Dietary Strategies to Enhance Micronutrient Adequacy: Experiences in Developing Countries

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Introduction

There is increasing recognition that in developing countries, where diets are mainly plant-based, dietary inadequacies of several micronutrients are likely. These inadequacies have been identified from FAO food balance sheet data as well as national and regional food consumption surveys, and confirmed by biochemical and clinical studies of micronutrient deficiencies, often involving randomised, double-blind clinical trials. Several factors are associated with the etiology of micronutrient deficiencies. Dietary factors are linked with low intakes of micronutrients arising from a low content of the same in the soil and crops, low energy intakes, and poor food selection patterns, as well as poor bioavailability of certain micronutrients. The latter is especially a problem among population groups consuming diets in which a high proportion of the energy and micronutrients is provided by cereals, and intakes of food from animal sources are low. Diets low in expensive foods from animal sources are also low in dietary components known to enhance micronutrient absorption, whereas those containing high amounts of unrefined cereals and legumes are high in inhibitors such as phytate and polyphenols. One useful measure of the bioavailability of zinc (Zn) in diets is the phytate-zinc molar ratio (PZMR). A PZMR value of less than 15 is associated with good zinc bioavailability, whereas a ratio above 15 is associated with poor zinc bioavailability. The diet of Canadian children has a PZMR of 5, whereas in countries such as Kenya and Malawi the PZMR of the habitual diet is often about 30. As a result, their zinc content is likely to be poor in terms of bioavailability. The Nepalese rice/lentil diet is also likely to have very poor bioavailability of Zn.

Increased losses of micronutrients due to diarrhoea and parasitic infections are common in developing countries and exacerbate micronutrient deficiencies. Risk of micronutrient deficiencies is also high during periods of the life cycle when physiological requirements are high such as infancy, childhood, pregnancy, and lactation. Low birth weight (LBW) and malnourished infants also have high physiological requirements, and hence are at risk in terms of micronutrient deficiencies.

As a result of the low content and/or poor bioavailability of micronutrients in the plant-based diets of developing countries, the prevalence of inadequate intakes of micronutrients is much higher than that of inadequate intakes of protein, as shown in Figure 1.

The consequences of micronutrient deficiencies to society are grave. They may include impairments in growth, development, cognitive function, immune function, and adverse outcomes of pregnancy. Such adverse health effects also have an economic impact, affecting productivity and cognitive development, and increasing the risk of morbidity and mortality among the population, as summarised below (Table 1).

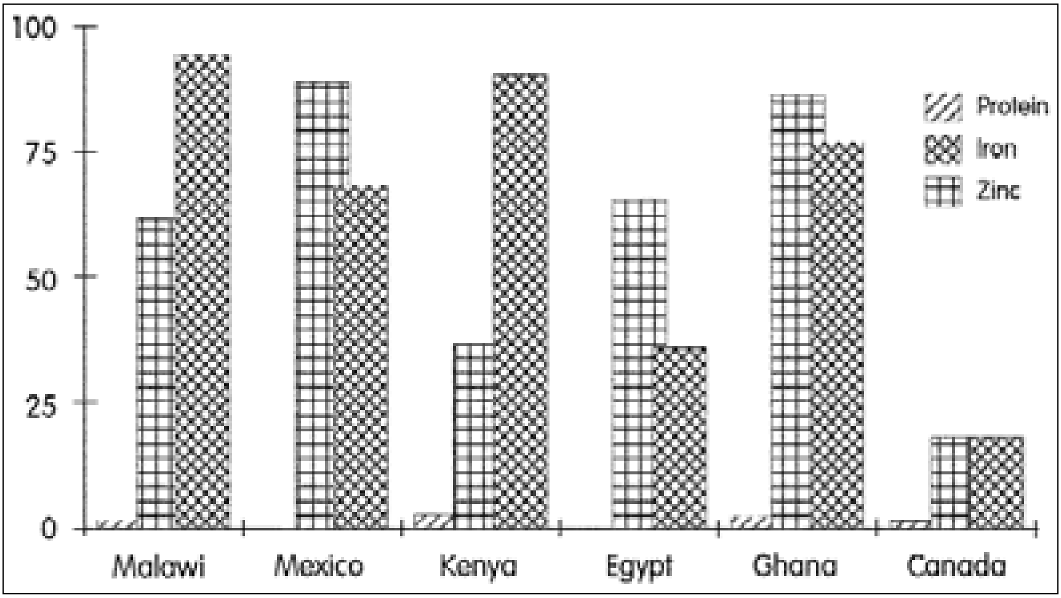

Figure 1: **Predicted prevalence of inadequate intakes**

Table 1: **Adverse effects of micronutrient deficiencies**	
Adverse effect	**Micronutrients**
• Productivity	Fe, Zn, I, Vit A
• Cognition	Fe, Zn, I, B-12
• Morbidity	Fe, Zn, Vit A, Se
• Mortality	Fe, Zn, I, Vit A
Key: Fe=iron; Zn=zinc; I=iodine; B=boron; Se=selenium; Vit=vitamin	

Nutrition interventions to combat micronutrient deficiencies can be divided into four strategies: supplementation, fortification, dietary diversification/modification and bio-fortification. Dietary strategies have several advantages over supplementation. They are culturally acceptable and can be designed so that they are likely to be sustainable and can reduce the risk of concurrent micronutrient deficiencies with a minimal risk of antagonistic interactions. They are also community-based, and thereby can empower communities to help themselves.

Case Study from Rural Southern Malawi

In the following, a case study from rural Southern Malawi is presented to illustrate the application of dietary diversification/modification; more details are given in Gibson et al. (2000, 2003). The strategies aimed to change food selection patterns and traditional household methods for preparing and processing indigenous foods, with the overall goal being to enhance the availability, access, and use of foods with a high content and bioavailability of micronutrients. The study applied both formative and laboratory-based research to develop appropriate dietary strategies, and these were later tested in the community to assess their feasibility and acceptability before implementing them. Nutrition education and interventions to promote behavioural change, such as social marketing, were used to implement and disseminate the dietary strategies. Finally, their efficacy was evaluated using a knowledge and practices' survey, and data on nutrient adequacy, biochemical status, and functional outcomes such as growth and morbidity. The study included weanlings aged 6-23 months and children aged 36-84 months, with a median age of 48 months.

Staple diets in Malawi are maize-based (>50% of energy) and hence contain high levels of phytic acid, a potent inhibitor of Zn, Fe, and calcium (Ca) absorption (Ferguson et al. 1993); consumption of foods from animals is low (3-7% of energy). In certain regions of Malawi there is a high prevalence of stunting (>50%), anaemia (>50%), and vitamin A and iodine deficiency in young children. As a result, four dietary strategies were tested, as outlined below.

1. Reduction of phytate content of cereal-based staples at the household level to enhance Zn, Fe, and Ca absorption
2. Increase in the intake of foods that enhance Zn, non-heme Fe, and vitamin A absorption
3. Increase in production and consumption of foods with a high content and bioavailability of micronutrients
4. Increase in the dry-matter content of porridges used for feeding young children to enhance energy and micronutrient density

Strategy 1 was based on changes in practices of food preparation such as soaking cereal and legume flours to allow passive diffusion of water soluble phytates, fermentation of cereal porridges to hydrolyse phytate acid via microbial phytase, and the addition of germinated cereal flours to provide a source of endogenous phytase for hydrolysis of phytate. Different methods of soaking were shown to reduce the phytate content of maize porridge from 11-36% compared to the unsoaked control preparation, resulting in a marked reduction in the PZMR (19 for the soaked porridge vs. 29 for the unsoaked porridge). Different methods of lactic fermentation can reduce the phytate content of maize porridge by 27 to 73%, depending on the fermentation treatment used.

Strategy 2 was based on encouraging the community to increase small livestock production and develop fish ponds to increase the intake of flesh foods such as meat; poultry; eggs; and dried, whole powdered fish with bones, and thus increase intakes of readily available sources of Zn, Ca, and Fe, as well as B-12, B-2, niacin, fat, and, in certain cases, preformed vitamin A. Consumption of indigenous foods rich in micronutrients, such as grubs/locusts and legumes, and the solar-drying of papaya and mangoes (sources of precursors of vitamin A) and fish were also encouraged.

Strategy 3 aimed to increase the dry matter content of porridges for feeding young children from 6 to 16% dry matter for weanlings and from 10 to 25% dry matter for young children. These trials were carried out with or without addition of amylase-rich germinated flour (ARF). ARF reduces the viscosity of porridges to a semi-liquid consistency suitable for feeding infants and young children without diluting with water, thus enhancing the energy and nutrient density of the porridges consumed.

Figure 2 shows the results of the dietary intervention study for weanlings.

Results confirmed that intakes of the complementary food (g/day), energy density of the complementary food, and intakes of Ca, Fe, available iron, Zn, and available Zn, all identified as 'problem nutrients' by the World Health Organization (WHO), were significantly higher, whereas the average PZMR of the diet was lower in the intervention compared to the control group. Nevertheless, these changes were still not enough to achieve the needs estimated by WHO due to poor access to nutrient-rich foods. Therefore, fortified complementary foods may still be needed in such subsistence settings.

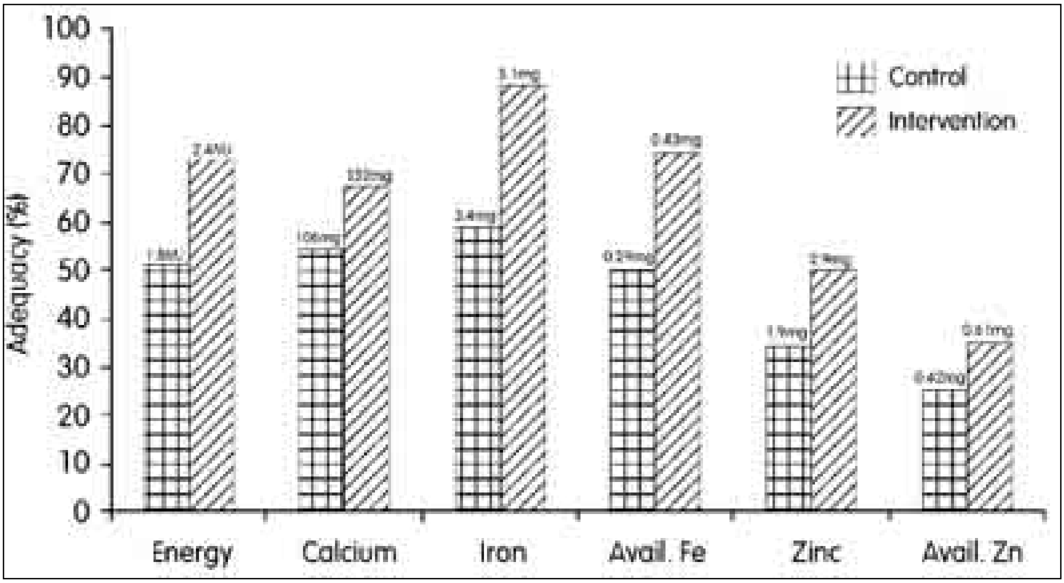

Figure 2: **Weanlings (12-23 months): Adequacy of energy, Ca, Fe, and Zn intakes from cereal foods**

Similar results were obtained in the dietary intervention for the children aged between 3 and 7 years old (Gibson et al. 2003). In this study, the quality of the diets in the intervention compared to the control group increased significantly, most notably as a result of an increase in intake of animal protein, fat, and hemi iron, and a significant reduction in the PZMR in the intervention compared to the control diets. These high-quality diets were accompanied by a significant reduction in the prevalence of inadequate intakes of several important nutrients, especially protein, vitamin B-12, Ca, and Zn (Table 2).

In addition, in this study, the intervention group had a higher haemoglobin concentration than the controls (107 vs. 102 g/l), and a significantly lower prevalence of anaemia (62 vs. 80%). No significant difference was found in hair Zn concentrations between the two groups, but there was a significant reduction in morbidity in the intervention compared to the control group. No effect on linear growth was found, but a higher lean body mass (via anthropometry) was also noted in the intervention compared to the control group.

Table 2: **Prevalence of inadequate intakes (as %) post-intervention: children 3 -7 years**

Nutrient	intervention	control
Protein	1	7*
Vitamin A	15	17
Vitamin B-12	23	41*
Calcium	34	54*
Iron	19	20
Zinc**	26	44*

** adjusted for 50% reduction in phytate; p<0.01

Other Strategies

The results suggest that alternative strategies must also be pursued. Strategies that are currently under investigation employ bio-fortification. These strategies may include the use of Zn, I, and Se fertilisers to increase the content of these micronutrients in grain, as practiced in Turkey for Zn and Finland for Se. Plant-breeding to produce efficient varieties with a higher content of grain micronutrients is another field of research carried out at the Consultative Group on International Agricultural Research (CGIAR) institutions. Breeding for a higher content of S-amino acids in cereal staples, which in turn act as promoters of Fe/Zn absorption, is another strategy. Genetic modification can be used to obtain the same results. A third R&D effort aims at reducing the effects of inhibitors through a decrease of phytic acid per se in the grain, or by increasing the content of heat-resistant phytase to break down phytic acid in grains during cooking.

The present research has documented that there are substantial differences between existing varieties in terms of efficiency of uptake and content of promoters and inhibitors. However, breeding should not stand alone. Even efficient varieties of wheat respond positively to fertilisation with Zn, both in terms of yield as well as content (Graham & Welch 1996).

Fortification of staple foods is also feasible in some countries. Sprinkles fortified with micronutrients which can be mixed with cooked cereal porridges used for feeding infants and young children have been developed and packaged in serving-sized packets. Nevertheless, they have some limitations. The micronutrient dose must be tailored to the infant's age, and the sachets are expensive for consumers of low socioeconomic status. Sustainability may also be a problem when donor agencies withdraw the supplies and the consumer is forced to pay the market price. UNICEF has also developed a 'foodlet': a micronutrient tablet to be mixed with cereal food. The foodlet is crushed into dispersible powder and may be suitable for emergency situations. Nutriset, France, has developed fat-based supplements in spreads fortified with micronutrients. They have low water content, and this reduces the potential for both micronutrient interactions and bacterial growth. Moreover, as a result of their high fat content, they have a high energy density and enhance absorption of fat soluble nutrients, addressing another common problem in the diets of population groups in developing countries. Other fortified products suitable for feeding infants and children include the broken-rice developed by the Institute of Nutrition, Mahidol University, Thailand, at a low cost.

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