Polyphenols and Phytic Acid Contribute to the Low Iron Bioavailability from Common Beans in Young Women¹,²

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Abstract

Low iron absorption from common beans might contribute to iron deficiency in countries where beans are a staple food. High levels of phytic acid (PA) and polyphenols (PP) inhibit iron absorption; however, the effect of bean PP on iron absorption in humans has not been demonstrated and, with respect to variety selection, the relative importance of PP and PA is unclear. To evaluate the influence of bean PP relative to PA on iron absorption in humans, 6 stable iron isotope absorption studies were conducted in women (16 or 17 per study). Bean PP (20, 50, and 200 mg) were added in studies 1–3 as red bean hulls to a bread meal. Studies 4–6 investigated the influence on iron absorption of PP removal and dephytinization of whole red bean porridge and PP removal from dephytinized porridge. Iron absorption was lowered by 14% with 50 mg PP (P < 0.05) and by 45% with 200 mg PP (P < 0.001). The mean iron absorption from whole bean porridge was 2.5%. PP and PA removal increased absorption 2.6-fold (P < 0.001) and removal of PP from dephytinized porridge doubled absorption (P < 0.001). Between-study comparisons indicated that dephytinization did not increase iron absorption in the presence of PP, but in their absence, absorption increased 3.4-fold (P < 0.001). These data suggest that in countries where beans a staple food, PP and PA concentrations should be considered when selecting bean varieties for human consumption. Lowering only one inhibitor will have a modest influence on iron absorption. J. Nutr. 140: 1977–1982, 2010.

Introduction

Iron deficiency (ID) is the most prevalent micronutrient deficiency worldwide, affecting mainly children under 5 y and women of childbearing age living in the poorer communities of the developing world (1). ID has a major negative impact on health and in pregnancy contributes to the risk of severe anemia, which is associated with higher maternal morbidity and mortality (2).

Iron fortification of foods or iron supplements have traditionally been the main intervention strategies used to combat ID; however, they are less suitable for the more remote rural communities in the developing world where few processed foods are purchased or the health care infrastructure is poor. In such communities, biofortification of staple foods could be a more cost effective and sustainable strategy. Biofortification is the process of increasing the level and/or bioavailability of essential nutrients in crops by traditional plant breeding or genetic engineering. Rice, wheat, maize, the common bean, and cassava are the main targeted crops (3,4). Biofortified crops can potentially deliver iron, zinc, and vitamin A to people in rural areas with limited access to commercial markets (5). The common bean is a crucial grain legume, because it is a major staple food in parts of Africa and Latin America (6) providing an important source of proteins and energy (6,7). It is also high in iron and zinc and vitamins such as thiamin and folic acid (6,8,9).

The iron concentration of common beans (Phaseolus vulgaris) is generally higher than in cereal staples and has been reported to vary from 3.5 to 9 mg/100 g beans, depending on the genotype, and appears to be relatively stable when grown under different environmental conditions (3,10). Selective plant breeding strategies have been reported to increase the iron concentration of common beans by 60–80% (10). Several human studies investigating iron bioavailability reported low iron absorption from beans in the range of 1–3% (11–13). Thus, for bean biofortification to have a positive impact on iron status, it would be beneficial to not only increase the iron concentration but also increase the iron bioavailability. Bean-based diets, like cereal-based diets, contain a considerable amount of phytic acid (PA); however, they additionally can be rich in phenolic compounds, mainly polymerized flavans (14–18). Both PA and

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³ Abbreviations used: CRP, C-reactive protein; GAE, gallic acid equivalent; Hb, hemoglobin; ID, iron deficiency; PA, phytic acid; PP, polyphenol; RM, reference meal; SF, serum ferritin.
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phenolic compounds can be potent iron absorption inhibitors, forming unabsorbable complexes in the gut lumen (19,20). The inhibiting effect of polyphenols (PP) on iron absorption has largely been demonstrated, but the capability of complex formation with iron in the intestine and thereby the reduction of iron uptake into the body depends on their structure (20–22). The PP concentration in beans varies widely depending on bean variety and color (16,23) and it is likely that bean PP also inhibit iron absorption. However, to our knowledge, this has never been tested. The molar ratio of PA:iron in beans ranges from 4:1 to 30:1 (23,24), which would also be expected to markedly inhibit iron absorption (25,26). However, no data are available concerning the independent effects of PP and PA on iron absorption from foods containing considerable amounts of both inhibitors. The following 6 stable isotope iron absorption studies in adult human volunteers were designed to evaluate the relative importance of PA and PP in iron absorption from common beans to provide information that would enable plant breeders to develop beans with iron optimized for bioavailability.

Methods

Participants. Ninety-seven apparently healthy, nonpregnant, nonlactating women aged between 18 and 45 y and weighing below 60 kg were recruited from among the students of ETH and University of Zurich. Participants were randomly allocated to the 6 crossover studies, with 16 or 17 (study 6) participants per study (Table 1). Women with known metabolic, chronic, and gastro-intestinal disease as well as women taking long-term medication (except oral contraceptives) were excluded from the studies. Intake of vitamin or mineral supplements was not allowed during and 2 wk before the studies. No women were recruited who had donated blood or experienced substantial blood loss within 6 mo of the beginning of the study. The experimental procedures were approved by the ethical committee of ETH Zurich and written informed consent was obtained from all study participants before the investigation began.

Test meals. In studies 1–3 (Table 1), the influence of different amounts of bean PP on human iron absorption was investigated. PP levels (20, 50, and 200 mg) were chosen based on the concentration expected in 100 g of low, middle, and high PP beans cooked and consumed without cooking water. Beans were first soaked and dehulled. The hulls, as the source of PP, were then steam-cooked before adding them to a noninhibitory reference meal (RM) consisting of a bread roll (80 g) made from yeast-fermented wheat flour, honey (7 g), and coconut fat (3 g). The amount of bean hulls added to the test meals provided 20, 50, and 200 mg PP [expressed in gallic acid equivalents (GAE)]. Each woman received a RM or a meal with added bean hulls on 2 consecutive days in random order. For dehulling, the beans were first cut in a circular manner with a sharp knife to facilitate hull removal and then soaked for 4.5 h at 4°C and pH 5.5 to minimize PP losses. Before adding the hulls to the test meals, they were steamed for 15 min at 100°C as a form of cooking. The bread rolls were prepared in batches by mixing 1 kg low extraction wheat flour with high-purity water (18 mol/L, 600 g), salt (10 g), sugar (32 g), and dried yeast (15 g). After fermentation for 5 h at room temperature, dough portions (80 ± 1 g) were baked for 15 min at 200°C and stored at −25°C until the day of consumption.

In studies 4–6, the inhibitory effect of PP and PA in beans was investigated either individually or combined. In these studies, the test meals were in the form of sweetened, homogenized bean porridge. In study 4, the influence of bean PP on iron absorption in the presence of PA was evaluated by comparing iron absorption from beans with and without hull. In study 5, the combined impact of PP and PA was investigated by comparing iron absorption from whole beans with dehulled, dephytinized beans and in study 6 the influence of PP on iron absorption in the absence of PA was evaluated by comparing dephytini- zed beans with dephytinized, dehulled beans. For studies 4–6, the test meals were based on 60 ± 1 g beans (accession no. SER 16; planted and harvested by CIAT, Columbia), either with or without bean hulls or with or without PA, soaked for 4.5 h at 4°C and pH 5.5 and boiled in water for 40 min. After cooking, the beans were homogenized and 60.0 g sugar per test meal was added. For meal B in study 5 and meal A and B in study 6, 100 phytase units phytase (DSM FS Phytase 20,000 G; DSM) was added to the bean slurry after the homogenization and the slurry was held at 55°C for 60 min to allow complete PA degradation. One phytase unit is defined as the amount of enzyme required to release 1 µmol inorganic phosphorus/min from sodium phytate. The slurry was heated to 80°C to inactivate phytase. The test meals were prepared in batches and stored frozen until the day of feeding. A total of 4 mg 58FeSO4 or 4 mg 57FeSO4 was added to each test meal in solution shortly before test meal administration. Exact amounts of added tracer were determined by weighing meals before and after the addition of tracer solutions. High-purity water (180 mL; 300 g) was served as a drink with each test meal.

Study design. Within each study, a randomized crossover design was used in which each participant acted as their own control. In all studies, each woman received 2 different test meals labeled with either 57Fe or 58Fe. On d 0, body weight and height were measured and the first blood sample was taken for iron status measurements. The following day (d 1), the first labeled meal was served between 0700 and 0900 h after an overnight fast. On d 2, the second meal was administered in the same way. Women had to consume test meals including water completely in the presence of the investigators. Participants did not eat or drink for 3 h after consuming the meal. Fourteen days after the second test meal (d 16), a second blood sample was taken after an overnight fast for Fe isotopic analysis. Fe absorption was calculated based on erythrocyte incorporation of Fe stable isotope labels 14 d after intake of labeled test meals (27).

The 97 participants in studies 1–6 were randomly assigned to groups of 16 or 17 (study 6) women each. Within each 2-d feeding period, the participants from all studies randomly consumed either test meal A or test meal B on d 1 and the other test meal on d 2 (Table 1).

Stable isotope labels. Isotopically labeled 58FeSO4 and 57FeSO4 were prepared from isotopically enriched elemental iron (95.3% enriched; 58Fe-metal: 91.7% enriched; both Chemgas) by dissolution in 0.1 mol/L sulfuric acid. The solutions were flushed with argon to keep the Fe in the +II oxidation state. Prepared iron tracer solutions were analyzed for iron isotopic composition and tracer iron concentration by reversed isotope dilution MS using the experimental techniques outlined below.

Analytical methods. The total PP concentration in bean meals was measured with a modified Folin–Ciocalteau method as suggested by Singleton (28). Iron, calcium, and zinc in bean meals and bread rolls were analyzed by graphite furnace atomic absorption spectrophotometry (AA240Z, Varian) after freeze-drying. Beans and bread rolls were mineralized by microwave digestion (MLS ETHOSplus, MLS) using an HNO3/H2O2 mixture. The PA concentration in bean meals and bread rolls was measured by a modification of the Makower method (29) in which iron was replaced by cerium in the precipitation step. Following the mineralization of food samples, inorganic phosphate was determined according to Van Veldhoven and Mannaker (30) and converted into PA concentrations. Ascorbic acid in honey was quantified by HPLC (31). Wheat bran (PA assay) and milled beans (PP assay) stored under argon to avoid PP oxidation were analyzed together with each series of samples.

<table>
<thead>
<tr>
<th>TABLE 1 Overview of iron absorption studies and test meals</th>
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<tbody>
<tr>
<td>Study</td>
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<td>4</td>
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<td>5</td>
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<td>6</td>
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</table>

1 Bread roll (80 g), honey (7 g), and coconut fat (3 g).
and were used as in-house quality control material to monitor reproducibility. Bovine liver (standard reference material 1577b; National Institute of Standards and Technology) was measured together with each series of samples to monitor accuracy of the atomic absorption spectrophotometry method.

Whole blood samples were mineralized using an HNO3/H2O2 mixture (7/3 mL) and microwave digestion followed by separation of the sample iron from the blood matrix by anion-exchange chromatography and a solvent/solvent extraction step into diethyl ether (27). All isotopic analysis were performed by negative thermal ionization MS using a magnetic sector field mass spectrometer (MAT 262; Finnigan MAT) equipped with a multi-collector system for simultaneous ion beam detection (27,32). Venous blood samples were drawn in EDTA-treated tubes to determine iron status, including hemoglobin (Hb) and serum ferritin (SF). Blood samples were divided into aliquots for the analysis of Hb and isotopic composition and plasma was separated, aliquoted, and frozen for the later analysis of SF. Hb was measured with a Coulter Counter. SF and serum C-reactive protein (CRP) were measured on an IMMULITE automatic system (DPC Bühlmann).

Calculation of Fe absorption. The amounts of 57Fe and 58Fe isotopic labels in blood 14 d after administration of the test meals were calculated on the basis of the shift in iron isotope ratios and on the estimated amount of iron circulating in the body. Circulating iron was calculated based on the blood volume estimated from height and weight according to Brown et al. (33) and measured Hb concentration. The calculations were based on the principles of isotope dilution and took into account that iron isotopic labels were not monoisotopic (27). For the calculation of fractional absorption, 80% incorporation of the absorbed Fe into RBC was assumed.

Statistical analysis. Analyses were conducted with SPSS statistical software (SPSS 16.0). Iron absorption values were converted to their logarithms for statistical analysis and reconverted for reporting. Iron absorption from different test meals within the same participant was compared by paired Student’s t test. A 1-way ANOVA was used for comparisons between studies/participant groups. A post hoc Bonferroni test was used for multiple comparisons. Results are presented as means ± SD. Differences were considered significant at P < 0.05. To compare iron absorption between groups (Fig. 1), individual absorption values were adjusted to a SF concentration of 15 μg/L to consider the well-documented effect of iron status on iron absorption efficiency (34). The studies were powered to resolve a 30% difference in iron absorption between test meals using each volunteer as her own control and to resolve a difference of 60% in absorption between groups.

Results

Four of the 97 study participants had a Hb concentration < 120 g/L and 23 had a SF concentration < 15 μg/L. Fifteen women had a slightly elevated serum CRP concentration of > 3 mg/L, but none had a CRP concentration > 10 mg/L. Their BMI was 20.5 ± 1.4 kg/m² and age was 22.7 ± 2.9 y. Hb and SF concentrations did not differ between any of the groups.

Studies 1–3: influence of different amounts of bean PP on iron absorption. RM fed with different amounts of bean hulls contained neither phytate nor ascorbic acid. Iron and zinc concentrations were constant in all test meals, whereas the calcium concentration increased with increasing amounts of bean hulls. The PP concentration as planned was 20 mg GAE/meal in study 1, 50 mg GAE/meal in study 2, and 200 mg GAE/meal in study 3 (Table 2). The fractional iron absorption of participants consuming the RM in studies 1–3 (Table 3) did not differ. The lowest amount of PP (20 mg GAE), fed in study 1, did not affect iron absorption. Fifty milligrams of GAE from beans, fed in study 2, reduced the mean iron absorption by 14% (P < 0.05), whereas 200 mg GAE (study 3) decreased mean iron absorption by 45% (P < 0.001).

Studies 4–6: combined influence of PA and PP on iron absorption. Dehulling of whole beans decreased the PP concentration by 85% with a negligible effect on PA. Similarly, dephytinization of whole beans decreased the PA concentration to below analytical detection limits (8 mg/100 g) with little or no influence on PP concentration. The dehulled, dephytinized beans were low in both PP and PA. Dephytinization had little influence on the iron, zinc, calcium, and magnesium concentrations of the whole beans, whereas dehulling resulted in relevant losses of zinc (18%), magnesium (34%), and calcium (72%) but not iron (Table 2).

Iron absorption from the whole bean meal was similar in studies 4 (2.6%) and 5 (2.4%) in participants with similar iron status, as assessed by SF concentrations (Table 3). In study 4, removing the PP by dehulling was expected to increase absorption; however, iron absorption decreased by 38% (P < 0.001). In contrast, in study 5, removing both PA and PP increased iron absorption 2.6-fold (P < 0.001). In study 6, removing the hulls, and thus most of the PP from beans prior to dephytinization, doubled iron absorption (Table 3).

The influence of bean dephytinization was not measured directly in the same women in a single study but can be estimated by comparing iron absorption between studies. For between-study comparisons, iron absorption values were adjusted to a SF concentration of 15 μg/L as the cutoff level for ID (35) using experimentally derived algorithms (34) (Fig. 1). After ferritin adjustment, iron absorption from the whole bean meal (meal A, studies 4 and 5) was 4.9%. Dephytinization in the presence of PP

![FIGURE 1](https://academic.oup.com/jn/article-abstract/140/11/1977/4630513) Fractional iron absorption of women from test meals served in studies 4–6 after normalization to a SF concentration of 15 μg/L. Each symbol represents an individual participant. Geometric means are indicated by horizontal bars. Means without a common letter differ, P < 0.05.
TABLE 2 Total PP, PA, iron, zinc, calcium, and magnesium as fed in studies 1–6

<table>
<thead>
<tr>
<th>Study</th>
<th>Test meal</th>
<th>PP GAE mg</th>
<th>PA mg</th>
<th>Iron a</th>
<th>Calcium mg</th>
<th>Zinc mg</th>
<th>Magnesium mg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A (RM + 20 mg PP)</td>
<td>20 ± 0.3(^b)</td>
<td>n.d.(^d)</td>
<td>4.7 ± 0.2(^a)</td>
<td>12.6 ± 0.3(^b)</td>
<td>0.6 ± 0.06(^a)</td>
<td>n.a.(^3)</td>
</tr>
<tr>
<td>B (RM)</td>
<td>n.a.(^3)</td>
<td>n.d.(^d)</td>
<td>4.6 ± 0.04(^a)</td>
<td>10.7 ± 0.5(^a)</td>
<td>0.6 ± 0.01(^a)</td>
<td>n.a.(^3)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>A (RM + 50 mg PP)</td>
<td>50 ± 0.9(^b)</td>
<td>n.d.(^d)</td>
<td>4.7 ± 0.1(^a)</td>
<td>15.3 ± 0.2(^b)</td>
<td>0.6 ± 0.01(^a)</td>
<td>n.a.(^3)</td>
</tr>
<tr>
<td>B (RM)</td>
<td>n.a.(^3)</td>
<td>n.d.(^d)</td>
<td>4.6 ± 0.04(^a)</td>
<td>10.7 ± 0.5(^a)</td>
<td>0.6 ± 0.01(^a)</td>
<td>n.a.(^3)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>A (RM + 200 mg PP)</td>
<td>200 ± 3.4(^a)</td>
<td>n.d.(^d)</td>
<td>4.8 ± 0.1(^a)</td>
<td>30.2 ± 0.5(^a)</td>
<td>0.6 ± 0.02(^a)</td>
<td>n.a.(^3)</td>
</tr>
<tr>
<td>B (RM)</td>
<td>n.a.(^3)</td>
<td>n.d.(^d)</td>
<td>4.6 ± 0.04(^a)</td>
<td>10.7 ± 0.5(^a)</td>
<td>0.6 ± 0.01(^a)</td>
<td>n.a.(^3)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>A (Whole bean meal)</td>
<td>187.4 ± 7.6(^a)</td>
<td>415 ± 10(^a)</td>
<td>6.1 ± 0.2(^b)</td>
<td>39.7 ± 3(^a)</td>
<td>1.1 ± 0.05(^b)</td>
<td>209.1 ± 7.5(^b)</td>
</tr>
<tr>
<td>B (Dehulled bean meal)</td>
<td>27.9 ± 3.1(^a)</td>
<td>419 ± 11(^a)</td>
<td>6.2 ± 0.1(^b)</td>
<td>11.3 ± 0.3(^b)</td>
<td>0.9 ± 0.04(^b)</td>
<td>137.4 ± 5.8(^b)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>A (Whole bean meal)</td>
<td>187.4 ± 7.6(^a)</td>
<td>415 ± 10(^a)</td>
<td>6.1 ± 0.2(^b)</td>
<td>39.7 ± 3(^a)</td>
<td>1.1 ± 0.05(^b)</td>
<td>209.1 ± 7.5(^b)</td>
</tr>
<tr>
<td>B (Dehulled, dephytinized bean meal)</td>
<td>28.9 ± 2.2(^a)</td>
<td>n.d.(^d)</td>
<td>6.0 ± 0.1(^b)</td>
<td>11.1 ± 0.4(^b)</td>
<td>0.9 ± 0.04(^b)</td>
<td>137.5 ± 1.1(^a)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>A (Depleted bean meal)</td>
<td>177.9 ± 3.5(^a)</td>
<td>n.d.(^d)</td>
<td>6.1 ± 0.2(^b)</td>
<td>37.7 ± 2.1(^b)</td>
<td>1.1 ± 0.1(^b)</td>
<td>205.3 ± 4.2(^b)</td>
</tr>
<tr>
<td>B (Dehulled, dephytinized bean meal)</td>
<td>28.9 ± 2.2(^a)</td>
<td>n.d.(^d)</td>
<td>6.0 ± 0.1(^b)</td>
<td>11.1 ± 0.4(^b)</td>
<td>0.9 ± 0.04(^b)</td>
<td>137.5 ± 1.1(^a)</td>
<td></td>
</tr>
</tbody>
</table>

1 Values are means ± SD, n = 3 independent analyses. Means in a column with superscripts without common letter differ, P < 0.05 (1-way ANOVA, Bonferroni).
2 Includes native iron and 4 mg Fe added as 57Fe or 58Fe.
3 n.a., not analyzed.
4 n.d., below the limit of detection (<8 mg/meal).

did not increase iron absorption; absorption from meal A in study 6 was 5.7%. Removing most of the PP in the presence of PA did not significantly change iron absorption; absorption from meal B in study 4 was 3.2%. Dephynization after dehulling (meal B, study 4) and removal of most of the PP increased iron absorption to 13.9% (B meals in studies 5 and 6; P < 0.001).

Discussion

Our results indicate that bean PP, as well as PA, contribute to low iron bioavailability from beans. We have shown that 50 and 200 mg GAE of bean PP (as quantified by the Folin-Ciocalteau method) decrease iron absorption by 14 and 45%, respectively, from a simple bread meal free of PA, whereas 20 mg GAE of bean PP had no effect. Bean PP would seem to be somewhat less inhibitory than the PP of common beverages, because Hurrell et al. (20) reported that 200 mg GAE of PP from herb teas, black tea, or red wine reduced iron absorption from a similar bread meal by 60–80% and 116 mg GAE of PP from cocoa reduced iron absorption by 70%. The reasons for these differences are unclear, although it is known that PP from different foods can have different iron-binding properties (21,22).

Depending on their structure, they can form nonabsorbable complexes with iron in the intestinal tract. Data suggests that PP with an ortho-dihydroxy (catechol) or trihydroxy-benzene group (galloyl) such as proanthocyanidins (catechol groups) and hydrolyzable tannins (galloyl groups) are the most potent iron absorption inhibitors (20,21). Common beans contain a wide range of flavanoids, including proanthocyanidins, anthocyanins, and flavonols as well as phenolic acids (15,36–38), and the PP concentration and profile are mainly determined by the seed color (10). White beans contain phenolic acids, but anthocyanins and condensed tannins are not present (37–39), whereas red beans usually have the highest PP concentration (7,10). Variations in PP level within a single color class, however, can be higher than between the different color classes (10).

The 3 levels of PP used in our studies (20, 50, and 200 mg GAE) were estimated to represent the PP concentration of 100 g cooked beans of high (300–900 mg GAE/100 g), middle (150–350 mg GAE/100 g), and low PP (60–100 mg GAE/100 g) concentrations (40). The PP amounts in our meals are based on 350 mg GAE/100 g), and low PP (60–100 mg GAE/100 g)

TABLE 3 Fractional iron absorption of women who consumed RM and bean test meals in studies 1–6

<table>
<thead>
<tr>
<th>Study</th>
<th>n</th>
<th>SF</th>
<th>Fractional iron absorption meal A</th>
<th>Fractional iron absorption meal B</th>
<th>Ratio(^b) B:A</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>%</td>
<td>%</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>16</td>
<td>17.8 (7.2–43.9)</td>
<td>13.9 (6.2, 31.3)</td>
<td>14.2 (6.8, 29.8)</td>
<td>1.02</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>18.0 (9.0–36.3)</td>
<td>20.2 (7.2, 56.7)</td>
<td>17.3* (6.5, 46.4)</td>
<td>0.86</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>18.1 (8.7–37.7)</td>
<td>14.3 (7.4, 27.9)</td>
<td>7.9* (3.9, 15.7)</td>
<td>0.55</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>29.7 (14.1–62.4)</td>
<td>2.6 (1, 6.7)</td>
<td>1.6* (0.5, 5.1)</td>
<td>0.62</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>29.3 (14.5–56.6)</td>
<td>2.4 (1, 5.7)</td>
<td>8.7* (0.5, 21.5)</td>
<td>3.63</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
<td>24.4 (9.5–62.4)</td>
<td>3.5 (1.3, 9.5)</td>
<td>7.1* (2.9, 17.3)</td>
<td>2.0</td>
</tr>
</tbody>
</table>

1 Values are geometric means (range). *Different from meal A, P < 0.05 (paired t test of log-transformed data).
2 A meals contained 4 mg 57Fe; B meals contained 4 mg 58Fe.
3 Absorption ratio of meal B:meal A.
concentration of the meals by addition of isotopes and decreasing the PP:iron molar ratio would be expected to increase iron absorption.

Removing the PP from the dephytinized bean meal by dehulling prior to dephytinization confirmed their inhibitory effect in the absence of PA by doubling iron absorption (study 6, Table 3). However, removal of PP from the whole bean meal (study 4) by dehulling unexpectedly led to a moderate decrease in iron absorption (38%; P < 0.001). Beans, and mainly bean hulls, contain various compounds such as nondigestible carbohydrates (42) that might influence mineral absorption. Dehulling might have led to the loss of a compound positively influencing iron absorption. If such a compound exists, it would need to be more active in the presence of PA (study 4) than in its absence (study 6). Our study design did not allow us to maintain a constant level of minerals over all test meals. A small amount of calcium and other minerals were removed with the hull (Table 2), but their removal would not be expected to decrease iron absorption (43). However, to clearly interpret the results of study 4, further investigations are needed.

A negative effect of PA on iron absorption has been shown many times (19,26) as has the beneficial effect of removing PA from legumes such as soy (25). As might be predicted from studies 1–3, removal of PA from whole beans containing some 180 mg PP did not increase iron absorption, whereas dephytinization in the absence of PP increased iron absorption ~3.4-fold (P < 0.001). Estimated iron absorption from a whole bean meal in iron-deficient women was 5% (Fig. 1), which is higher than expected from other studies and encouraging for bean biofortification (11–13).

From these studies, we conclude that both PA and PP inhibit iron absorption from beans and it seems that their inhibitory effect on iron absorption is not additive. It is likely, therefore, that modulating one without major changes in the other will have only modest effects on iron absorption and that the first priority of breeders should be to breed for a high iron concentration. The most common situation in relation to high-bean diets is to have a relatively constant level of PA (44) but varying amounts of PP, depending on the bean variety. We have demonstrated the inhibitory effect of bean PP only in the absence of PA and, from our results, it is not possible to predict the influence of varying amounts of PP on iron absorption in the presence of PA. This will be the subject of future studies. The PA: iron molar ratio in the common bean is high (4–30:1). Selective presence of PA. This will be the subject of future studies. The PA: iron molar ratio in the common bean is high (4–30:1). Selective breeding for a lower PA level in high-PP beans would not be recommended, but selecting for lower PA varieties might improve iron absorption in communities consuming low- or moderate-PP beans, particularly if they were consumed within mixed diets with some enhancing foods (45,46).

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Literature Cited


