

# Dietary interventions to prevent zinc deficiency<sup>1-3</sup>

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**ABSTRACT** This review describes household dietary strategies to improve the content and bioavailability of zinc in predominantly plant-based diets and the implementation of these strategies in a community-based dietary intervention study in rural southern Malawi. The strategies involve increasing intakes of foods with high bioavailable-zinc contents, absorption enhancers, or both and using germination, fermentation, and soaking to reduce intake of phytic acid, a potent inhibitor of zinc absorption. The strategies were implemented at the household level in Malawi through a participatory research process that focused on building relationships with the community and involving them in the design, implementation, and monitoring and evaluation processes. In this way, community participation and awareness of zinc deficiency might be enhanced and the dietary strategies planned will be appropriate and sustainable. *Am J Clin Nutr* 1998; 68(suppl):484S-7S.

**KEY WORDS** Dietary strategies, bioavailable zinc, participatory research, rural Malawi, zinc deficiency

## INTRODUCTION

Dietary modification and diversification involve changes in food selection patterns and traditional household methods for preparing and processing indigenous foods. These strategies are more culturally acceptable, equitable, economically feasible, and sustainable than supplementation and fortification, and can be used to alleviate several micronutrient deficiencies simultaneously, without the risk of antagonistic interactions. Furthermore, they are community based and hence can enhance community and human development (1). However, knowledge of local dietary patterns; knowledge of food beliefs, preferences, and taboos; knowledge of information on the availability and cost of foods; and the ability to change attitudes and practices are all prerequisites for effective dietary intervention strategies.

This review describes 4 dietary strategies that were used to enhance the content and bioavailability of dietary zinc in predominantly plant-based diets of rural southern Malawi. We anticipate that the principles involved in the strategies should be widely applicable to other regions in sub-Saharan Africa where unfermented maize is the major staple food. After the discussion of these 4 strategies and the principles involved, we describe their implementation in a community-based dietary intervention in rural southern Malawi.

## DIETARY STRATEGIES TO PREVENT ZINC DEFICIENCY IN RURAL SOUTHERN MALAWI

The strategies outlined below can be implemented at the household level. They are designed to improve both the content and bioavailability of zinc by increasing the consumption of flesh foods, which are rich sources of readily available zinc, and making certain modifications to food preparation and processing practices to reduce the amount of higher inositol phosphates in the diet. The latter are potent inhibitors of zinc absorption in many plant-based staples.

### Increase intakes of foods with a high content and bioavailability of zinc

Several species of fish caught in Lake Malawi are sold fresh or dried in local markets. Currently, fish, as well as meat such as chicken and goat, are sold for cash and are often not consumed by rural Malawian families. Fish is a rich source of readily available zinc and its consumption is encouraged. Consumption of boiled, ground nuts as snacks and the addition of ground-nut flour to maize-based porridges and nsima are also being recommended to enhance the zinc density, as well as that of energy, fat, and iron, of the rural diets.

### Increase intakes of foods known to enhance zinc absorption

Certain amino acid- and cysteine-containing peptides, released during the digestion of cellular animal proteins (ie, from fish, chicken, and goat) and organic acids (eg, citric, lactic, acetic, butyric, and formic acids) produced during fermentation, enhance zinc absorption, possibly by forming soluble ligands with zinc or by preventing the formation of the insoluble zinc-phytate complex (2, 3).

### Use soaking, germination, and fermentation to induce phytase hydrolysis of phytic acid (*myo*-inositol hexaphosphate)

Most plant-based foods contain some phytase enzymes, although in dry or dormant seeds activity is negligible. The

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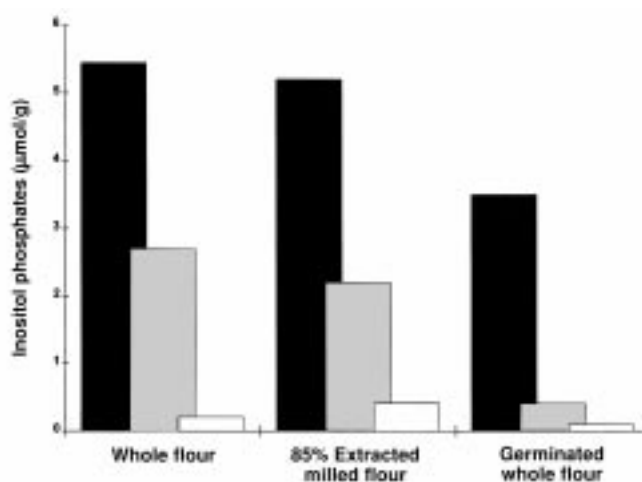
amount of phytase activity depends on the species and variety; tropical cereals such as maize and sorghum have a lower endogenous phytase activity (EC 3.1.3.26) than do wheat and rye (4). Phytase enzymes hydrolyze phytic acid to yield inorganic orthophosphate and *myo*-inositol via intermediate *myo*-inositol phosphates (IP-5, IP-4, IP-3, IP-2, and IP-1), the extent of hydrolysis depending on the stage of germination, pH, moisture content, temperature, solubility of the phytate, and presence of certain inhibitors. Only the higher inositol phosphates (IP-5 and IP-6) inhibit zinc (and nonheme iron) absorption (5).

During germination, phytase activity in cereals and legumes increases as a result of *de novo* synthesis, activation of endogenous phytase, or both (6), the rate of phytic acid hydrolysis varying with the species and variety. Hence, to enhance enzymatic hydrolysis of phytate, some germinated cereal or legume flours should be added to the ungerminated maize flour before soaking the slurry in water at ambient temperature for  $\approx 12$ –24 h to allow phytase-induced hydrolysis of phytate to occur. **Figure 1** shows the reduction in IP-6 and IP-5 that can be achieved after soaking germinated whole sorghum flour compared with soaking ungerminated 85% extracted and untreated whole sorghum flour (7).

$\alpha$ -Amylase activity is also increased during germination. These enzymes hydrolyze amylose and amylopectin to dextrins and maltose. As a result, addition of some germinated flour (at concentrations of 1–5%) can also be used to reduce the viscosity of thick porridges prepared from flour concentrations of 20–25%. This generates an easy-to-swallow, semi-liquid consistency (viscosity of 3000 cPa) suitable for infant and child feeding without dilution with water (8). Such gruels will have higher energy and nutrient densities, including zinc, but lower phytate-to-zinc molar ratios, which are important advantages for infant and child feeding.

Microbial fermentation can also enhance zinc bioavailability via hydrolysis induced by microbial phytase enzymes (EC 3.1.3.8) derived from naturally occurring microflora on the surface of cereal grains or from microbial starter cultures (9). Microbial phytases act over a broader pH range (1.0–7.5) than cereal phytases (4.5–5.0) (10), enabling phytate hydrolysis to occur even when the pH has fallen to a level required to reduce the growth of diarrheal pathogens (ie,  $<4.0$ ). Phytate reductions after fermentation may be as high as 98% for a variety of fermented products based on cassava, cocoyam, maize, sorghum, rice, soybeans, cowpeas, and lima beans consumed in West Africa (11, 12), depending on the conditions of preparation, storage, and cooking. Note in Figure 1 the even greater reduction in the IP-6 and IP-5 content after fermenting the sorghum porridges (7). Microbial enzymes may also partially solubilize cellulose and hemicellulose and thus decrease the dietary fiber content of the plant (13). However, it has also been suggested that although there is a slight increase in insoluble fiber during fermentation, soluble fiber decreases so that there is no net change in fiber content (14). The organic acids, such as lactic, acetic, butyric, propionic, and formic acids, produced during fermentation, may further potentiate zinc absorption by forming soluble ligands with zinc (2). Fermentation also reduces the energy required for cooking and improves the safety of the final food product because the reduced pH inhibits the growth of diarrheal pathogens during fermentation (9).

In the future, pure culture microorganisms may be developed that reduce the fermentation times necessary to decrease or eliminate phytic acid and other antinutrients (eg, polyphenols), and



**FIGURE 1.** Effect of soaking and fermentation on the inositol phosphate (IP-6 and IP-5) content of different sorghum porridges made from whole flour, milled flour (85% extraction), and germinated whole flour. ■, untreated; ▒, soaked for 12 h at pH 6; □, fermented for 48 h. Modified from reference 7.

may enhance the nutrient content and quality, and avoid toxin production problems (9). Alternatively, commercial phytase enzymes prepared from *Aspergillus oryzae* or *A. niger*, which are stable over wide pH (3.5–7.8) and temperature ranges, could theoretically be used (15), although their high cost precludes their use in Malawi at the present time.

#### Use nonenzymatic methods to reduce the phytic acid content of plant-based staples

The phytic acid content of some plant-based staples can also be reduced nonenzymatically by thermal processing, soaking, and milling. The extent of the degradation depends on the plant species, variety, and conditions such as temperature, pH, and presence of certain cations.

Thermal processing at high temperatures may induce some partial nonenzymatic hydrolysis of phytic acid (16), the degree of hydrolysis depending on the product, time, pH, and the presence of calcium, magnesium, and sodium ions. In some legumes, heat treatment may actually result in the formation of insoluble calcium and magnesium phytate salts from soluble potassium salts (17). In general, use of excessive or harsh heat treatments (eg, extrusion cooking) is not a practical method for destroying phytic acid because such treatments also reduces nutrient bioavailability (including zinc) by causing chemical changes (18, 19). Mild heat treatment increases the digestibility of most foods and appears to reduce the phytic acid content of tubers, but not of cereals and legumes (11).

Soaking is a practical method that is being recommended in rural southern Malawi to reduce the phytic acid content of maize and most legumes, including soybeans, because their phytic acid is stored in a relatively water-soluble form such as sodium or potassium phytate and hence can be removed by diffusion. Concentrations of water-soluble phytate range from 10% in defatted sesame meal to 70–97% in California small white beans, red kidney beans, corn germ, and soya flakes (15, 20, 21). There are discrepancies in the reported amounts of soluble phytic acid in these staples, perhaps produced by variations in the conditions

used to extract the phytic acid, pH, and the content of protein, calcium, and magnesium ions. Soaking may also remove other antinutrients such as saponins and polyphenols (22).

Combinations of prior soaking of maize flour containing germinated flour as an additive and fermentation with use of a microbial starter culture as shown in Figure 1 can result in further reductions in the IP-5 and IP-6 content of sorghum-based porridges (7). Addition of the microbial starter culture provides a source of exogenous microbial phytases that act over a wider pH range (2.5–5.5) than cereal phytases. Such a combination of strategies enhances the bioavailability of zinc and nonheme iron while simultaneously improving protein quality and digestibility, improving microbiological safety, and maintaining quality (10).

Milling can also be used to reduce the phytic acid (and dietary fiber) content of cereals and some oil seeds (except soybeans), provided phytic acid is localized within a specific part of the grain or seed. For example, most of the phytic acid is localized in the outer aleurone layers in wheat, triticale, rice, sorghum, and rye, whereas 90% of the phytic acid in maize is in the germ (23). Because most of the zinc (as well as iron, calcium, magnesium, manganese, and copper) is also removed after refining, the molar ratios of phytate to zinc in refined cereals are not dramatically reduced. By contrast, the cotyledons, not the seed coats, contain most of the phytate in peas and beans, so that if the testa is removed, the phytate concentration actually increases.

#### APPLICATION OF DIETARY STRATEGIES TO IMPROVE ZINC NUTRITION IN RURAL SOUTHERN MALAWI

The Tulumbe Nutrition Project, located in the Mangochi district in rural southern Malawi, is a collaborative dietary intervention between the Department of Community Health, College of Medicine, and Bunda College of Agriculture, University of Malawi, and the Department of Human Nutrition, University of Otago, New Zealand. The name “Tulumbe,” which means “let us be strong,” was chosen by the group leaders of the community because it embodies the idea of empowerment or self-reliance.

Rural Malawi was selected as the site for this intervention because it is a country in which dietary zinc deficiency is likely to be widespread. Staple diets in Malawi are predominantly plant based; intakes of flesh foods, a rich source of readily available zinc, are low (24). In rural southern Malawi the major staple is a stiff, unfermented maize-based porridge (nsima) consumed with relishes prepared from green leaves, legumes, and occasionally fish. As a result, the staple diet contains high concentrations of phytic acid and dietary fiber. Phytic acid is the most potent inhibitor of zinc absorption, forming insoluble zinc–phytic acid complexes at the pH of most food. As well, high amounts of insoluble cereal and vegetable fibers (eg, cellulose and lignin) may exacerbate the adverse effect of phytate on zinc absorption, especially in the presence of low protein intakes. Hence, the bioavailability of zinc in rural Malawian diets is low (24).


Before implementing the dietary strategies described above, we used dietary survey data to develop some modified menus for rural Malawian children aged 4–6 y. Next, we assessed the effect of these modifications on the calculated intakes of zinc and selected nutrients and the molar ratios of phytate to zinc, with use of our Malawian food composition tables. Details of the nutrient and antinutrient concentrations of these modified menus for Malawian children were described earlier (24). Relishes prepared from okra, pumpkin leaves, and small fish; snacks of

boiled ground nuts; nsima and porridges prepared from fermented unrefined maize (ie, mgaiwa) instead of unfermented refined maize (ufa); and the addition of ascorbic acid–rich fruit to meals (to enhance nonheme iron absorption) were some of the modifications incorporated into the proposed menus. Calculated results confirmed that the dietary strategies markedly reduced the phytate-to-zinc molar ratios of the diets while simultaneously increasing the content of other limiting nutrients such as protein, calcium, and riboflavin.

The next step was to implement these dietary strategies in a community setting in rural southern Malawi. A team of specialists in agriculture, foods and nutrition, dietetics and home economics, psychology, rural extension, and community health have been involved in this multidisciplinary project. A participatory research process is being used that focuses on building relationships with the community and involving them in the design, implementation, and monitoring and evaluation processes. In this way, community participation and awareness of micronutrient malnutrition will be enhanced and the dietary strategies planned will be appropriate and sustainable (25–27).

The participatory research process used for the Tulumbe Nutrition Project began by formulating an organizational structure for community participation and ownership at national, regional, district, and program area levels (26). At the district level, a consultative committee was made up of district officers and field staff representing the Ministry of Agriculture’s Rural Development Project, the Ministry of Health’s District Hospital, the Ministry of Community Services and Social Welfare, and a non-governmental organization. The committee met quarterly with the Tulumbe project team who reported on Tulumbe activities and sought advice on implementing, monitoring, and evaluating the dietary strategies. These same district officers were also invited to a series of workshops held in conjunction with their own field staff, program area field staff, and the community leaders of the intervention and comparison villages to plan the activities associated with the dietary interventions.

At the program area level, community leaders included village headmen, councilors, religious leaders, initiation leaders, leaders of political parties, traditional birth attendants, and teachers. Agricultural and health clubs in the communities were also consulted. The health club had drama groups and bands who conveyed Tulumbe messages through plays and songs. Finally, a cadre of group leaders, both men and women, were elected by the village communities. These volunteers were consulted and trained by Tulumbe program staff to direct and implement the dietary interventions.

In summary, dietary strategies that do not jeopardize overall dietary adequacy can be devised to enhance the content and bioavailability of zinc in predominantly plant-based diets. These strategies should be introduced into rural communities through a participatory research process involving nutrition communication and social marketing strategies that aim to change attitudes and food-related behaviors and practices in an effort to enhance adoption and sustainability. 

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