Traditional Food-Processing and Preparation Practices to Enhance the Bioavailability of Micronutrients in Plant-Based Diets[1]

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Abstract

Dietary quality is an important limiting factor to adequate nutrition in many resource-poor settings. One aspect of dietary quality with respect to adequacy of micronutrient intakes is bioavailability. Several traditional household food-processing and preparation methods can be used to enhance the bioavailability of micronutrients in plant-based diets. These include thermal processing, mechanical processing, soaking, fermentation, and germination/malting. These strategies aim to increase the physicochemical accessibility of micronutrients, decrease the content of antinutrients, such as phytate, or increase the content of compounds that improve bioavailability. A combination of strategies is probably required to ensure a positive and significant effect on micronutrient adequacy. A long-term participatory intervention in Malawi that used a range of these strategies plus promotion of the intake of other micronutrient-rich foods, including animal-source foods, resulted in improvements in both hemoglobin and lean body mass and a lower incidence of common infections among intervention compared with control children. The suitability of these strategies and their impact on nutritional status and functional health outcomes need to be more broadly assessed. J. Nutr. 137: 1097–1100, 2007.

In resource-poor communities, it has become clear that malnutrition is attributable not solely to insufficient amounts of food but also to the poor nutritional quality of the available food supply (1,2), particularly among plant-based diets containing only small amounts of micronutrient-dense animal-source foods. The low bioavailability of nutrients, arising from the presence of antinutrients such as phytate, polyphenols, and oxalate, is another factor that limits the quality of predominantly plant-based diets (3,4). Given the heavy reliance of low-income populations on cereals as a food source, the negative effects of low mineral bioavailability on mineral status and subsequent health are potentially quite substantial. A variety of interventions that are appropriate for the rural poor need to be considered to overcome these limitations.

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Several traditional food-processing and preparation methods can be used at the household level to enhance the bioavailability of micronutrients in plant-based diets. These methods include thermal processing, mechanical processing, soaking, fermentation, and germination/malting. These methods have been discussed in detail elsewhere (5) and are summarized briefly below.

Thermal processing

Thermal processing may improve the bioavailability of micronutrients such as thiamin and iodine by destroying certain antinutritional factors (e.g., goitrogens, thiaminases), although whether it degrades phytate, a potent inhibitor of iron, zinc, and calcium absorption, depends on the plant species, temperature, and pH. There is some evidence that boiling of tubers (5,6) and blanching of green leaves (7) induce moderate losses (i.e., 5–15%) of phytic acid. Thermal processing can also enhance the bioavailability of thiamin, vitamin B-6, niacin, folate, and carotenoids by releasing them from entrapment in the plant matrix (6,8). However, whether such improvements in bioavailability compensate for the losses in activity of heat-labile and water-soluble vitamins (e.g., thiamin, riboflavin, vitamin C, folate) remains to be determined. To minimize the oxidation of carotenoids and loss in cooking water, shorter cooking times and use of steaming rather than boiling are recommended (8).

Mechanical processing

Household pounding is used to remove the bran and/or germ from cereals, which in turn may also reduce their phytate content when it is localized in the outer aleurone layer (e.g., rice, sorghum, and wheat) or in the germ (i.e., maize) (9). Hence, bioavailability of iron, zinc, and calcium may be enhanced, although the content of minerals and some vitamins of these pounded cereals is simultaneously reduced. In some industrialized countries, milled cereal flours are enriched to compensate for the micronutrients lost. Methods that can reduce the phytate content of cereals while maintaining the maximum amount of micronutrients would be most beneficial, and these include soaking, fermentation, and germination/malting, as described below.

The mechanical processing of vegetables may help to improve the bioavailability of carotenoids by disrupting the subcellular membranes in which they are bound and making them more accessible for micellarization. Results from several studies directly comparing different mechanical processing methods have been equivocal (10). This effect requires better quantification among vitamin A–deficient populations, and its relevance to the adaptation of usual preparation practices needs to be explored.

Soaking

Soaking cereal and most legume flours (but not whole grains or seeds) in water can result in passive diffusion of water-soluble Na, K, or Mg phytate, which can then be removed by decanting the water (11,12). The extent of the phytate reduction depends on the species, pH, and length and conditions of soaking. A simple soaking procedure appropriate for rural subsistence households has been developed that can reportedly reduce the phytate content of unrefined maize flour by ~50% (12). This is important because several recent in vivo isotope studies in adults (13–16) and infants (17) have reported improvements in absorption of iron, zinc, and calcium in cereal-based foods prepared with a reduced phytate content. Some polyphenols and oxalates that inhibit iron and calcium absorption, respectively, may also be lost by soaking (5).

Fermentation

Fermentation can induce phytate hydrolysis via the action of microbial phytase enzymes, which hydrolyze phytate to lower inositol phosphates. Such hydrolysis is important because *myo*-inositol phosphates with <5 phosphate groups (i.e., IP-1 to IP-4) do not have a negative effect on zinc absorption (18), and those with <3 phosphate groups do not inhibit nonheme iron absorption (19,20).

Microbial phytases originate either from the microflora on the surface of cereals and legumes or from a starter culture inoculate (21). The extent of the reduction in higher inositol phosphate levels during fermentation varies; sometimes 90% or more of phytate can be removed by fermentation of maize, soy beans, sorghum, cassava, cocoyam, cowpeas, and lima beans. In cereals with a high tannin content (e.g., bulrush millet and red sorghum), phytase activity is inhibited, making fermentation a less-effective phytate-reducing method for these cereal varieties (21). Fermentation also improves protein quality and digestibility, vitamin B content, and microbiological safety and keeping quality.

Low-molecular-weight organic acids (e.g., citric, malic, lactic acid) are also produced during fermentation and have the potential to enhance iron and zinc absorption via the formation of soluble ligands while simultaneously generating a low pH that optimizes the activity of endogenous phytase from cereal or legume flours (22). Most of the evidence for the enhancing effect of organic acids on iron and zinc absorption has been based on in vitro dialyzability studies and needs to be confirmed by in vivo stable isotope absorption studies.

Germination/malting

Germination/malting increases the activity of endogenous phytase activity in cereals, legumes, and oil seeds through de novo synthesis, activation of intrinsic phytase, or both. Tropical cereals such as maize and sorghum have a lower endogenous phytase activity than do rye, wheat, triticale, buckwheat, and barley (23). Hence, a mixture of cereal flours prepared from germinated and ungerminated cereals will promote some phytate hydrolysis when prepared as a porridge for infant and young child feeding. The rate of phytate hydrolysis varies with the species and variety as well as the stage of germination, pH, moisture content, temperature (optimal range 45–57°C), solubility of phytate, and the presence of certain inhibitors (19,23). Egli et al. (23) observed that during germination, rice, millet, and mung bean had the largest reductions in phytate content.

α-Amylase activity is also increased during germination of cereals, especially sorghum and millet. This enzyme hydrolyzes amylase and amylopectin to dextrins and maltose, thus reducing the viscosity of thick cereal porridges without dilution with water while simultaneously enhancing their energy and nutrient densities (24). Certain tannins and other polyphenols in legumes (e.g., *Vicia faba*) and red sorghum may also be reduced during germination as a result of the formation of polyphenol complexes with proteins and the gradual degradation of oligosaccharides (25). Such reductions in polyphenols may facilitate iron absorption.

Combined strategies

These effects emphasize that an integrated approach that combines a variety of the traditional food-processing and preparation practices discussed above, including the addition of even a small amount of animal-source foods, is probably the best strategy to improve the content and bioavailability of micronutrients in plant-based diets in resource-poor settings (26). Use of such a combination of strategies can almost completely remove phytate. This is important because phytic acid is a potent inhibitor of iron absorption, even at low concentrations (20).

In a large community-based randomized controlled trial of 6-mo-old Tanzanian infants, the effects of feeding unprocessed and processed complementary food on anemia and iron status were compared (27). The processed complementary food was based on soaked and germinated finger millet and kidney beans with roasted peanuts and mango puree. No significant differences in hemoglobin or zinc protoporphyrin concentrations between the 2 groups were reported after 6 mo, perhaps in part because there was only a 34% reduction in the phytate content of the processed complementary food. Although the phytate:iron molar ratio was lower in the processed food (11.8) than in the unprocessed food (16.5), the ratio was still quite high and may not permit significant improvements in iron absorption. Further, the unprocessed food had a higher total iron content than the processed food (5.9 vs. 4.7 mg/100 g dry matter). Phytate:iron ratios that permit significantly improved iron absorption from plant-based diets should be determined so that diets can be designed to optimize iron bioavailability. Hair zinc concentration was also not improved in the infants consuming the processed complementary food (28).

We have employed a combination of traditional food-processing and preparation practices, including the addition of animal-source foods, notably fish, in 2 community-based trials among weanlings and young children in rural Malawi. Details of these strategies and their implementation have been published earlier (24,26,29,30). Briefly, the strategies used in the children's study (24,26,29) included germination, fermentation, and soaking to reduce phytate content of maize and/or legumes, incorporating foods that may lead to enhanced iron, zinc, and provitamin A carotenoids, and increasing the production and consumption of micronutrient-dense foods (e.g., orange-red fruits, flesh foods, including whole dried fish with bones). The pilot study with weanlings (30) focused on soaking methods to reduce the phytate content of maize, methods to enrich weaning foods with nutritious ingredients available in the community including animal-source foods, methods to increase the energy density of maize porridges, and feeding behaviors that encourage weanlings to eat (30).

The efficacy of these interventions was evaluated by determining knowledge, trial and adoption of the new practices, comparing dietary quality and the adequacy of the energy and nutrient intakes of the intervention and control groups post-intervention (26,30), and, for the children only, changes in growth and body composition, morbidity, and hemoglobin and hair zinc concentrations (29). In the weanlings, higher intakes of bioavailable zinc and iron in the intervention group were attributed to the higher total intakes and intakes of animal-source foods (i.e., meat, poultry, or fish) rather than to the phytate-reducing methods because the latter were not yet used widely enough to result in a significant reduction in phytate of the whole diet (30). Among the children, dietary strategies significantly reduced the prevalence of inadequate intakes of protein, calcium, zinc, and vitamin B-12 (26). The estimated amount of bioavailable zinc was significantly higher in the intervention group, and this was partly attributed to significantly higher intakes of animal-source foods (i.e., fish) and a significantly lower phytate:zinc molar ratio in the diet of the intervention group. The estimated amount of bioavailable iron in the diet was not higher in the intervention group, but it is noteworthy that the algorithm used to estimate nonheme iron bioavailability did not take phytate into account. After controlling for baseline variables, mean hemoglobin was higher postintervention, whereas incidence of anemia and common infections was lower in the intervention compared with the control groups, with no change in malaria incidence or hair zinc status (26). To be sustainable, however, such strategies must be integrated with ongoing national agriculture, food, nutrition, and health education programs and implemented using a participatory approach to ensure their acceptability and adoption.

The identification and suitability of different processing strategies on nutritional adequacy in resource poor populations should be assessed in other settings. Despite the promotion of household-level food processing and other food-based strategies to improve nutritional adequacy, there has been little effort to assess their impact in well-designed trials. Further studies of the efficacy of these strategies to determine their impact on nutritional status are needed. In particular, controlled, long-term feeding trials are needed to provide information on the specific goals for phytate reduction that would result in a measurable impact on mineral status. Strategies found to be suitable and with good potential of improving micronutrient intakes could be integrated into existing interventions to improve the quality of diets, particularly those interventions that provide nutrition and health education at the community level.

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