A review of phytate, iron, zinc, and calcium concentrations in plant-based complementary foods used in low-income countries and implications for bioavailability

Rosalind S. Gibson, Karl B. Bailey, Michelle Gibbs, Elaine L. Ferguson

Abstract

Plant-based complementary foods often contain high levels of phytate, a potent inhibitor of iron, zinc, and calcium absorption. This review summarizes the concentrations of phytate (as hexa- and penta-inositol phosphate), iron, zinc, and calcium and the corresponding phytate:mineral molar ratios in 26 indigenous and 27 commercially processed plant-based complementary foods sold in low-income countries. Phytate concentrations were highest in complementary foods based on unrefined cereals and legumes (~600 mg/100 g dry weight), followed by refined cereals (~100 mg/100 g dry weight) and then starchy roots and tubers (< 20 mg/100 g dry weight); mineral concentrations followed the same trend. Sixty-two percent (16/26) of the indigenous and 37% (10/27) of the processed complementary foods had at least two phytate:mineral molar ratios (used to estimate relative mineral bioavailability) that exceeded suggested desirable levels for mineral absorption (i.e., phytate:iron < 1, phytate:zinc < 18, phytate:calcium < 0.17). Desirable molar ratios for phytate:iron, phytate:zinc, and phytate:calcium were achieved for 25%, 70%, and 57%, respectively, of the complementary foods presented, often through enrichment with animal-source foods and/or fortification with minerals. Dephytinization, either in the household or commercially, can potentially enhance mineral absorption in high-phytate complementary foods, although probably not enough to overcome the shortfalls in iron, zinc, and calcium content of plant-based complementary foods used in low-income countries. Instead, to ensure the World Health Organization estimated needs for these minerals from plant-based complementary foods for breastfed infants are met, dephytinization must be combined with enrichment with animal-source foods and/or fortification with appropriate levels and forms of mineral fortificants.

Key words: Bioavailability, calcium, children, complementary foods, infants, iron, low-income countries, phytate, zinc

Introduction

Complementary foods based almost exclusively on plants are often the major source of energy and nutrients from nonmilk foods for many infants and young children living in resource-poor households in low-income countries; consumption of animal-source foods is often low due to economic or religious concerns. Such plant-based complementary diets are frequently associated with micronutrient deficits, notably of iron, zinc, and calcium [1, 2], exacerbated in part by poor bioavailability, especially when the complementary foods are based on unrefined cereals and legumes. Unrefined cereals and legumes have a high content of phytate, a potent inhibitor of mineral absorption [3]. Moreover, if these high-phytate complementary foods are consumed with breastmilk, they may actually compromise the bioavailability of certain minerals in the breastmilk [4]. Such deficits in iron, zinc, and calcium can have far-reaching adverse consequences on growth, health, and cognitive development during childhood.

Several strategies, including the addition of organic acids (especially ascorbic acid), ethylenediaminetetraacetic acid (EDTA) complexes, and dephytinization, have the potential to reduce the negative effect of phytate on mineral absorption in cereal- and/or legume-based complementary foods. Only the impact of dephytinization on absorption of both intrinsic and mineral fortificants will be discussed in this review; details of the other approaches are available elsewhere [5, 6]. It is recognized, however, that the impact of
Phytate, iron, zinc, and calcium concentrations in plant-based complementary foods

dehyphinization alone on overcoming the mineral de-
cits in complementary foods that contain high levels of
phytate can be expected to be limited, and additional
strategies, including enrichment of the complementary
foods with animal-source and vitamin C–rich foods
and fortification, should also be considered.

This review discusses the effect of phytate on mineral
bioavailability, discusses the chemical analysis of phytate
and minerals in complementary foods, and summarizes
the phytate, iron, zinc, and calcium concentrations of
indigenous and processed plant-based complementary
foods used in low-income countries. Molar ratios
of phytate:iron, phytate:zinc, and phytate:calcium are
also presented to provide an estimate of the relative
bioavailability of these minerals in the complementary
foods. The concentrations of phytate and minerals
were calculated for the indigenous complementary
foods from traditional recipes using food composition
values, whereas for the manufactured processed com-
plementary foods, concentrations were determined by
direct chemical analysis. Strategies at the household
or commercial level that have the potential to reduce
the phytate content of cereal- and/or legume-based
complementary foods used in low-income countries,
and thus enhance absorption to some degree of both
their intrinsic minerals and mineral fortificants, are
also briefly discussed. However, because most of the
research on dietary phytate and mineral bioavailability
has been conducted on adults, caution must be used
when extrapolating these results to the complementary
diets of infants and young children.

Effect of phytate on mineral bioavailability

The term “bioavailability” is defined as the proportion
of an ingested nutrient in food that is absorbed and
utilized through normal metabolic pathways [7]. It is
influenced by both host- and diet-related factors. This
review focuses on the diet-related factors, specifically
the inhibitory effect of phytate on mineral absorption.
Phytate refers to phytic acid (myo-inositol hexaphos-
phate), made up of an inositol ring with six phosphate
groups, and its associated salts: magnesium,
calcium, or potassium phytate. It is noteworthy that
myo-inositol phosphates with less than three phosphate
groups (i.e., IP-1 to IP-4) do not have a negative effect
on zinc absorption [8], whereas myo-inositol phosph-
ates with less than three phosphate groups do not
inhibit iron absorption [9].

Phytate is the principal storage form of phosphorus
in cereals, legumes, and oleaginous seeds. The con-
tent of phytate in cereals varies from 0.06% to 2.22%,
with polished rice containing the lowest amount [10].
In most cereals, phytate is concentrated in the bran
(aleurone layer), although in maize more than 90% is
located in the germ [11]. In whole legumes, the phytate
content ranges from 0.17% to 9.15% and is uniformly
distributed throughout the cotyledons, where it is
associated with protein. Hence, when the hull or seed
coat of legumes is removed, their phytate concentration
increases. Environmental conditions (climate, soil, and
irrigation), fertilizer applications, and stage of matura-
tion influence the phytate content of cereals, legumes,
and oleaginous seeds: the highest levels are reached at
seed maturity [10]. Roots and tubers and most leafy
vegetables and fruits contain very low amounts of
phytate, and animal foods contain none.

Phytic acid chelates metal ions, especially zinc, iron,
and calcium, but not copper [12], forming insoluble
complexes in the gastrointestinal tract that cannot be
digested or absorbed in humans because of the absence
of intestinal phytase enzymes [13]. Phytate also com-
plexes endogenously secreted minerals such as zinc
[14] and calcium [15], making them unavailable for
reabsorption into the body. The inhibitory effect
of phytate on mineral absorption has been confirmed by
in vivo radioactive and stable isotope studies, in which
fractional absorption of iron, zinc, and calcium has
been reported to be significantly lower from diets with
a high content of phytate than from diets with a lower
phytate content [12, 16–19]. This inhibitory effect is
now recognized to be exaggerated, at least for iron [20]
and zinc [21], in single test meal studies compared with
that obtained on total diets.

At present, studies on the influence of phytate on
the bioavailability of iron, zinc, and calcium in infants
and young children are limited. Hence, whether the
phytate-to-mineral molar ratios said to be desirable
for adult diets are also appropriate for complementary
diets of infants and young children is unclear [22].
Likewise, whether children have the ability to adapt to
the inhibitory effect of a high-phytate complementary
diet on absorption of these minerals is uncertain. There
is some evidence that adults can adapt to diets with a
low content of zinc and phytate by increasing intestinal
zinc absorption. However, no comparable adaptation
appears to occur with high-phytate diets [23], although
there may be some decrease in endogenous excre-
tion of fecal zinc [24]. Similarly, iron absorption is
not increased in adults consuming high-phytate diets
[25], a trend that is probably also apparent in children,
given that the effects of enhancers and inhibitors on
iron absorption are comparable in adults and infants
[26]. Unlike zinc and iron, the high phytate content
of cereal-based complementary foods does not have
a major impact on calcium status during infancy and
early childhood: apparent absorption of calcium was
reported to be high (60%) in infants receiving a high-
phytate complementary food [27]. Instead, calcium
deficiency among young children is more likely to be
due to a low intake rather than poor absorption [28].

The adverse effect of phytate on zinc absorption fol-
lows a dose-dependent response [29], and there is no
threshold for the inhibitory effects of dietary phytate on zinc bioavailability [30]. Indeed, Hambidge and coworkers [18] have demonstrated a negative relationship between fractional zinc absorption and dietary phytate over a range of dietary phytate:zinc molar ratios from 7:1 to 37:1.

There is some evidence that high dietary calcium impairs zinc absorption, but probably only in the presence of high intakes of phytate. Certainly, fractional zinc absorption from corn bread was reported to be significantly higher than that from calcium-rich tortillas prepared by nixtamalization of the same maize [31]. Nevertheless, the International Zinc Nutrition Consultative Group (IZiNCG) recommends that the phytate:zinc molar ratio of the diet alone can be used to estimate the negative effect of phytate on zinc bioavailability. They concluded that in most diets, neither calcium (nor protein) adds significant predictive power to the algorithm used to predict the percentage of zinc absorbed. As a result, Hotz and Brown [32] divided diets into two categories based on their range of phytate:zinc molar ratios. For diets with phytate:zinc molar ratios > 18 (i.e., unrefined cereal-based diets), IZiNCG estimates zinc absorption to be 18% and 25% for adult males and females, respectively, whereas for diets with phytate:zinc molar ratios between 4 and 18 (classified as mixed or refined vegetarian diets), the corresponding estimates for adults are 26% and 34%, respectively [32]. Hurrell [33] has estimated, based on data from isotope studies in adults, that in non-zinc-fortified foods, phytate:zinc molar ratios between 4 and 8 should result in a zinc absorption of ~20% in adults. Whether these absorption estimates are applicable to the complementary diets of infants and young children is less certain.

The inhibitory effect of phytic acid on iron absorption is also dose-dependent [34], and occurs even at very low phytate concentrations. For example, even when ratios are as low as 0.2:1.0, phytate still exhibits a strong inhibitory effect [34, 35]. Consequently, where possible, all of the phytate should be degraded from cereal- and legume-based complementary foods to achieve the maximum benefit of a four- to fivefold increase in nonheme iron absorption. If this is not feasible, then the phytate should be reduced so that the phytate:iron molar ratio is less than 1.0:1.0. At this level, iron absorption would be expected to increase twofold, as would zinc absorption in adults [33].

The critical molar ratio above which calcium absorption is compromised by phytate is uncertain, although some investigators suggest that phytate:calcium molar ratios less than 0.17 are desirable [36]. Whether the adverse effect of inositol phosphates on calcium absorption is restricted to the higher inositol phosphates, such as IP5 and IP6, is currently unknown.

Analysis of phytate and mineral concentrations in complementary foods

Selection of the most appropriate method for the analysis of phytic acid is critical. In the past, the method most frequently used was an anion-exchange column separation of phytate, followed by acid hydrolysis and spectrophotometric determination of liberated inorganic phosphorus [37]. However, this method is not specific to inositol hexaphosphate, as it also measures lower inositol phosphates, some of which do not compromise mineral absorption, as noted earlier. Hence, if complementary foods also contain some lower inositol phosphates through phytase-induced hydrolysis, this anion-exchange method should not be used.

The preferred method for the analysis of phytate is the use of high-performance liquid chromatography (HPLC), which can separate and quantify the individual inositol phosphates. Several HPLC methods have been developed for the analysis of inositol phosphates. The most recent method developed by Oberleas and Harland [38] uses a spectrophotometric detector. A standard wheat bran sample is available from the American Association of Cereal Chemists, which can be used to determine the accuracy of the HPLC analytical method for phytate. If this is not available, then an interlaboratory comparison of replicates of a series of internal laboratory controls analyzed by the same HPLC method should be performed. To assess precision, replicates of a pooled sample, such as 95% extraction maize flour, can be analyzed and the inter-run coefficient of variation calculated.

Special precautions must be taken to avoid adventitious contamination during the collection, preparation, and analysis of complementary food samples for trace elements, including iron and zinc; details are given in Gibson and Ferguson [39]. Flame atomic absorption spectrophotometry (AAS) is the most widely used method for mineral analysis, although increasingly, multielement methods, including x-ray fluorescence [40], instrumental neutron activation analysis (INAA), inductively coupled plasma (ICP) spectroscopy, and ICP mass spectrometry, are employed. Some methods (e.g., AAS and ICP) are susceptible to interference from the sample matrix, so the organic material in the samples must first be removed by acid digestion or dry ashing using either a muffle furnace or a microwave digest method. Ashed samples are then dissolved in hyperpure hydrochloric acid prior to analysis. Standard reference materials must be included with each batch of analysis as a check on the accuracy and precision of the analytical procedures. These can be purchased from the National Institute of Standards and Technology (NIST) (Gaithersburg, MD, USA); examples include rice flour (SRM-1568a) and citrus leaves (SRM-1572).
Iron, zinc, calcium, and phytate concentrations of indigenous complementary foods based on recipes from low-income countries

Table 1 summarizes data on the iron, zinc, calcium, and IP5 + IP6 concentrations of complementary foods compiled from indigenous recipes and based on maize, wheat, rice, and starchy roots and tubers. Corresponding phytate:mineral molar ratios are also given.

Details of the recipes have been published earlier [1, 41]. The ingredients of each recipe are listed, together with the concentrations of iron, zinc, calcium, and phytate (expressed as milligrams per 100 g dry weight) and the molar ratios of phytate:zinc, phytate:iron, and phytate:calcium for each complementary food. The mineral and phytate concentrations of most of these complementary foods were calculated from food composition values derived from the analysis of

<table>
<thead>
<tr>
<th>Recipe no.</th>
<th>Ingredients</th>
<th>Iron</th>
<th>Zinc</th>
<th>Calcium</th>
<th>IP5 + IP6</th>
<th>Phytate: iron</th>
<th>Phytate: zinc</th>
<th>Phytate: calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>17:10:5:68 unrefined maize flour, cowpeas, groundnuts, water</td>
<td>3.4</td>
<td>2.2</td>
<td>19</td>
<td>634</td>
<td>15.8</td>
<td>29</td>
<td>2.03</td>
</tr>
<tr>
<td>2</td>
<td>8:2:90 unrefined maize flour, soy flour, water</td>
<td>3.0</td>
<td>3.0</td>
<td>50</td>
<td>770</td>
<td>21.7</td>
<td>25</td>
<td>0.94</td>
</tr>
<tr>
<td>3</td>
<td>20:3:4:1:72 unrefined maize flour, soy flour, groundnuts, sorghum, water</td>
<td>2.9</td>
<td>2.5</td>
<td>39</td>
<td>643</td>
<td>18.7</td>
<td>25</td>
<td>1.00</td>
</tr>
<tr>
<td>4</td>
<td>20:80 Refined maize grits (sieved), water</td>
<td>0.6</td>
<td>0.5</td>
<td>4</td>
<td>62</td>
<td>8.7</td>
<td>12</td>
<td>0.94</td>
</tr>
<tr>
<td>5</td>
<td>22:6:72 refined maize flour, soy flour, water</td>
<td>3.2</td>
<td>1.4</td>
<td>46</td>
<td>421</td>
<td>11.1</td>
<td>30</td>
<td>0.56</td>
</tr>
<tr>
<td>6</td>
<td>20:10:70 refined maize grits, mungbean grits, water$^a$</td>
<td>2.2</td>
<td>1.0</td>
<td>35</td>
<td>368</td>
<td>14.0</td>
<td>36</td>
<td>0.64</td>
</tr>
<tr>
<td>7</td>
<td>20:15:65 refined maize grits, chicken liver, water$^a$</td>
<td>10.4</td>
<td>3.5</td>
<td>12</td>
<td>26</td>
<td>0.2</td>
<td>1</td>
<td>0.13</td>
</tr>
<tr>
<td>8</td>
<td>23:7:70 refined maize grits, egg yolk, water$^a$</td>
<td>5.6</td>
<td>3.2</td>
<td>124</td>
<td>29</td>
<td>0.4</td>
<td>1</td>
<td>0.01</td>
</tr>
<tr>
<td>9</td>
<td>25:5:70 refined maize grits, dried anchovy powder, water$^a$</td>
<td>2.5</td>
<td>2.7</td>
<td>784</td>
<td>41</td>
<td>1.4</td>
<td>2</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Based on refined wheat flour

<table>
<thead>
<tr>
<th>Recipe no.</th>
<th>Ingredients</th>
<th>Iron</th>
<th>Zinc</th>
<th>Calcium</th>
<th>IP5 + IP6</th>
<th>Phytate: iron</th>
<th>Phytate: zinc</th>
<th>Phytate: calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>15:12:3:2:68 wheat flour, brown sugar, oil, sorghum, water</td>
<td>2.5</td>
<td>0.9</td>
<td>94</td>
<td>256</td>
<td>8.7</td>
<td>28</td>
<td>0.17</td>
</tr>
<tr>
<td>11</td>
<td>5:95 wheat flour, water</td>
<td>2.1</td>
<td>0.4</td>
<td>10</td>
<td>130</td>
<td>5.2</td>
<td>32</td>
<td>0.79</td>
</tr>
</tbody>
</table>

Based on white rice flour or rice grains

<table>
<thead>
<tr>
<th>Recipe no.</th>
<th>Ingredients</th>
<th>Iron</th>
<th>Zinc</th>
<th>Calcium</th>
<th>IP5 + IP6</th>
<th>Phytate: iron</th>
<th>Phytate: zinc</th>
<th>Phytate: calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>12:88 rice flour, water$^a$</td>
<td>1.7</td>
<td>1.5</td>
<td>31</td>
<td>82</td>
<td>4.1</td>
<td>5</td>
<td>0.16</td>
</tr>
<tr>
<td>13</td>
<td>4:5:1:90 rice flour, mungbeans, sugar, water$^a$</td>
<td>3.9</td>
<td>2.2</td>
<td>79</td>
<td>440</td>
<td>9.5</td>
<td>20</td>
<td>0.34</td>
</tr>
<tr>
<td>14</td>
<td>47:53 rice, water$^a$</td>
<td>0.5</td>
<td>1.5</td>
<td>5</td>
<td>19</td>
<td>3.2</td>
<td>1</td>
<td>0.23</td>
</tr>
<tr>
<td>15</td>
<td>20:10:70 rice, mungbean grits, water$^a$</td>
<td>1.4</td>
<td>2.0</td>
<td>19</td>
<td>275</td>
<td>16.6</td>
<td>14</td>
<td>0.88</td>
</tr>
<tr>
<td>16</td>
<td>20:15:65 rice, chicken liver, water$^a$</td>
<td>10.4</td>
<td>3.5</td>
<td>12</td>
<td>3</td>
<td>0.0</td>
<td>&lt; 1</td>
<td>0.02</td>
</tr>
<tr>
<td>17</td>
<td>23:7:70 rice, egg yolk, water$^a$</td>
<td>4.9</td>
<td>4.5</td>
<td>138</td>
<td>7</td>
<td>0.1</td>
<td>&lt; 1</td>
<td>0.00</td>
</tr>
<tr>
<td>18</td>
<td>25:5:70 rice, dried anchovy, water$^a$</td>
<td>2.2</td>
<td>3.5</td>
<td>663</td>
<td>5</td>
<td>0.2</td>
<td>&lt; 1</td>
<td>0.00</td>
</tr>
<tr>
<td>19</td>
<td>20:4:4:72 rice, soy flour, sesame, water</td>
<td>3.9</td>
<td>2.5</td>
<td>125</td>
<td>504</td>
<td>10.9</td>
<td>20</td>
<td>0.24</td>
</tr>
<tr>
<td>20</td>
<td>7:4:1:7:1:87 rice, kidney beans, roasted sesame, sugar, water</td>
<td>6.9</td>
<td>3.8</td>
<td>377</td>
<td>792</td>
<td>9.7</td>
<td>21</td>
<td>0.13</td>
</tr>
</tbody>
</table>

continued
TABLE 1. Iron, zinc, calcium, and hexa- (IP6)- and penta- (IP5)-inositol phosphate concentrations (mg/100 g dry weight) and phytate:mineral molar ratios of complementary foods based on indigenous recipes from low-income countries (continued)

<table>
<thead>
<tr>
<th>Recipe no.</th>
<th>Ingredients</th>
<th>Iron</th>
<th>Zinc</th>
<th>Calcium</th>
<th>IP5 + IP6</th>
<th>Phytate: iron</th>
<th>Phytate: zinc</th>
<th>Phytate: calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>13:18:24:45 banana flour, peanuts, sugar, water</td>
<td>2.0</td>
<td>1.1</td>
<td>71</td>
<td>113</td>
<td>4.8</td>
<td>10</td>
<td>0.10</td>
</tr>
<tr>
<td>22</td>
<td>72:12:4:8:4 coco yam, avocado, soybeans, coconut milk, pumpkin leaf</td>
<td>1.1</td>
<td>0.6</td>
<td>28</td>
<td>88</td>
<td>6.8</td>
<td>15</td>
<td>0.19</td>
</tr>
<tr>
<td>23</td>
<td>63:17:8:2:10 potato, kale, chick-pea flour, oil, water</td>
<td>1.4</td>
<td>0.4</td>
<td>44</td>
<td>79</td>
<td>4.8</td>
<td>20</td>
<td>0.11</td>
</tr>
<tr>
<td>24</td>
<td>47:28:6:3:3:13 sweet potato, egg, dried skim milk, oil, brown sugar, water</td>
<td>1.8</td>
<td>0.9</td>
<td>122</td>
<td>7</td>
<td>0.3</td>
<td>1</td>
<td>0.00</td>
</tr>
<tr>
<td>25</td>
<td>35:12:41:12 sweet potato, pumpkin leaves, mackerel, water</td>
<td>2.0</td>
<td>0.5</td>
<td>53</td>
<td>14</td>
<td>0.6</td>
<td>3</td>
<td>0.02</td>
</tr>
<tr>
<td>26</td>
<td>16:1:10:4:69 sago flour, refined wheat, brown sugar, oil, water</td>
<td>1.3</td>
<td>0.3</td>
<td>35</td>
<td>16</td>
<td>1.1</td>
<td>5</td>
<td>0.03</td>
</tr>
</tbody>
</table>

a. Based on chemical analysis from recipes prepared in our laboratory

representative samples of staple foods collected from the country in which the recipe originated [40, 42-45]. Data for the few exceptions (identified by a superscript letter a) were based on direct chemical analysis of the complementary foods prepared from the recipes in our laboratory [41, 44].

Not surprisingly, the complementary food recipes based on starchy roots and tubers (recipes 24, 25, and 26), or prepared from white rice (recipe 14, 16, 17, and 18) and no added legumes, had the lowest concentrations of IP5 + IP6. In most cases, these same complementary foods also had very low concentrations of iron and zinc unless they were enriched with animal-source foods (recipes 16, 17, 18, 24, and 25). Molar ratios of phytate:zinc were also very low, indicating that zinc absorption was unlikely to be markedly compromised by phytate. In contrast, not all the complementary foods had phytate:iron molar ratios less than 1, the level considered desirable for iron bioavailability [33]. Indeed, only those complementary foods enriched with animal-source foods in Table 1 had molar ratios of phytate:iron less than 1.

The three complementary food recipes based mainly on unrefined maize with added legumes had some of the highest IP5 + IP6 concentrations, closely followed by those based on a mixture of cereals and legumes, notably soybean flour (recipe 5), mungbeans (recipes 6, 13, and 15), or sesame (recipes 19 and 20). Molar ratios of phytate:zinc, phytate:iron, and phytate:calcium for these complementary foods followed a similar trend, suggesting that, despite their higher iron and zinc concentrations compared with the complementary foods based on starchy roots and tubers, mineral bioavailability is likely to be low.

As expected, complementary foods prepared from recipes containing refined cereals such as degermed maize grits (recipes 7, 8, and 9) or refined wheat flour (recipe 11) (unless another cereal or legume is also included) have lower phytate concentrations than their counterparts prepared from unrefined ingredients, because during processing most of the phytic acid is removed, as noted earlier. However, processing also removes some of the minerals, so that the phytate:mineral molar ratios for complementary foods prepared from refined versus unrefined cereals are not dramatically changed unless they are enriched with animal-source foods such as chicken liver (recipes 7 and 16), whole powdered anchovy with bones (recipes 9 and 18), egg yolk (recipes 8 and 17), or dried skim milk powder (recipe 24). Note that of the enrichment strategies, the complementary foods containing chicken liver (recipes 7 and 16), egg yolk (recipes 8 and 17), or dried anchovy powder (recipes 9 and 18) had zinc concentrations greater than 3.0 mg/100 g dry weight, and those containing dried anchovy powder, egg yolk, or dried skim milk powder had calcium concentrations greater than 100 mg/100 g dry weight. As a consequence, their corresponding molar ratios of phytate:zinc and phytate:calcium were lower than those of recipes without these animal-source foods.

Iron, zinc, calcium, and phytate concentrations of selected processed complementary foods

Table 2 lists the ingredients, including details of the fortificants when available, of selected manufactured processed complementary foods purchased from countries in Africa and Asia and analyzed in our laboratory. Concentrations of iron, zinc, calcium, and IP5 + IP6, expressed as milligrams per 100 g dry weight, together
<table>
<thead>
<tr>
<th>Recipe no.</th>
<th>Ingredients</th>
<th>Iron</th>
<th>Zinc</th>
<th>Calcium</th>
<th>IP5 + IP6</th>
<th>Phytate: iron</th>
<th>Phytate: zinc</th>
<th>Phytate: calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Based on maize flour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Maize flour, semi-DSM, sugar, oil, vanilla. Fortificants: calcium, iron, vitamins</td>
<td>1.6</td>
<td>1.4</td>
<td>363</td>
<td>116</td>
<td>6.1</td>
<td>8</td>
<td>0.02</td>
</tr>
<tr>
<td>2</td>
<td>Maize flour, DSM. Fortificants: unspecified</td>
<td>3.8</td>
<td>6.1</td>
<td>205</td>
<td>152</td>
<td>3.4</td>
<td>2</td>
<td>0.05</td>
</tr>
<tr>
<td>3</td>
<td>Maize flour, soy flour, carrots, fish. Fortificants: iron, calcium, iodine</td>
<td>10.2</td>
<td>2.0</td>
<td>53</td>
<td>452</td>
<td>3.7</td>
<td>22</td>
<td>0.52</td>
</tr>
<tr>
<td>4</td>
<td>Unrefined maize flour, soy flour, DSM. Extrusion cooked. Fortificants: iron, zinc, calcium, vitamins A, C, B</td>
<td>43</td>
<td>7.8</td>
<td>126</td>
<td>593</td>
<td>1.2</td>
<td>8</td>
<td>0.29</td>
</tr>
<tr>
<td>5</td>
<td>Unrefined maize flour, soy flour. Fortificants: iron, zinc, calcium, vitamin C, other vitamins</td>
<td>21.9</td>
<td>8.1</td>
<td>135</td>
<td>586</td>
<td>2.3</td>
<td>7</td>
<td>0.26</td>
</tr>
<tr>
<td>Based on wheat flour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Wheat flour, sugar, honey, maltodextrin, salt. Fortificants: iron, calcium, vitamin C, other vitamins</td>
<td>7.8</td>
<td>1.7</td>
<td>318</td>
<td>326</td>
<td>3.5</td>
<td>19</td>
<td>0.06</td>
</tr>
<tr>
<td>7</td>
<td>Roasted unrefined wheat flour, salt. Fortificants: vitamins and minerals</td>
<td>4.1</td>
<td>2.3</td>
<td>25</td>
<td>468</td>
<td>9.7</td>
<td>20</td>
<td>1.14</td>
</tr>
<tr>
<td>8</td>
<td>Wheat flour, DWM, salt, flavors. Fortificants: vitamins and minerals</td>
<td>7.1</td>
<td>1.6</td>
<td>129</td>
<td>146</td>
<td>1.7</td>
<td>9</td>
<td>0.07</td>
</tr>
<tr>
<td>Based on refined wheat flour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Refined wheat flour, DWM, sugar, pumpkin, salt. Fortificants: iron, calcium, vitamins A, C, folic acid, B vitamins</td>
<td>9.4</td>
<td>1.9</td>
<td>511</td>
<td>19</td>
<td>0.2</td>
<td>1</td>
<td>0.00</td>
</tr>
<tr>
<td>10</td>
<td>Refined wheat flour, milk solids, sugar, oil, salt, FOS, inulin, taurine, vanilla. Fortificants: iron, zinc, iodine, folic acid, biotin, vitamins</td>
<td>11.2</td>
<td>1.4</td>
<td>389</td>
<td>24</td>
<td>0.2</td>
<td>2</td>
<td>0.00</td>
</tr>
<tr>
<td>Based on white rice flour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Rice flour, corn starch, sugar, dried fruits, oil, soy lecithin, beetroot juice. Fortificants: iron, vitamins</td>
<td>8.3</td>
<td>0.3</td>
<td>18</td>
<td>7</td>
<td>0.1</td>
<td>2</td>
<td>0.02</td>
</tr>
<tr>
<td>12</td>
<td>Rice flour, soybean flour, sugar. Fortificants: vitamins and minerals</td>
<td>1.9</td>
<td>1.7</td>
<td>210</td>
<td>136</td>
<td>6.2</td>
<td>8</td>
<td>0.04</td>
</tr>
<tr>
<td>13</td>
<td>Rice flour, soy flour, sugar, DSM, oil, salt, taurine, vanilla. Fortificants: iron, calcium, biotin, vitamins</td>
<td>9.5</td>
<td>3.8</td>
<td>495</td>
<td>261</td>
<td>2.3</td>
<td>7</td>
<td>0.03</td>
</tr>
<tr>
<td>14</td>
<td>Rice flour. Fortificants: vitamins and minerals</td>
<td>4.6</td>
<td>4.3</td>
<td>9</td>
<td>12</td>
<td>0.2</td>
<td>&lt; 1</td>
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continued
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<thead>
<tr>
<th>Recipe no.</th>
<th>Ingredients</th>
<th>Iron</th>
<th>Zinc</th>
<th>Calcium</th>
<th>IP5 + IP6</th>
<th>Phytate: iron</th>
<th>Phytate: zinc</th>
<th>Phytate: calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Rice, soy protein, DWM, maltodextrin, whey, FOS, inulin, DHA, taurine. Fortificants: iron, zinc, calcium, vitamins A, D, E, C, K, folic acid, B vitamins</td>
<td>8.1</td>
<td>5.0</td>
<td>294</td>
<td>743</td>
<td>7.8</td>
<td>15</td>
<td>0.15</td>
</tr>
<tr>
<td>16</td>
<td>Rice, beef, broccoli, lecithin, FOS. Fortificants: vitamins and minerals; omega-3 and -6 fatty acids</td>
<td>2.9</td>
<td>2.1</td>
<td>277</td>
<td>75</td>
<td>2.2</td>
<td>4</td>
<td>0.02</td>
</tr>
<tr>
<td>17</td>
<td>Jasmine rice, soybean flour, pumpkin. Fortificants: iodized salt</td>
<td>0.5</td>
<td>1.7</td>
<td>10</td>
<td>47</td>
<td>8.0</td>
<td>3</td>
<td>0.29</td>
</tr>
<tr>
<td>18</td>
<td>Rice flakes, DWM, oil, soy protein, inulin, fish powder, carrot, spinach, flavorings. Fortificants: vitamins and minerals</td>
<td>13.5</td>
<td>1.9</td>
<td>590</td>
<td>35</td>
<td>0.2</td>
<td>2</td>
<td>0.00</td>
</tr>
</tbody>
</table>

Based on brown rice

<table>
<thead>
<tr>
<th>Recipe no.</th>
<th>Ingredients</th>
<th>Iron</th>
<th>Zinc</th>
<th>Calcium</th>
<th>IP5 + IP6</th>
<th>Phytate: iron</th>
<th>Phytate: zinc</th>
<th>Phytate: calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Brown rice, rice, lysine, FOS. Fortificants: vitamins and minerals</td>
<td>10.4</td>
<td>4.5</td>
<td>399</td>
<td>285</td>
<td>2.3</td>
<td>6</td>
<td>0.04</td>
</tr>
<tr>
<td>20</td>
<td>Brown rice, rice, chicken, vegetables. Fortificants: vitamins and minerals</td>
<td>8.2</td>
<td>2.6</td>
<td>508</td>
<td>256</td>
<td>2.6</td>
<td>10</td>
<td>0.03</td>
</tr>
</tbody>
</table>

Based on mungbeans

<table>
<thead>
<tr>
<th>Recipe no.</th>
<th>Ingredients</th>
<th>Iron</th>
<th>Zinc</th>
<th>Calcium</th>
<th>IP5 + IP6</th>
<th>Phytate: iron</th>
<th>Phytate: zinc</th>
<th>Phytate: calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>Mungbeans, rice, soy, corn, lecithin, FOS. Fortificants: vitamins and minerals</td>
<td>9.2</td>
<td>1.9</td>
<td>456</td>
<td>223</td>
<td>2.0</td>
<td>12</td>
<td>0.03</td>
</tr>
<tr>
<td>22</td>
<td>Mungbeans, spinach, rice, soy, lecithin, FOS. Fortificants: vitamins and minerals, omega-3 and -6 fatty acids</td>
<td>9.5</td>
<td>6.8</td>
<td>474</td>
<td>298</td>
<td>2.7</td>
<td>4</td>
<td>0.04</td>
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Based on mixed cereals and legumes

<table>
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<tr>
<th>Recipe no.</th>
<th>Ingredients</th>
<th>Iron</th>
<th>Zinc</th>
<th>Calcium</th>
<th>IP5 + IP6</th>
<th>Phytate: iron</th>
<th>Phytate: zinc</th>
<th>Phytate: calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>Tef, chickpeas, DSM, sugar, salt. Fortificants: calcium, phosphorus, vitamins and minerals</td>
<td>8.4</td>
<td>3.5</td>
<td>82</td>
<td>324</td>
<td>3.3</td>
<td>9</td>
<td>0.24</td>
</tr>
<tr>
<td>24</td>
<td>Oats (precooked), soybeans, sorghum, tef, wheat, peas, haricot beans, sunflower seeds, rice, maize, niger. Fortificants: vitamins and minerals</td>
<td>8.3</td>
<td>2.9</td>
<td>42</td>
<td>635</td>
<td>6.5</td>
<td>22</td>
<td>0.92</td>
</tr>
<tr>
<td>25</td>
<td>Oats, barley, wheat, peanuts, lentils, haricot beans, soybeans, red sorghum, bulla, sesame, linseed, tef, chickpeas. Fortificants: not specified</td>
<td>22.9</td>
<td>3.1</td>
<td>30</td>
<td>558</td>
<td>2.1</td>
<td>18</td>
<td>1.13</td>
</tr>
<tr>
<td>26</td>
<td>Wheat, oats, rice, barley, millet, sugar, malto-dextrin, FOS, inulin. Fortificants: iron, zinc, calcium, vitamins</td>
<td>17.7</td>
<td>12.3</td>
<td>182</td>
<td>144</td>
<td>0.7</td>
<td>1</td>
<td>0.05</td>
</tr>
</tbody>
</table>

continued
with corresponding phytate:mineral molar ratios, are presented (unpublished data). Most (93% [25/27]) of these processed complementary foods claimed to be fortified, most frequently, when details were supplied, with iron and/or calcium; only 22% (6/27) were fortified with zinc. In most cases, neither the level nor the form of the fortificants added was specified by the manufacturer (data not shown). Analyses of iron, zinc, and calcium were performed by AAS, and analyses of hexa- and penta-inositol phosphates were performed by HPLC using the procedure of Lehrfeld [46], as modified by Hotz and Gibson [47].

Again, the processed complementary foods based on unrefined cereals, oleaginous seeds, and/or legumes (recipes 4, 5, 24, 25, and 27) had the highest concentrations of IP5 and IP6, whereas those based on refined wheat flour (recipes 9 and 10), white rice flour (recipes 11 and 14), or rice flakes (recipe 18) had the lowest. Indeed, it is noteworthy that three of the processed complementary foods based on mixed cereals and legumes (recipes 24, 25, and 27) had concentrations of IP5 + IP6 that were as high as the values for the indigenous complementary foods based on unrefined maize (table 1).

In most cases, because of the addition of iron as a fortificant, the concentrations of iron in the processed complementary foods were consistently higher than those in complementary foods based on indigenous recipes, except for the indigenous recipes containing chicken liver (recipes 7 and 16). Fewer processed complementary foods (18% [5/27]) listed zinc as a fortificant, so not surprisingly, with few exceptions, those fortified with zinc had the highest zinc concentrations. In general, calcium concentrations were also consistently higher in the processed complementary foods that claimed to be fortified with calcium or an unspecified mixture of minerals (78% [21/27]) and/or that contained milk solids. Exceptions were three processed complementary foods (recipes 11, 17, and 25) that did not contain a calcium fortificant, minerals, or milk solids, and as a consequence, all had extremely low calcium concentrations (≤3.0 mg/100 g dry weight), and one processed complementary food based on white rice flour, which had the lowest calcium concentration (9 mg/100 g dry weight), despite claiming to be fortified with minerals (recipe 14).

It is of interest that less than a third of the indigenous (27%) or processed (22%) complementary foods had phytate:iron molar ratios less than 1, even though 89% (24/27) of the processed complementary foods claimed to be fortified either specifically with iron (11/27) or with a premix of vitamins and minerals (13/27). In contrast, almost all of the processed complementary foods (82% [22/27]), as compared with 58% (15/26) of the indigenous complementary foods, had phytate:zinc molar ratios within the range indicative of an omnivorous diet or a vegetarian diet based on refined cereals (i.e., ratios of 5 to 18) with moderate zinc absorption [32]. Similarly, more of the processed complementary foods than the indigenous complementary foods had phytate:calcium molar ratios less than 0.17 (67% [18/27] vs. 50% [13/26]). In total, desirable molar ratios for phytate:iron (<1), phytate:zinc (<18), and phytate:calcium (<0.17) were achieved for 25%, 70%, and 57%, respectively, of the complementary foods presented in tables 1 and 2.

Despite fortification, almost none of the processed complementary foods itemized in table 2 met the World Health Organization (WHO) estimated needs for iron, zinc, or calcium for breastfed infants aged 9 to 11 months, when a daily ration of 40 g dry weight was assumed [48]. Clearly, manufacturers should fortify processed complementary foods appropriately to ensure they meet the WHO estimated needs for iron, zinc, and calcium for breastfed infants and young children. For the high-phytate, cereal-based, processed complementary foods available in low-income countries, the potential for using “protected” iron compounds such as NaFeEDTA should be explored, because this compound partially protects the fortificant iron from reacting with absorption inhibitors such as phytate (and polyphenols), as noted earlier [5]. Fortification guidelines are available in Allen et al. [49]. These same mineral deficits have also been reported earlier for infants and young children consuming the indigenous complementary foods itemized in table 1 [1] and elsewhere [2, 50]. Only one of the processed complementary foods analyzed in table 2 had an iron concentration with the potential to exceed the upper tolerable level for some age groups [51].

TABLE 2. Iron, zinc, calcium, and hexa- (IP6)- and penta- (IP5)-inositol phosphate concentrations (mg/100 g dry weight) and phytate:mineral molar ratios of manufactured processed complementary foods from low-income countries (continued)

<table>
<thead>
<tr>
<th>Recipe no.</th>
<th>Ingredients</th>
<th>Iron</th>
<th>Zinc</th>
<th>Calcium</th>
<th>IP5 + IP6</th>
<th>Phytate: iron</th>
<th>Phytate: zinc</th>
<th>Phytate: calcium</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>Maize, sorghum, soy, millet. Fortificants: vitamins and minerals</td>
<td>22.1</td>
<td>5.2</td>
<td>145</td>
<td>585</td>
<td>2.2</td>
<td>11</td>
<td>0.25</td>
</tr>
</tbody>
</table>

DHA, docosahexaenoic acid; DWM, dried whole milk powder; DSM, dried skim milk powder; FOS, fructo-oligosaccharides
a. Prepared from false banana (Ensete ventricosum).
Use of phytate reduction strategies to enhance mineral bioavailability in plant-based complementary foods

In many low-income countries, the inhibitory effect of phytate on mineral bioavailability in cereal- and/or legume-based complementary foods is unlikely to be attenuated by the addition of expensive cellular animal protein- or ascorbic acid-rich foods, known enhancers of zinc, and nonheme iron absorption, respectively [3]. Instead, reducing the phytate content of these cereal- and/or legume-based complementary foods may be a more feasible alternative to enhance mineral bioavailability. Such an approach could also be used to improve the absorption of mineral fortificants in high-phytate processed complementary foods.

Food preparation and processing methods to reduce the phytate content of cereal- and/or legume-based complementary foods in the household include soaking, germination, fermentation, and pounding. Only a brief outline is given here; more details are available elsewhere [3]. Conventional heat treatments induce only moderate losses (5% to 15%) of phytic acid, depending on the plant species, temperature, and pH, whereas soaking cereal and, to a lesser extent, legume flours under optimal conditions can markedly reduce their IP5 and IP6 content, by a combination of passive diffusion of water-soluble sodium or potassium phytate [52] and hydrolysis of phytate by endogenous phytases. The extent of the IP5 + IP6 reduction after soaking varies, depending on the species, pH, and length and conditions of soaking; only modest reductions in IP5 + IP6 are achieved after soaking whole seeds or legumes [41]. Some loss of minerals, water-soluble vitamins, and possibly other antinutrients (e.g., polyphenols) may also occur with soaking [53].

Germination and fermentation also induce enzymatic hydrolysis of IP6 and IP5 to lower inositol phosphates through the action of endogenous or microbial phytase enzymes, respectively [3, 54]. For example, germination leads to an increase in phytase activity in certain cereals (e.g., maize, millet, and sorghum), most legumes, and oilseeds through de novo synthesis, activation of intrinsic phytase, or both. Egli et al. [55] observed that during germination, rice, millet, and mungbean had the largest reductions in phytate content, ranging from 50% for mungbean to 64% for millet. Germination also decreases the content of certain tannins and other polyphenols in legumes (e.g., *Vicia faba*) and red sorghum as a result of the formation of polyphenol complexes with proteins [56].

Fermentation of cereal- and/or legume-based complementary foods can be achieved in the household by adding starter cultures that contain microbial phytases such as molds or yeasts to the food. The organic acids produced during fermentation lower the pH, thus generating a pH that is optimal for the intrinsic phytases in the cereal and legume flours to further degrade the phytic acid. The extent of the reduction in higher inositol phosphate levels during fermentation varies; sometimes as much as 90% of the phytate can be removed when the conditions for fermentation are optimized [57]. In some circumstances, however, metal ions can inhibit the activity of certain phytases [58]. For example, calcium added as a fortificant to bread dough inhibits the activity of phytase in yeast [59].

Fermenting complementary foods has several other nutritional advantages. The low pH prevents the growth of pathogenic microorganisms, while the organic acids have the potential to form soluble ligands with iron and zinc, thus enhancing absorption. Improvements in protein quality have also been documented after fermentation, associated with the destruction by microbial enzymes of protein inhibitors that interfere with nitrogen digestibility, or from the ability of starter cultures to synthesize certain amino acids [3].

Home pounding can also be used to reduce the phytic acid content of unrefined cereals that have phytic acid localized in the outer aleurone layer (rice, sorghum, and wheat) or in the germ (maize) [11], as noted earlier, although the mineral content is also simultaneously reduced by this procedure. Removal of the hull or seed coat in legumes does not reduce their phytic acid content, however, because it is distributed throughout the cotyleonds.

Dephytinization at the commercial level can be achieved by milling or the addition of exogenous phytase (*myo*-inositol hexakisphosphate phosphohydrolases) enzymes. When milling is used to remove the bran and/or germ from cereals, as much as 90% of the phytate can be lost. Several sources of phytase enzymes are available. Many are extracted from molds, which act over a broader pH range (2.5 to 5.5) than cereal phytases (4.5 to 5.6) and at the physiological conditions of the stomach and the small intestine. They include *Aspergillus ficuum* (a genetically modified variety of *A. niger*), *A. oxyzae*, and *A. fumigatus*. *A. fumigatus* has the added advantage of resisting heat treatment at temperatures up to 100°C for 20 minutes [60]. These commercial phytase enzymes can degrade phytate completely in approximately 2 hours, provided the phytase enzyme is added to an aqueous slurry of the complementary foods held at the pH optimum of the enzyme. Iron absorption was reported to be significantly increased in women receiving an iron-fortified, whole-maize porridge meal (phytate:iron molar ratio ~ 8:1) containing added microbial phytase derived from a genetically modified culture of *A. niger* and active at the pH of the gastrointestinal tract [61]. However, the high cost of microbial phytases may preclude their use in low-income countries. Further, because some phytase enzymes (e.g., *A. ficuum*) are derived from a genetically modified variety of *A. niger*, their use may also be restricted by national legislation in some countries.
Naturally occurring phytase enzymes in some whole-grain cereals (wheat, barley, and rye) have also been used to facilitate phytate hydrolysis in cereal-based complementary foods [55, 62]. Cereals with the highest phytase activity are whole wheat, whole rye, buckwheat, and barley, whereas sorghum, maize, and rice have low phytase activity. Legumes and oilseeds have lower phytase activity than cereals. When 10% whole wheat or rye flour was added to a complementary food slurry based on cereals and legumes, phytic acid was completely degraded after 1 to 2 hours when the mixture was maintained under optimum conditions for phytase activity [62].

Thus, complete degradation of phytate in cereal- and/or legume-based complementary foods can be achieved at the commercial level by using either exogenous or intrinsic phytases [63, 64], as long as optimal conditions for enzyme activity are maintained. Dephytinization by these methods has resulted in significant increases in the absorption of iron [17, 65] and zinc (but not copper [12]) in several isotope studies in adults. Studies on infants and young children are more limited, although there are some reports of significant increases (p < .05) in zinc (16.7% vs. 22.5%) [66] and iron (3.9% vs. 8.7%) [67] absorption after feeding infants commercial dephytinized soy formula compared with regular formula. Whether these commercial dephytinization strategies enhance calcium absorption from cereal- and/or legume-based complementary foods in infants and young children is less certain.

Unlike commercial dephytinization, household strategies such as soaking, germination, or fermentation can remove only about 50% of the phytate in cereal- and/or legume-based complementary foods [47]. Whether this level of phytate reduction can enhance mineral absorption from cereal- and/or legume-based complementary foods in infants and young children has not been investigated by in vivo isotope studies. In adults, significant increases in absorption of both zinc [18, 68] and calcium [19] have been achieved from test meals prepared with 60% phytate-reduced maize and administered over a whole day as compared with meals made from wild-type maize. Modest increases in absorption of intrinsic iron have also been reported in low-phytate versus wild-type maize [16].

These findings suggest that some improvement in mineral absorption is likely with a 50% reduction of phytate content in high-phytate complementary foods. Nevertheless, the magnitude of the increase in fractional absorption is difficult to predict and will vary depending on the composition of the complementary food and the dietary intakes, age, and nutritional status of the target group [69, 70]. For example, even complete phytate degradation by commercial phytase enzyme improved iron absorption from cereal porridges prepared with water but not from porridges prepared with milk [17]. This finding is important, because manufacturers often recommend preparing fortified complementary foods with milk rather than water. The health status of infants and young children is also likely to have a major impact on mineral absorption, especially in settings where environmental enteropathy may be widespread [71, 72].

Conclusions and recommendations

There is an urgent need to address the problems associated with poor mineral bioavailability in both indigenous and commercially processed cereal-based complementary foods used in low-income countries. Many of these complementary foods have very high concentrations of phytate and phytate:mineral molar ratios at levels likely to inhibit absorption of iron, zinc, and calcium. Dephytinization strategies exist to reduce the phytate content of both indigenous and processed complementary foods, and some improvement in mineral absorption is likely if these strategies are implemented. The magnitude of the increase in fractional absorption, however, is difficult to predict and will vary, depending on the composition of the complementary food and the dietary intakes, age, health, and nutritional status of the target group. However, dephytinization alone is unlikely to be sufficient to overcome the shortfalls in iron, zinc, and calcium that have been consistently reported in cereal- and/or legume-based complementary foods used in low-income countries. Instead, dephytinization should be combined with enrichment strategies such as the addition of animal-source and vitamin C-rich foods, where feasible, in an effort to overcome, at least in part, these mineral deficits in indigenous complementary foods.

Cereal- and/or legume-based complementary foods can also be fortified with micronutrients, including minerals, in an effort to close the gap that may still remain between the level of absorbed minerals in high-phytate cereal- and/or legume-based complementary foods and the WHO recommendations. Use of “protected” iron compounds such as NaFeEDTA, which partially protects the fortificant iron from reacting with phytate or polyphenols, should also be explored. Manufactured fortified complementary foods can be provided through commercial markets or freely distributed in national government programs. Alternatively, resource-poor households can be supplied with fortificant premixes in single-dose sachets containing micronutrient powders or lipid-based nutrient supplements that can be added to home-prepared complementary foods. However, even when high-phytate complementary foods are fortified with minerals, the level and form of the mineral fortificants do not necessarily ensure that the fortified complementary foods meet the mineral needs of infants and young children. More effort should be made to ensure that fortified
cereal- and/or legume-based complementary foods in low-income countries meet the WHO recommendations for iron, zinc, and calcium for breastfed infants and children. Attention must also be given when setting the fortificant levels to avoid antagonistic interactions between minerals and intakes that may exceed the tolerable upper intake levels.

References

32. Hotz C, Brown KH, eds. International Zinc Nutrition...
Phytate, iron, zinc, and calcium concentrations in plant-based complementary foods


63. Greiner R, Konietzny U. Phytase for food application.


