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The Adequacy of Micronutrients in Complementary Foods

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The nutritional adequacy of micronutrients depends on their amount and bioavailability in the complementary foods. In many developing countries, cereals or starchy roots and tubers are used as a basis for complementary foods. They are usually prepared as thin gruels, and as a result, their energy and micronutrient content and density are likely to be low, but their content of phytic acid, polyphenols, and/or dietary fiber can be relatively high, all components that can inhibit absorption of certain micronutrients. Nevertheless, there have been very few in vivo isotope studies that have measured the bioavailability of micronutrients directly in complementary foods used in developing countries; some exist for Fe and Zn in complementary foods used in developed countries.

Dietary components affecting the bioavailability of Fe and Zn in foods are well-documented.[1] Hence, complementary foods can be classified as having high, moderate, or low bioavailability for iron (Fe) and zinc (Zn) based on certain criteria set by the Food and Agricultural Organization and/or the World Health Organization.[2,3] Estimates for both Fe and Zn bioavailability depend first on the content in a meal of animal and fish protein relative to plant-based foods. Secondly bioavailability of iron also depends on the content of ascorbic acid, and, for some models, on the consumption of tea or coffee at the same time. For Zn, the calcium (Ca) content ($<$ or $>$1 g Ca/d), and the daily molar ratios of phytate to Zn ($<$5, 5-15, and $>$15) are also important; molar ratios above 15 compromise Zn status. Molar ratios for most complementary foods based on unrefined cereals and legumes probably range from 15 to 36; those based on rice tend to be lower (approximately 15).[4]

By contrast data on dietary components influencing the bioavailability of copper (Cu), manganese (Mn), selenium (Se), and iodine (I) in foods are limited. As a result, their bioavailability from complementary foods will be difficult to estimate until more in vivo studies are undertaken. If complementary foods are enriched with animal protein such as liver and dried fish, the bioavailability and/or content of certain trace elements, notably Fe, Zn, Cu, Se, and I (in marine fish) increases, while their phytate:Zn ratios decrease.

For plant-based complementary foods with a low fat content, bioavailability of fat-soluble vitamins A, D, E, and K, and carotenoids may be compromised when breastfeeding ceases. Use of mild heat treatment (ie, preparation of porridges) may release bound carotenoids from the food matrix and binding proteins, but if severe heat treatment is used, it can be detrimental. Fiber, specifically pectin, impairs β-carotene absorption by interfering with gastric emptying and with mixed-micelle formation.

The Micronutrient Deficit of Complementary Foods

Recently, Brown and co-workers[4] have calculated the energy and nutrients needed from complementary foods for infants of various ages. This work shows that, theoretically, the estimated requirement for vitamin C, folate and B_{12}, Se, and I for infants 9 to 11 months old can be met exclusively from breast milk. In contrast, complementary foods should provide approximately 12% of the vitamin A, 25% to 50% of the Cu, riboflavin, 50% to 75% of thiamin, Mn, and 75% to 100% of niacin, Zn, and Fe, assuming an average composition and intake of breast milk. Indeed, as much as 98% of the Fe and Zn must be provided from complementary foods when the requirement estimates for moderate bioavailability set by the Food and Agricultural and/or the World Health Organizations are assumed.[2,3] These estimates emphasize the critical role that complementary foods play in providing adequate quantities of these trace minerals.

We have calculated the daily nutrient and antinutrient intakes of children receiving 750 g per day of 23 complementary foods used in parts of Africa, India, Papua (New Guinea), the Philippines and Thailand. These calculated intakes were compared with the estimated needs for infants aged 9 to 11 months receiving breast milk in average amounts and composition.[5] Most of the complementary foods, with the exception of sago and the maize-based gruels with only 10% dry matter, meet the estimated thiamin, riboflavin, and niacin needs. Of the trace elements, the estimated needs for Cu are provided by all the complementary foods, whereas those for Mn, Fe, and Zn are consistently not met when even moderate bioavailability for Fe and Zn are assumed.[4] Limited data are available from developing countries of actual micronutrient intakes of infants from complementary foods for comparison with these estimated needs, with the exception of that compiled for infants from Peru and Mexico.[4] Our work in rural Malawi indicates actual deficits similar to those noted by the theoretical analysis of Brown and co-workers[4] and to our computed estimates.[5]

The dietary quality of complementary foods can be compared by expressing their nutrient content per 100 kcal (ie, nutrient density). The adequacy of the nutrient densities can also be evaluated by comparison with desired nutrient densities.[4] Again data from Peru and Mexico and our data for Malawi show similar trends as those noted above, with the deficits persisting for Zn and Fe even when their bioavailability is assumed to be high. In addition, for Malawian infants, only thiamin met the desirable density for infants 6 to 8 months, while niacin, Fe, and Zn (assuming low bioavailability) fail to meet the desirable densities at any age. Not surprisingly, therefore, there is evidence that iron deficiency anemia and zinc deficiency are widespread in infancy and childhood in many developing countries,[6,7] including Malawi[8,9] whereas I deficiency exists in certain regions. Deficiencies of Mn, Se, niacin, and possibly riboflavin may also be widespread, but the extent to which they are associated with adverse health consequences during infancy and childhood in developing countries is unknown.

Improving the Content and Bioavailability of Micronutrients in Complementary Foods Used in Developing Countries at the Household Level

Germination, fermentation, and soaking can be used to enhance bioavailability of Fe and Zn, and probably Cu and Mn in complementary foods, by reducing the content of phytic acid, and in some cases, polyphenols. A detailed discussion of these strategies is given in Gibson and Ferguson.[10] All 3 methods induce some enzymatic hydrolysis of phytic acid (hexa-inositol phosphate) and penta-inositol phosphate to form lower inositol phosphates that do not inhibit Zn and Fe absorption. Exogenous microbial phytase, isolated from molds such as *Aspergillus niger,* could also be used to improve Fe and Zn bioavailability. Soaking also results in some diffusion of water-soluble phytate and polyphenols from certain cereals (eg, maize) and some legumes.

Our work in Malawi shows that 65% to 85% reductions in the hexa- and penta-inositol phosphate can be achieved by soaking maize flour before making it into porridges for infant and child feeding. Smaller reductions in phytate can be gained by incorporating germinated cereals high in phytase as an additive (ie, 5% of total cereal), This strategy simultaneously enhances micronutrient density due to hydrolysis of amylose and amylopectin to dextrins and maltose induced by enhanced α-amylase activity during germination.[5] As a result, the viscosity of thick cereal porridges (ie, 20%-25% dry matter) can be reduced to a semi-liquid consistency suitable for infant feeding (ie, an acceptable viscosity, 3000 centipoise) without diluting with water.

The bioavailability of non-heme Fe or Zn in the complementary foods can also be improved by enriching the complementary foods with sources of absorption enhancers such as ascorbic acid (for non-heme Fe), other organic acids and cellular animal protein (for non-heme iron and Zn), and fat (for retinol and provitamin A carotenoids). These enhancers can be added in the form of fresh fruits (eg, citrus fruits), vegetables (eg, tomatoes, green leaves), legumes (eg, ground nut flour) or small amounts of meat, poultry or fish (perhaps as dried flours) and their inclusion in complementary foods should be encouraged.[5]

Future Strategies for Increasing the Content and Bioavailability of Micronutrients in Complementary Foods

In the future, possibilities exist for increasing the content of certain micronutrients (eg, Zn, Fe, Se) in cereal staples used for complementary foods by using "field fortification" strategies such as use of soil (for Zn and Se) or foliage (for Fe) fertilizers, or plant breeding to produce cereal varieties with increased grain micronutrient content (eg, Zn, Fe). Alternatively, genetic engineering can be used to alter the content of absorption modifiers in cereal staples by increasing the content of promoters (eg, methionine for Zn and Fe), decreasing the content of inhibitors such as phytic acid to <50% of the original levels, and/or manipulating the phytase content of low phytase cereals (eg, rice) to enhance enzymatic-induced phytate hydrolysis.[8]

Micronutrient Fortification of Complementary Foods

Even if the strategies outlined above are employed, they will probably not be sufficient to overcome the deficits in Fe and Zn in many home-based complementary foods used in developing countries. Consequently, the feasibility of fortifying plant-based complementary foods with a multi-micronutrient fortificant must be considered. The fortificants selected must be safe, stable, acceptable, bioavailable, and added at levels that do not induce any adverse nutrient-nutrient interactions or influence the organoleptic qualities and shelf-life of the complementary food. Ideally, protected fortificants that are resistant to common inhibitors (eg, phytic acid) of iron (ie, sodiumFe-ethylenediamine-tetraacetic acid [EDTA]), zinc (ie, amino acid chelate), Cu, and probably Mn should be used. In developing countries where use of centrally processed fortified complementary foods is not feasible, use of micronutrient "sprinkles," possibly with added phytase enzyme, packaged in sachets so that they can be used by rural mothers, may be a feasible strategy, although quality assurance issues should be addressed. Tentative levels of micronutrients to be added to complementary foods have been published in the summary of the workshop on Micronutrient Interactions.[10] These recommended levels for fortifying complementary foods are not applicable for the treatment of severely malnourished infants and children who have special micronutrient requirements.

Research Issues

These can be summarized as follows:

1. Generate more comprehensive data on the content and bioavailability of micronutrients in complementary foods used in developing countries.
2. Determine how actual micronutrient intakes (per day and per 100 kcal) from complementary foods compare with the estimated needs and desirable nutrient densities for infants of various ages and seasons.
3. Determine what improvements in the micronutrient content and bioavailabilty of complementary foods can be expected by using dietary strategies at the crop production and household levels.
4. Develop better biochemical indices of Zn, Mn, Se, niacin, and B-2 status to confirm whether deficiencies of these micronutrients exist in infants in developing countries, and the extent to which they are associated with adverse health consequences.
5. Establish the optimal levels and forms of micronutrient fortificants for complementary foods for use by apparently healthy and severely malnourished infants.
6. Determine the efficacy and effectiveness of using food-based strategies to improve the content and bioavailabilty of micronutrients in complementary foods on micronutrient status, growth, morbidity, cognitive development, and mortality in infants in developing countries.

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