useful gene has been identified (which can require a major research project and many years), it is attached to both marker and promoter genes and then inserted into a plant, usually using a non-viable virus called Agrobacterium as a carrier. GE produces plants that are known as transgenics, or less precisely as GMOs.

GE has great reach because it can add valuable characteristics that are not currently found in the seeds of individual plant species. GE was necessary for the development of Golden Rice, which contains the precursor to VA from a daffodil plant. This was a trait missing from rice plants, and it could not be introduced conventionally since daffodils cannot be crossed with rice plants. In addition, GE can take much less time to incorporate desired traits into a crop plant than either traditional or molecular breeding.

Table 3 provides a summary of nutritional enhancements in crops that are either currently available or might be available within the next decade, divided as to whether the principal benefit will go to high-income or low-income consumers. The areas of overlap between research for high-income and low-income consumers are few due to the differing nutritional status and health needs of these groups. This factor reduces potential spillover benefits from commercial research in industrialized countries (USNAS, 2004).

Table - 3: Examples of enhanced nutritional characteristics in crops

	Low-income consumers	High-income consumers
Nutrient characteristics	Improve amino acid profile for more complete protein in maize, sorghum, soy More protein in potato, cassava Address micronutrient deficiencies: Vitamin E in oils Caretonoids in mustard, canola oils Folic acid in rice, maize Iron and zinc in rice, sorghum, maize, beans Beta-carotene in rice, sorghum, maize, cassava, yam, sweet potato, potato Iron in wheat	Improve oil profile in soy, canola, corn, sunflower, to reduce risk of coronary heart disease, *e.g.*, low-linoleic soy and canola, lower saturated fat content in maize oil, high oleic in soy Long chain Omega 3 fatty acids in soy or corn oils Phytonutrient content increased, such as suphrophane in broccoli, lycopene in tomatoes, isoflavones in soy Vitamin E in lettuce (Japan) Alter glycemic index in corn, whea t, rice to prevent diabetes Produce inulin (a prebiotic) in crops where it does not occur naturally Leverage benefits of soy protein for cholesterol reduction
Bioavailability	Lower phytate in corn to improve iron and zinc uptake Lower toxicity in potatoes, cassava Improve digestibility in beans, sorghum	Improve digestibility for animal feeds such as maize, soy, to improve meat production efficiency, reduce animal waste externalities, and improve meat quality, that increase phosphorous uptake from maize in animals to reduce its excretion

Data from African Biofortified Sorghum Consortium (ABSC) website; Donald Danforth Plant Science Center website; HarvestPlus (2004); ISAAA (2007); H. Glick, personal communication (July 28, 2006); G. Kishore, personal communication (July 28, 2006); D. Stark, personal communication (February 22, 2007); and Pew Initiative on Food and Biotechnology (2001).

Cost-effectiveness of food fortification: Micronutrient interventions are among the most cost-effective investments in the health sector. Addressing micronutrient deficiencies globally will require an estimated $1 billion per year about $1 per affected person (all dollar amounts are U.S. dollars). That figure is equivalent to the economic costs of endemic deficiencies of vitamin A, iodine, and iron in a single country of 50 million people. Most of these costs will ultimately be borne by consumers when purchasing food with higher nutritional quality (World Bank, 1994).

Miracles of nutrient additions to food fortification:

Cereals and cereal based products: This is one of the most important areas for consideration of food fortification technologies. Foods from this category form the major component of diets around the world. This is especially true in the case of developing countries where dietary diversity is limited. On average, cereals provide 52% of caloric intake globally. For Africans and Asians they represent 60-75% of the caloric intake; for Latin Americans, 50%; and in the United States of America, 26% (Bauernfeind, 1991). In developing countries 95% of the population consume cereals as a dietary staple which also provide about 47% of the per capita protein intake.

Milling of cereal grains prior to their consumption is a common practice. During the milling process a substantial proportion of the nutrients are lost from the refined product. The fortification/enrichment of cereal grains can therefore be rationalised in more than one way. One valid reason is to restore to refined products, nutrients which have been removed during the milling process. Another reason is to improve the nutrient intake levels of target populations which are at risk of micronutrient deficiency.

Rice and other whole cereal grains: There are distinct advantages of choosing rice as a vehicle for fortification. It is the main dietary staple in many countries including India. Secondly, day-to-day consumption of rice is almost constant within each age group, gender and for all income and occupational categories of population. Thirdly, rice also accounts for proportion of total calorie intake. In addition there are two more reasons which favour the selection of rice as India produces about 83.5 million tonnes of rice per year and rice contributes to the consumption of approximately 350 g/day per person. Rice can be fortified with both vitamin A and iron.

Ultra rice: This is the name given to the reconstituted vitamin A or iron fortified rice. Vitamin A fortified rice is made by blending either vitamin A acetate or palmitate as fortificant into the rice flour and extruding the paste to yield a concentrated rice product that has an appearance, density and taste of unfortified rice. This is blended with unfortified rice in the ratio of 1:100 to 1:200 to provide an appropriate dietary level of micronutrients.

Normally, one kilogram of ultra rice is fortified with 11.4 g of vitamin A palmitate. Iron fortification of ultra rice with a chelated, highly bioavailable form of iron has been demonstrated. In comparison with vitamin A fortification, it is easier to fortify rice with iron owing to the inherent stability of the iron compound. Fortifying rice with both iron as well as vitamin A was not possible because vitamin A gets oxidised by iron leading to discolouration of rice on storage. Hence, it is only possible to produce two separate forms of ultra rice, one fortified with vitamin A and other with the iron.

Among the cereals, rice presents unique problems in fortification. These are due to the fact that it is most commonly consumed as a whole grain and also in many countries; extensive washing of the grain prior to cooking is the normal practice. The earliest methods of rice enrichment involved the production of parboiled and converted rice. By this means nutrients from the bran layer were transferred to the starchy endosperm. The parboiling process involved the soaking of the rough rice, the application of heat followed by drying and milling. It was demonstrated that in this way 50-90% of the thiamine was retained .

After parboiling and converting, the next methods of enrichment involved the actual addition of nutrients to the milled products. Techniques used for this have been classified into two main groups 'powder type' and 'grain type' enrichment .

In powder type enrichment, a powdered pre-blended mixture of vitamins and minerals has been added at a rate of 1, 0.5. or 0.25 oz. per 100 lbs of rice (a w/w ratio of 1:1600, 1:3200 or 1:6400). For white parboiled rice, the normal practice has been to add the premix soon after milling as the heat and moisture at the grain surface at this point facilitates adherence of the powder. A major disadvantage of this method of nutrient addition has been that 20-100% of the nutrients are lost on washing. In the USA, rice enriched in this way must bear a label stating 'to retain vitamins do not rinse before or drain after cooking'.

In the second major type of enrichment, a powdered nutrient mixture has been applied to the milled rice grains followed by coating with a water insoluble substance. A fortified rice premix produced in this way has then been added to milled rice at a rate of 0.5%, to yield an enriched product conforming to the required standard of identity. In the United States of America, this standard requires between 2.0 - 4.0 mg of thiamine, 1.2 - 2.4 mg of riboflavin, 16 - 32 mg of niacin or niacinamide and 13 - 26 mg of iron per 100 lbs. of rice. It may contain 250 -1000 USP units of vitamin D and 500 - 1000 mg of calcium. The requirement regarding riboflavin has been stayed pending final action.

Ferric orthophosphate (white iron) is a recommended form of iron for use in the fortification of rice . This iron compound is almost water insoluble and has been preferred for mixing with milled rice due to its white colour. When it is oxidised or contains excessive moisture it may become tan, yellow, purple and or black (Hurrel, 1992).

Apart from these well established procedures there have been other innovations regarding alternative methods for rice fortification, like using a premix containing thiamine, riboflavin, niacin and pyridoxine. This procedure involved soaking the milled rice in an acid medium containing the water soluble vitamins followed by the cross linking of starch granules in the enriched grains. The cross linking procedure itself was demonstrated to have caused significant vitamin loss, but the added vitamins were highly cook and wash stable. It is possible that this method could have some utility in the future.

Use of fortified simulated grains has featured prominently in attempts at rice fortification in the developing countries (Murphy 2005). The synthetic rice grains were produced by extrusion of rice flour in a pasta machine. The best formulation contained vitamin A stabilised by a mixture of tocopherol, ascorbate and lipids with a low level of unsaturation. Retinyl palmitate stabilised in an acacia matrix, type 250 SD (Sigma Chemical Co.) was the fortificant used. Retention of vitamin A after washing was reported to be 100%. Vitamin retention after cooking, however, ranged from 60 - 94%. The formulations which demonstrated the better storage stability, particularly at high humidity, suffered greater cooking losses. Drawbacks with this technology have been reported to exist with respect to blending with the natural product and in the consistency of the simulated grains after cooking.

The enrichment of whole wheat grains with vitamin A has been attempted .The fortificant used was a premix comprised of concentrated vitamin A attached to wheat grains, for mixing at a level of 0.25% with wheat grains. The feasibility of this procedure was not determined. The fortification of whole grain cereals with soluble iron compounds is difficult because they promote oxidation of the lipid component of the grain, thus reducing the shelf life (Murphy 2005).

Flours, cornmeal and bread and pasta: In the fortification of flour the required nutrient mixture is mixed with an appropriate diluent to produce a premix, which is then accurately metered into the flour. The addition of vitamins B_1 and B_2, niacin, iron and calcium to wheat flour is a common practice in many developed countries. It is technologically feasible to add other vitamins and minerals as well. The vitamin/iron premix demonstrated excellent stability on storage. The flour enriched with both premixes also demonstrated excellent stability on storage at room temperature.

The form of vitamin A most commonly used in the fortification of flour was dry stabilised vitamin A palmitate (type 250-sd) powder form. The water soluble vitamins (thiamine, riboflavin, niacin, pyridoxine, folate and calcium pantothenate) are used in pure crystalline form. The mononitrate salt of thiamine is preferred for this use. Iron is normally used in its reduced elemental form. Ferrous sulphate was also used as the source of iron and there was no significant difference demonstrated between the flour enriched with ferrous sulphate and that enriched with elemental iron.

Iodisation of bread has been carried out in the Netherlands and Tasmania by the addition of 2-4 ppm KIO_3 to the bread improver which was already in general use. KIO_3 has been used in bread production in the past, not as a fortificant but as an oxidising agent to improve dough quality.

In many countries pasta or noodles are commonly eaten and these can therefore be important vehicles for fortification. The manufacture of such products involves the production of a dough which is then extruded and dried. Enrichment can be through the use of enriched flour or alternatively, wet addition of a dispersion of the required vitamins can be carried out at the dough-making stage. Vitamin losses during production depend largely on the drying conditions employed. Durum wheat flour enriched with a vitamin mixture containing riboflavin, thiamine mononitrate and niacin for the production of spaghetti. High temperature drying treatments result in significant losses of riboflavin, whereas the other vitamins were stable to the processing conditions. In all cases cooking losses, estimated between 40 - 50%, exceeded those experienced during processing.

Breakfast cereals: The fortification of ready to eat breakfast cereals is a wide-spread practice. In the United States the general practice has been to provide 25% of the RDA of thiamine, riboflavin, niacin, pyridoxine, folate, ascorbic acid and vitamin A per 1 ounce. 10 or 25% iron, up to 20% RDA for calcium have also been added; vitamin D has also sometimes been included (Bauernfeind, 1991).

The minerals and the more heat stable vitamins like niacin and riboflavin have been added to the basic formula mix prior to processing .The heat labile vitamins such as vitamins A, C and thiamine are usually sprayed onto the cereals after the high temzs have been assessed in the fortification of pasteurised whole milk. At pasteurisation temperatures below 79 °C off-flavours due to lipolytic rancidity developed but these problems were greatly reduced by increasing the pasteurisation temperature to 81 °C. De-aeration of the milk prior to the addition of iron compounds was also found to reduce flavour problems. The best fortification procedure was judged to be the addition of ferric ammonium citrate followed by pasteurisation at 81 °C. In this way fortified milk containing 30 ppm iron was found to be acceptable after 7 days storage. Levels of vitamin E, vitamin A and carotene were not affected by the presence of iron. In the production of iron fortified evaporated milk, ferric orthophosphate was shown to be useful (Krutz, 1995). The uniform distribution of the iron compound was, however, identified as a problem due to its low solubility.

Calcium fortification of milk and milk-based beverages has been carried out. Calcium fortificant preparations including stabilisers and emulsifiers have been used for this .In Germany a milk-based fruit beverage has been marketed which is fortified with calcium, phosphorous as well as vitamins A, E, B and C.

Powdered milk products: The fortification of powdered milk has been achieved by the addition of dry vitamin preparations to the milk powder as well as by vitamin addition to the liquid milk just prior to spray drying. As with other dry products, effective mixing has been best achieved in two steps: the initial dilution of the vitamin mixture with a suitable quantity of milk powder, followed by mixing into the bulk. Consideration of particle size and density are important to prevent separation of the components on storage.

In the iron fortification of powdered non-fat dry milk, ferrous sulphate at a level of 10 ppm was found to be stable for a period of 12 months. Ferric ammonium citrate and ferric chloride at a level of 20 ppm iron in the reconstituted product gave acceptable results.

Other dairy products: The addition of vitamins to other dairy products such as yoghurt and ice-cream has been practised and enrichment of cheese with iodine through the use of iodised salt has been approved in Germany.

In the case of ice-cream, there were no technological difficulties to overcome. The unit operations used in the manufacture of ice-cream are not highly destructive to vitamins. Vitamins are added in the dry form to the mix. Since whipping and consequent aeration of the mix is carried out around freezing temperature, oxidative losses of vitamins are minimal. Perhaps the greatest processing losses are due to pasteurisation of the mix.

In the production of yoghurt, the low pH conditions render it unsuitable as a carrier for vitamins such as vitamin. The water soluble B-vitamins are best used in a coated form, protected for odour and flavour considerations. When vitamins are added to the yoghurt by addition to the base, some vitamin loss can occur through metabolism by fermentation microorganisms .

Margarine fats: Margarine is a spread which has been widely used interchangeably with butter. For this reason, in many countries fortification of this spread with vitamins A and D is practised, since the food that it replaces is a good source of these vitamins. The vitamin A requirement is met using β-carotene as well as oil soluble vitamin A esters (Bauernfiend, 1991). The oil soluble vitamins are added in the required amounts to a portion of warmed oil which is then added to the bulk prior to homogenisation. Particularly in the case of margarines with a high content of polyunsaturated fatty acids, vitamin E has also been added. Due to the mild processing conditions only small overages are required to compensate for processing losses: 10 % for vitamins A and D and between 5-15% for vitamin E .

Oils: Fortification of oil with vitamin A in the form of retinyl palmitate has been attempted in Brazil (Nestel *et al*., 2003). Storage studies demonstrated that after 18 months of storage in dark sealed containers losses of more than half of the vitamin content were experienced. When storage was not carried out in the dark, most of the vitamin content was lost after 6 months. Packaging of the fortified oil in opaque containers was therefore demonstrated to be a critical consideration.

Vitamin A fortified oil showed good vitamin retention after 5 months of storage in sealed metal containers at high temperature and humidity. Partially hydrogenised vegetable oil was used in the study and the fortificant was all-trans retinyl palmitate, at a level of 491 and 10 g BHA and BHT were used as antioxidants.

Accessory food items: Although staple foods are generally used as vehicles in food fortification programmes, at times when none can be identified which has all the required characteristics, it has been necessary to find other options, that is condiments which may be fortified but only with nutrients that are deficient in the diet and provided that such food is an appropriate vehicle for the micronutrient and is widely consumed by the general population or is intended for intervention programmes to address deficiency in a specific target population.

Salt: Salt iodisation began in 1922 in Switzerland and has been implemented in many countries as the major mechanism for eliminating iodine deficiency. Today, IDD remains a problem in many countries. WHO and UNICEF have established the goal of ‘Universal Salt Iodisation’ to be achieved by the end of 1995. Salt has been favoured as a carrier for iodine due to its wide spread coverage, effectiveness, simple technology involved and low cost .Based on the suitability of salt as a widely used and low cost vehicle, fortification of salt with other nutrients has also been attempted (Nestel *et al*., 1993).

According to the Codex standard for food grade salt, use can be made of potassium or sodium iodides and iodates (FAO/WHO, 1995). The iodates have been found to be more stable than the iodides under a wide range of conditions. Stability studies of iodised salt using potassium iodate as the fortificant demonstrated that there was no significant loss of iodine on storage in polyethylene bags for up to two years and that boiling of the salt solutions led to negligible iodine loss.

According to Bauernfeind (1991), an acceptable iron fortificant for salt is one which does not discolour the salt nor impart a flavour or odour and remains stable and bio-available on storage. Ferrous fumarate, ferric orthophosphate and ferrous pyrophosphate have all been recommended by INACG (Nestel *et al*., 2003) for use with salt .In the fortification of salt with iron, it must first be ground to a coarse powder to facilitate uniform mixing and distribution of the iron fortificant. The addition of both iodine and iron fortificants to salt can lead to the decomposition of the iodine compound and its subsequent liberation. Nestel *et al*. (2003) reported on the use of a fortificant mixture containing 40 ppm of potassium iodate, and 1000 ppm of iron as ferrous sulphate and 10,000 ppm of a permitted stabiliser which rendered good bioavailability of both iodine and iron after prolonged storage. Cost was identified as a constraint in the use of this fortificant system as it added 50% to the retail price of salt.

Fortification of salt with vitamin A has been attempted under laboratory conditions (Nestel *et al*., 2003). The fortificant used was dry vitamin A palmitate type 250 SD protected by a lipid. The fortificant was found to be unstable at moisture contents above 2%, since salt is hygroscopic, packaging material with an adequate moisture barrier must be used. Impurities in the salt were also found to destabilise the vitamin A. The particle size and shape must be such that uniform mixing could be achieved and segregation does not occur on storage.

Monosodium glutamate: MSG is a condiment which is widely used in many Asian countries. It has GRAS status in Codex Alimentarius as a flavour enhancer. This additive has been thoroughly scrutinised due to the allergic response which it has been alleged to induce in susceptible individuals (Alien, 1991). It is worthy of note that the Joint Expert Committee on Food Additives concluded that MSG should not be used in infant foods even though there was no cause for concern about health risks (FAO/WHO, 1987).

Field studies on MSG fortification with vitamin A have been conducted in the Philippines and Indonesia (Bauernfeind, 1991; Nestel *et al*., 2003). In the Philippines dry vitamin A type 250 SD was used. This is vitamin A palmitate stabilised in an acacia-lactose matrix. The MSG was first ground to 100 mesh to facilitate mixing with the fortificant. Problems were encountered with segregation of fortificant and carrier, loss of vitamin A activity and colour deterioration of the fortified product. Vitamin A acetate 325 L, a granular fortificant stabilised in a gelatin - sucrose matrix, was used in place of the finely powdered vitamin A palmitate 250 SD. Under conditions of high humidity, there was hardening of the gelatin coat with associated loss of vitamin potency. In the Indonesian study, dry vitamin A palmitate type 250 CWS dispersed in an edible carbohydrate, stabilised with antioxidants and coated with a white protective layer, was used. This product was hot and cold water miscible. This fortificant was demonstrated to retain over half of its potency when stored at 25 °C for 18 months. Under moist dark conditions, half of the activity is retained after 7 months. When subjected to light the fortificant is destabilised more rapidly, the uncoated form of the vitamin is less stable under these conditions. The fortificant mixture was added to MSG at the rate of 0.171 wt. %. The vitamin A was aggregated into clusters so as to minimise the problem of segregation during mixing and storage. Segregation of the product was still, however, identified as a problem. Colour deterioration of the fortified product was another constraint to the continued application of this technology .

Iron fortification of MSG has also been attempted using micronised ferric orthophosphate and zinc stearate coated ferrous sulphate (Bauernfeind, 1991). The coated ferrous sulphate had reduced bioavailability relative to the uncoated form ,but the fortified product was judged to have acceptable colour, taste, bioavailability and particle size properties. Preliminary investigations indicated that the inclusion of dry stabilised vitamin A (type 250 SD) into the iron fortified mixture might be technically feasible.

Sugar: Sugar has been found to be a suitable vehicle for nutrients in fortification programmes in Latin America and the Caribbean. In the vitamin A fortification of sugar, vitamin A 250-CWS was proven to be the most effective fortificant. The premix is produced by mixing sugar and fortificant in a revolving drum mixer. Physical separation of the fortificant beadlets from the sugar was prevented by the addition of an edible bonding agent. Stabilisers are added by first dissolving in warmed oil under anaerobic conditions, achieved by bubbling nitrogen through the oil, followed by intermittent addition to the fortified sugar with continuous mixing. Peanut, cotton seed, soya bean and coconut oils have all been used in this procedure. It has been suggested that shark liver oil be used in place of the vegetable oils. The natural vitamin A content of this source reduced the need for vitamin A fortificant by 10-12% .The successful use of shark oil would be expected to require rigorous deodorising and refining treatments and stabilisation of polyunsaturated fatty acids. Satisfactory storage stability of the premix was obtained when packaged in double polyethylene bags with an outer paper layer, and stored in a cool, dry place.

The premix was added to the sugar such as to achieve vitamin A levels of 50 IU per g in the final product Addition of fortificant can take place in the centrifuge at the end of the washing cycle in the sugar refining process, or along the transporting belts prior to packaging. Retention of vitamin A after 6 months at 25 °C was 92%. Higher losses were recorded with storage at 45 °C, with 76% retention of vitamin activity after 3 months.

Fortification of sugar with iron has also been attempted. Bauernfeind (1991) reported promising results using sodium ferric EDTA as the fortificant. Segregation of the fortificant and the carrier was not a problem as the iron compound became stuck to the sugar crystals at moisture contents exceeding 1% .A major problem which exists with iron fortified sugar is that on addition to coffee or tea, there is marked discolouration. This phenomenon is reduced with the use of NaFeEDTA, but it is still evident.

Sauces: Iron fortification of strongly flavoured or dark coloured food products is often simplified due to the fact mat less care is required in consideration of the avoidance of off-flavours and off-colours. Largely for this reason iron fortification of curry powder demonstrated no technical difficulties. In the fortification of fish sauces the major problem was the formation of a precipitate on addition of iron. When sodium iron EDTA was the fortificant, however, this phenomenon was greatly reduced. The inclusion of iron in an EDTA complex greatly restricted its availability for interaction with macro-molecules and other compounds in foods which could eventually lead to precipitation or other deteriorative reaction.

Curry powder: Curry powder is a popular dietary item in most of the households, especially in South India. It is normally a mixture of turmeric, coriander, red chillies, black pepper, curcumin and fenugreek seeds. Since the average intake of curry powder is found to be over 5 g/day/person in India, this powder can act as a suitable vehicles for fortification. In Thailand, the spicy powder accompanying noodles is fortified with iron, vitamin A and iodine.

Role of legislation and food control: The primary purposes of food legislation are to protect the health of the consumer and to protect the consumer from fraud. In the case of fortified foods, there is a need to ensure that the population is not at risk of receiving toxic doses of any micronutrient. Food laws must also ensure that the target population does not receive nutritionally ineffective levels of micronutrients. Procedures for monitoring premises where fortified foods are prepared, packed, stored or held for sale as well as mechanisms for penalising defaulters must be clearly defined within the food regulations

It has been found that food law is managed most effectively in two parts: a basic food act and food regulations. The act itself should set out broad principles while the regulations should contain the detailed provisions governing the different categories of products. Within the regulations should be found lists of approved fortificant compounds and food standards stating the allowed levels of nutrients in the fortified foods. This organization gives some flexibility to food law as it is much more difficult to have laws amended than to revise regulations. Prompt revision of regulations may become necessary because of new scientific knowledge, changes in new processing technology or emergencies requiring quick action to protect the public health. With respect to regulations dealing with fortified foods, changes might be prompted as a result of safety evaluations on nutrient compounds or new information regarding the roles and optimal levels of specific micronutrients in the maintenance of good health. Changes in food processing and packaging technologies could be shown to result in a significant reduction in processing and storage losses of micronutrients, thus requiring a revision in the allowed levels of addition of nutrients. In the face of demonstrated micronutrient deficiencies, regulations regarding standards.

Conclusion

Micro-nutrient deficiency in India is a complex problem , the determinants of which vary from food adequacy, literacy levels, conditioning infections, access to healthcare & safe drinking water to economic growth. Historically, nutritional deficiencies have been addressed through a variety of interventions beyond the farm gate. While efforts to advance industrial fortification of foods have accelerated in developing countries during the past decade, such efforts cannot reach all of the populations most at risk from micronutrient deficiencies. The advent of modern biotechnology, together with widespread appreciation of the importance of nutrition, has opened the door for biofortified or nutritionally enhanced food crop varieties ,.but no single organization can ever address the multifaceted problem of micro nutrient deficiency alone. Many inputs in different sphere are required from different sectors both public & private especially the educational programs are required along with food fortification and consider it as only a part of the over all nutritional programe not a substitute of it.

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