

## The influence of different cereal grains on iron absorption from infant cereal foods<sup>1,2</sup>

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**ABSTRACT** Iron absorption from various cereal grains was evaluated in the present study to identify possible preferences for the preparation of infant weaning foods. In six separate studies, four radioiron absorption tests were performed in each of 57 volunteer subjects by using a sequential double-isotopic method. Serum ferritin concentration was used to adjust for the effect of differences in the iron status of subjects participating in separate studies. Identical commercial processing and test meal composition were used to evaluate iron absorption from 50 g cooked cereal prepared from rice, wheat, maize, oats, millet, and sweet or bitter quinoa. In an initial evaluation of cereals fortified with 2.5 mg Fe as FeSO<sub>4</sub>, geometric mean absorption values were uniformly < 1% for all cereals and were not significantly different. In subsequent studies, percentage iron absorption was enhanced by either eliminating the fortifying iron or adding 50 mg ascorbic acid to the test meal. The effect was similar for most of the cereals tested with a composite mean increase in absorption of 37% when fortifying iron was removed and 270% when ascorbic acid was added. There was a strong inverse correlation between iron absorption and the phytate content of different cereals. Except for a modestly lower absorption of iron from quinoa and a remarkably higher absorption from one lot of maize, we conclude that the type of cereal grain has little influence on iron bioavailability of infant cereals. On the other hand, modification in the milling and processing methods for cereal grains that reduce their content of phytic acid is likely to improve iron availability significantly. *Am J Clin Nutr* 1997;65:964-9.

**KEY WORDS** Iron absorption, infant cereal foods, cereal grains, iron fortification, iron bioavailability, phytate, grain milling, ascorbic acid

### INTRODUCTION

A full-term newborn infant receives a generous endowment of iron from his or her mother that lasts for the first 4-6 mo of life. Beyond this, diet becomes the only source of iron for growth and physiologic losses. From 6 mo until sometime during the second year of life when the infant adapts to the family diet, weaning or transitional foods are the major dietary sources of iron. Processed cereals are widely used for this purpose. Infant cereals are usually fortified with iron in industrialized countries but not in most developing countries, where cereal grains are commonly grown and milled locally. In some countries, infant food supplements containing a blend of processed cereals, le-

gumes, and dairy products are distributed by local or international donor agencies to the lower socioeconomic segments of the population. The major cereal grains used for infant cereals are wheat, maize, and rice, which are produced in roughly equal amounts worldwide (1).

Many radioisotope studies have been performed in humans to characterize the iron bioavailability of different cereals (1). Early workers used intrinsically labeled cereals grown in hydroponic media to produce a grain tagged biosynthetically (1). Subsequently, studies of iron bioavailability were simplified by using an extrinsic labeling procedure in which a tracer amount of radioactive iron is added to the meal at the time of consumption (2). The results of iron bioavailability studies with different cereals that used both experimental approaches have been summarized (1, 3). However, a considerable variation in absorption data exists in studies reported from different laboratories because of differences in the size and composition of the test meal, the iron status of the subjects tested, the amount or type of mineral or vitamin supplement added to the cereal, and variations in the method of milling and processing the cereal grain. Processing variations are especially important because of the influence of processing techniques on the phytic acid content, which inhibits iron absorption (4-8).

The present investigation was undertaken to evaluate the absorption of iron contained in, or added to, dry cereals used for infant feeding. Identical commercial processing methods were used for all cereals tested. Besides wheat, maize, and rice, we evaluated millet, oat, and quinoa, which are used in some regions of the world for infant feeding. We compared iron absorption in adult human subjects from cereals fortified with FeSO<sub>4</sub>. In addition, with selected cereals we compared the effects of removing the fortifying iron and of adding ascorbic acid.

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## SUBJECTS AND METHODS

### Subjects

Six studies were performed in groups containing 8–12 volunteer subjects. Absorption was measured from four separate test meals in each subject. The 57 volunteers who participated included 30 males and 27 females ranging in age from 21 to 37 y (mean: 25 y). The participants denied any history of disorders or current use of medications that might affect the gastrointestinal absorption of iron and all stated that they were in good general health. There were substantial differences in iron status among the study groups as reflected by the geometric mean serum ferritin concentrations, which ranged from 13.5 to 73.7  $\mu\text{g/L}$  with an overall mean of 41.1  $\mu\text{g/L}$ . Ten of the subjects (one male, nine females) were iron deficient as defined by a serum ferritin concentration  $\leq 12 \mu\text{g/L}$ , but only one was anemic. Written informed consent was obtained from each volunteer before the investigation. All experimental procedures were approved by the Human Subjects Committee at the University of Kansas Medical Center.

### Preparation of infant cereals

Two separate lots of cereals were used: lot A for studies 1 and 2, and lot B for the remaining four studies. The cereal flour was prepared in the same manner for both lots, with the exception of maize. For lot A, maize imported from France was prepared from nondegermed whole maize ground to a flour whereas for lot B, degermed and debranned maize semolina ground to a flour was used. The bitter and sweet quinoa were imported from Ecuador and ground on a hammer mill to obtain whole-meal flour. Oat grain from Germany was dehulled, treated with steam to inactivate the lipase, dried, flaked, and ground to a whole-meal flour. Rice flour was milled white Italian rice. Wheat was 65% extraction flour purchased in Switzerland.

The same processing method was used to prepare all experimental infant cereals. A 10% sucrose solution was added to the cereal flour to produce a slurry that was then cooked by steam injection and roller-dried at 125–130 °C. The biochemical composition of the unfortified cereals is listed in **Table 1**.

### Iron absorption measurements

Double radioiron labels were administered on 2 successive days for the first pair of iron absorption measurements and repeated 2 wk later to obtain a total of four measurements in each subject. On the day preceding the first test meal, 30 mL blood was drawn for determination of background blood radioactivity, packed cell volume, and serum ferritin concentration (9). The first two test meals labeled with either  $^{59}\text{Fe}$  or  $^{55}\text{Fe}$  were then fed on the following two mornings between 0700 and 0900. The subjects were required to fast for 10 h before each test meal and were allowed nothing but water for 3 h after the meal.

The dry cereals were prepared on the morning of administration by adding 0.5 g salt, 10 g sugar, and 300 mL deionized water to 50 g dry cereal. When the cereals were fortified with iron, 2.5 mg Fe was added as  $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  in 1 mL 0.01 mol HCl/L with radioactive iron. Because a dark color formed when iron was added to bitter quinoa, the radioiron was diluted in 15 mL water, which the subjects were instructed to sip while eating the cereal. In certain studies, 50 mg ascorbic acid was mixed with the cereal. All test meals, with or without added iron, were tagged extrinsically by adding either 37 kBq  $^{59}\text{FeCl}_3$  or 111 kBq  $^{55}\text{FeCl}_3$  in 1 mL 0.01 mol HCl/L containing 0.1 mg Fe as  $\text{FeCl}_3$  (10). Thirty milliliters blood was obtained 2 wk after the second test meal to measure the incorporation of absorbed radioactivity in circulating red blood cells. The second pair of separately labeled test meals were fed on the next two mornings and a final blood sample was drawn 2 wk later to determine the increase in red blood cell radioactivity. A modification of the method of Eakins and Brown (11) was used to determine the  $^{59}\text{Fe}$  and  $^{55}\text{Fe}$  radioactivity in duplicate 10-mL samples of whole blood. Percentage absorption was calculated from the total blood volume of each subject as estimated from their height and weight (12, 13). We assumed that 80% of the absorbed radioactivity was incorporated into circulating red blood cells 14 d after each test dose (14).

### Statistical analysis

Because of the skewed distribution of percentage absorption values, they were converted to logarithms for statistical anal-

**TABLE 1**  
Analytical data for roller-dried cereal flours

| Studies and cereal | Moisture | Nitrogen | Fat | Ash  | Sucrose | Phytic acid | Iron  |
|--------------------|----------|----------|-----|------|---------|-------------|-------|
|                    | %        | %        | %   | %    | %       | %           | mg/kg |
| 1, 2               |          |          |     |      |         |             |       |
| Bitter quinoa      | 3.5      | 2.04     | 6.9 | 1.98 | 9.3     | 0.885       | 44.4  |
| Millet             | 2.1      | 1.81     | 2.3 | 1.81 | 9.6     | 0.340       | 17.1  |
| Rice               | 2.1      | 1.26     | 1.0 | 0.51 | 9.1     | 0.075       | 4.4   |
| Maize              | 2.6      | 1.12     | 3.9 | 0.87 | 10.1    | 0.360       | 26.9  |
| Oat                | 2.4      | 1.52     | 6.1 | 1.29 | 9.9     | 0.310       | 24.5  |
| Wheat              | 2.3      | 2.16     | 1.8 | 0.70 | 9.9     | 0.079       | 14.1  |
| Sweet quinoa       | 3.5      | 1.95     | 7.4 | 2.20 | 11.4    | 0.770       | 33.9  |
| 3–6                |          |          |     |      |         |             |       |
| Rice               | 1.9      | 1.12     | 1.0 | 0.58 | 10.6    | 0.165       | 4.3   |
| Maize              | 2.3      | 1.46     | 0.6 | 0.28 | 10.6    | 0.028       | 4.8   |
| Oat                | 1.8      | 2.03     | 6.7 | 1.56 | 12.8    | 0.500       | 22.5  |
| Wheat              | 2.2      | 2.03     | 1.1 | 0.55 | 10.4    | 0.122       | 8.2   |
| Sweet quinoa       | 1.4      | 2.26     | 6.6 | 2.70 | 13.0    | 0.763       | 26.5  |

ysis and the results reconverted as antilogarithms to recover the original units (15). Comparisons of absorption values for different test meals within each group of subjects were performed by paired *t* tests to determine whether the mean log absorption ratio differed significantly from zero. Mean differences among more than two absorption tests within a given study were analyzed by analysis of variance (ANOVA). When absorption results obtained in different studies were compared, an adjustment was required for differences in iron status between different groups of subjects as reflected by their serum ferritin concentrations. These comparisons were made by analysis of covariance (ANCOVA) using the log serum ferritin concentration as a covariant. Significant differences in least-square means were analyzed by Scheffé test (SAS; SAS Institute Inc, Cary, NC).

## RESULTS

The first two studies were performed to directly compare iron absorption from seven different cereals, 50 g of each of which was fortified with 2.5 mg Fe as FeSO<sub>4</sub> (study 1, meals A-D; study 2, meals B-D; Table 2). Mean absorption from all meals was < 1%, ranging from a low of 0.23% with bitter

quinoa to a high of 0.72% with rice. When evaluated by ANCOVA, the differences were not significant ( $F = 1.75$ ,  $P = 0.12$ ).

Further studies were performed to determine whether greater differences in iron absorption existed between cereals when absorption was enhanced by either omitting the fortifying iron or adding ascorbic acid. The effect of removing the fortifying iron was evaluated with five cereals. With sweet quinoa (meals A and B, study 2), mean absorption increased from 0.58% to 0.67% with a ratio of absorption without fortifying iron to with fortifying iron of 1.16 ( $\pm 1$  SE, 0.97–1.39), which was not significant ( $P = 0.43$ ). The increase with wheat was also not significant; mean absorption increased from 0.79% to 1.22% when iron was eliminated (meals A and B, study 3), giving a mean ratio of absorption without to with iron of 1.55 ( $\pm 1$  SE, 1.22–1.95,  $P = 0.12$ ). However, the increase when fortifying iron was omitted was significant with the remaining cereals. Absorption with rice (meals C and D, study 3) increased from 1.02% to 1.77%, giving a mean ratio of absorption without to with iron of 1.73 ( $\pm 1$  SE, 1.54–1.95,  $P = 0.002$ ). Absorption from maize increased from 8.37% to 13.12% (meals A and B, study 4), giving a ratio of absorption without to with iron of 1.57 ( $\pm 1$  SE, 1.42–1.73,  $P = 0.002$ ). Finally, the increase in

**TABLE 2**  
Iron absorption from cereal-based meals in adults

| Study and meal           | Subject age | Subject serum ferritin     | Cereal additions <sup>1</sup> | Absorption                    | Adjusted absorption <sup>2</sup> |
|--------------------------|-------------|----------------------------|-------------------------------|-------------------------------|----------------------------------|
|                          | <i>y</i>    | $\mu\text{g/L}$            |                               | % of dose                     | % of dose                        |
| 1 ( <i>n</i> = 7 M, 4 F) | 27          | 47.0 (13–108) <sup>3</sup> |                               |                               |                                  |
| A, bitter quinoa         |             |                            | Iron                          | 0.23 (0.15–0.35) <sup>4</sup> | 0.24                             |
| B, millet                |             |                            | Iron                          | 0.44 (0.31–0.63)              | 0.44                             |
| C, rice                  |             |                            | Iron                          | 0.72 (0.57–0.92)              | 0.72                             |
| D, maize                 |             |                            | Iron                          | 0.40 (0.30–0.52)              | 0.40                             |
| 2 ( <i>n</i> = 4 M, 8 F) | 23          | 47.0 (5–197)               |                               |                               |                                  |
| A, sweet quinoa          |             |                            | —                             | 0.67 (0.55–0.82)              | 0.65                             |
| B, sweet quinoa          |             |                            | Iron                          | 0.58 (0.48–0.69)              | 0.56                             |
| C, oat                   |             |                            | Iron                          | 0.52 (0.40–0.66)              | 0.50                             |
| D, wheat                 |             |                            | Iron                          | 0.58 (0.39–0.84)              | 0.56                             |
| 3 ( <i>n</i> = 3 M, 5 F) | 23          | 36.0 (8–125)               |                               |                               |                                  |
| A, wheat                 |             |                            | Iron                          | 0.79 (0.64–0.97)              | 0.77                             |
| B, wheat                 |             |                            | —                             | 1.22 (0.98–1.51)              | 1.18                             |
| C, rice                  |             |                            | Iron                          | 1.02 (0.86–1.22)              | 0.99                             |
| D, rice                  |             |                            | —                             | 1.77 (1.45–2.16)              | 1.71                             |
| 4 ( <i>n</i> = 5 M, 4 F) | 25          | 13.5 (2–173)               |                               |                               |                                  |
| A, maize                 |             |                            | Iron                          | 8.37 (6.88–10.17)             | 5.64                             |
| B, maize                 |             |                            | —                             | 13.12 (10.75–16.02)           | 8.83                             |
| C, oat                   |             |                            | —                             | 2.05 (1.78–2.36)              | 1.38                             |
| D, oat                   |             |                            | —                             | 3.51 (2.56–4.80)              | 2.36                             |
| 5 ( <i>n</i> = 5 M, 4 F) | 25          | 73.7 (19–209)              |                               |                               |                                  |
| A, maize                 |             |                            | —                             | 5.06 (4.09–6.26)              | 6.68                             |
| B, maize                 |             |                            | AA                            | 11.57 (9.43–14.21)            | 15.29                            |
| C, wheat                 |             |                            | —                             | 2.31 (1.74–3.06)              | 3.05                             |
| D, wheat                 |             |                            | AA                            | 8.45 (6.65–10.75)             | 11.17                            |
| 6 ( <i>n</i> = 8 M, 1 F) | 27          | 68.9 (15–153)              |                               |                               |                                  |
| A, sweet quinoa          |             |                            | —                             | 0.93 (0.68–1.26)              | 1.21                             |
| B, sweet quinoa          |             |                            | AA                            | 1.61 (1.10–2.35)              | 2.07                             |
| C, rice                  |             |                            | —                             | 1.67 (1.12–2.50)              | 2.16                             |
| D, rice                  |             |                            | AA                            | 5.99 (4.33–8.28)              | 7.71                             |

<sup>1</sup> 2.5 mg Fe as FeSO<sub>4</sub> · 7 H<sub>2</sub>O; AA, 50 mg ascorbic acid.

<sup>2</sup> Geometric mean absorption adjusted for iron status by ANCOVA with log serum ferritin as a covariant.

<sup>3</sup> Geometric mean; range in parentheses.

<sup>4</sup> Geometric mean;  $\pm 1$  SE in parentheses.

absorption when fortifying iron was removed from oat cereal was also significant; absorption increased from 2.05% to 3.51% (meals C and D, study 4) giving a mean ratio of absorption without to with iron of 1.71 ( $\pm 1$  SE, 1.37-2.14,  $P < 0.05$ ).

Although iron absorption from the unfortified cereal was significantly greater than from the fortified for only three of the five cereals, the effect was similar with all (Figure 1). The difference was only 14% for sweet quinoa as compared with 35-42% for the remaining four cereals; the weighted mean increase for all cereals was 38%. When the ratios for the five cereals were compared by ANOVA, the differences were not significant ( $F = 0.94$ ,  $P = 0.45$ ).

In studies 5 and 6, the enhancing effect of adding 50 mg ascorbic acid to the unfortified cereals was evaluated. With maize (meals A and B, study 5), absorption increased from 5.06% to 11.57%, resulting in a ratio of absorption with ascorbic acid to without ascorbic acid of 2.28 ( $\pm 1$  SE, 2.02-2.59), a highly significant increase ( $P < 0.002$ ). An even greater relative increase was observed with wheat (meals C and D, study 5); absorption increased from 2.31% to 8.45% corresponding to an absorption ratio of 3.66 ( $\pm 1$  SE, 3.33-4.03) ( $P < 0.001$ ). With sweet quinoa (meals A and B, study 6), absorption increased significantly from 0.93% to 1.61%, giving a mean absorption ratio of 1.73 ( $\pm 1$  SE, 1.45-2.06) ( $P = 0.02$ ). Finally, iron absorption from rice increased from 1.67% to 5.99% (meals C and D, study 6), giving a mean absorption ratio of 3.58 ( $\pm 1$  SE, 2.84-4.50) ( $P = 0.001$ ).

The relative increases in absorption with the addition of ascorbic acid are compared in Figure 2. When examined by ANOVA, the ratios differed significantly ( $F = 5.13$ ,  $P < 0.01$ ). With Scheffé comparisons, two groups of subjects were identified within which there were no significant differences: quinoa and maize in the first, and wheat, rice, and maize in the

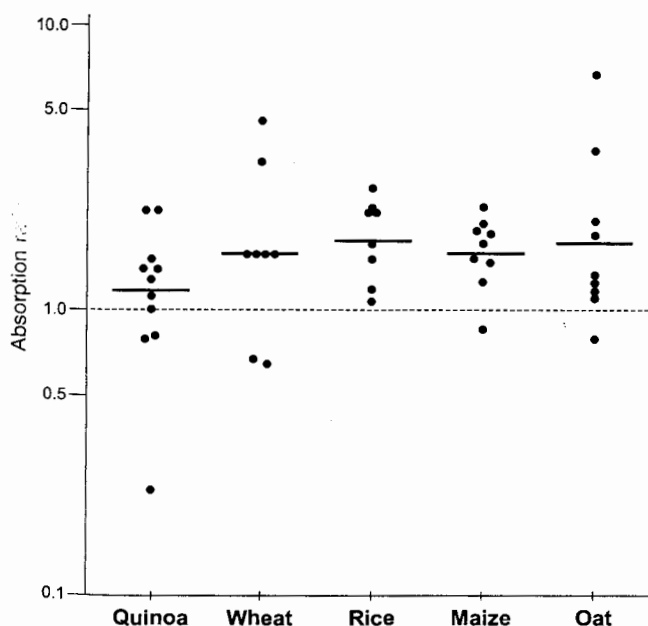


FIGURE 1. The enhancing effect of removing fortifying iron from five cereal foods. The absorption ratios without to with added iron are plotted on logarithmic coordinates. The solid horizontal bars represent geometric mean ratios and the dashed line denotes a ratio of 1.0.

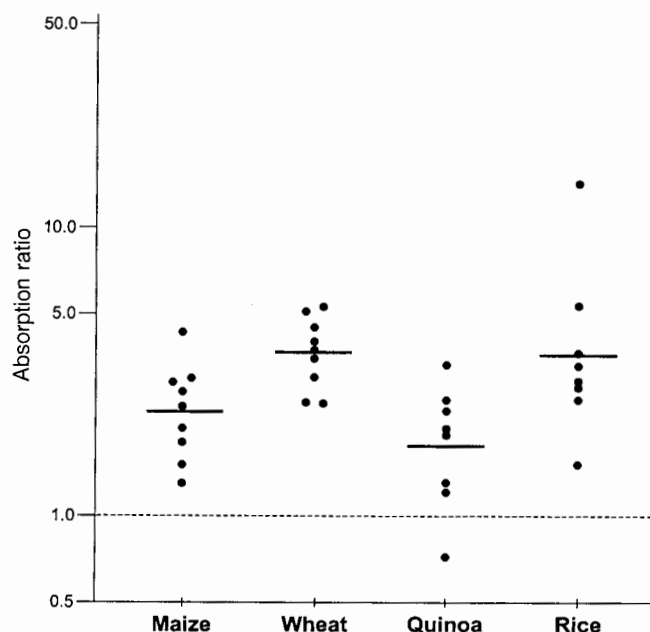


FIGURE 2. The enhancing effect on iron absorption of adding ascorbic acid to four unfortified cereal foods. The absorption ratios with to without ascorbic acid are plotted on logarithmic coordinates. The solid horizontal bars represent geometric mean ratios and the dashed line denotes a ratio of 1.0.

second. The weighted mean increase for all cereals was 270%. When the four cereals containing added ascorbic acid were compared by ANCOVA, iron absorption differed significantly ( $F = 13.6$ ,  $P < 0.001$ ); iron absorption from sweet quinoa was significantly lower than from maize, rice, or wheat whereas there was no significant difference in absorption among the latter three cereals.

As noted previously, there were significant differences in iron status among the various study groups as reflected in mean serum ferritin values. Least-square-mean values for iron absorption adjusted for differences in iron status by ANCOVA are listed in Table 2. In most studies, the adjustments were small, except for study 4, in which five of nine subjects were iron deficient as defined by serum ferritin concentrations  $\leq 12$   $\mu\text{g/L}$ . The adjusted mean square absorption values provide a more valid comparison of absorption data obtained for a particular cereal in different studies than do unadjusted values. With fortified cereals, mean absorption values of 0.72% and 0.99% were obtained with rice (studies 1 and 3) and 0.56% and 0.77% with wheat (studies 2 and 3). Slightly greater divergence was seen with oat, as reflected in mean absorption values of 0.50% and 1.38%. On the other hand, a dramatic 10-fold difference was observed with maize; iron absorption averaged 0.44% in study 1 and 5.64% in study 4V. This difference was due to the use of degermed maize in the latter study.

Additional comparisons between studies were available for cereals that were fed without fortifying iron. For example, mean iron absorption with rice was 1.71% in study 3 and 2.16% in study 6. With maize, absorption averaged 8.83% in study 4 and 6.68% in study 5. A greater relative difference was observed with sweet quinoa as shown by mean absorption values of 0.65% in study 2 and 1.21% in study 6. A modest difference was also observed with wheat, which had mean iron

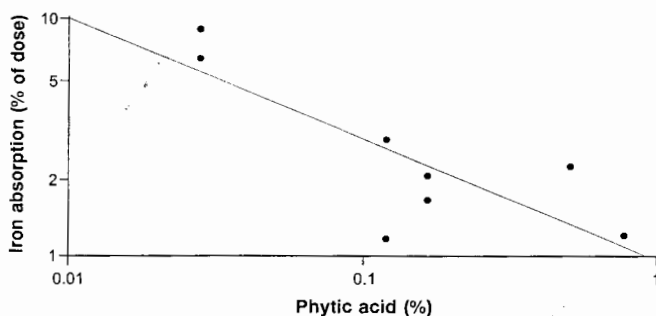


FIGURE 3. Double logarithmic relation observed with lot B cereals between iron absorption and phytic acid content of maize, wheat, rice, oat, and quinoa containing no fortifying iron or ascorbic acid. There was a significant inverse correlation ( $r = -0.801$ ,  $P < 0.02$ ).

absorption values of 1.18% in study 3 and 3.05% in study 5. Although other comparisons between studies are possible depending on whether iron or ascorbic acid was added to the cereal, absorption data for a particular cereal in different studies were similar except for the markedly higher absorption observed with one lot of maize. On the other hand, the variation in iron absorption from different cereals was due primarily to the inhibitory effect of their phytic acid contents (Figure 3).

## DISCUSSION

A comprehensive interim summary on the iron bioavailability of different cereal grains as determined from radioisotopic measurements of iron absorption in humans was published in 1982 (1). Direct comparisons of intrinsic and extrinsic radioiron labeling of a particular cereal showed that the two methods gave similar results. The emphasis in that review was on studies with rice, wheat, and maize—the major food staples consumed globally. Arithmetic mean iron absorption from rice meals ranged from 1.2% to 11.6% in five separate studies in 221 subjects with a weighted mean of 6.5%. Given the lower values typically seen with geometric means calculated in the present study, our absorption values with rice of 1.71% and 2.16% are comparable. A greater disparity was observed with iron absorption from wheat, which averaged 30.9% in the previous report as compared with 1.18% and 3.05% in the present study. A marked difference in the opposite direction was observed with maize, which averaged 3.7% in 167 subjects reviewed previously compared with 8.83% and 6.68% in the present study. In a single earlier study of iron absorption from oat porridge incorporated into a breakfast meal containing both coffee and ascorbic acid, an arithmetic mean absorption of 3.9% was observed (16), which is similar to the adjusted geometric mean of 2.36% in our study 4. We are not aware of previous studies in humans of iron absorption from millet or quinoa.

One of the difficulties in comparing results of iron absorption studies performed in different laboratories is the marked influence of the iron status of the subjects on iron absorption. One of the more common methods used to minimize this effect is to include a measurement of iron absorption from a reference dose of inorganic iron in all subjects and to calculate the ratio of absorption from the test meal to that of the reference dose (17). In the review (1), the surveyed reports were limited to

studies in men or to those in which a reference dose was used. Direct comparison with our current results is not possible because we did not use a reference dose of inorganic iron. We have found that corrections based on iron absorption from a standard meal or the serum ferritin concentration are less variable (18). The optimal approach to eliminating the effect of differences in iron status is to compare iron absorption from different meals in the same subjects. However, we could not compare all seven cereals in the same group of subjects because we did not perform more than four tests with each individual. We therefore used ANCOVA to adjust for differences in iron status as determined by serum ferritin assays. The adjustments were modest as shown by the least-square means in Table 2, except for study 4, in which the majority of subjects were iron deficient.

Another important variable, when comparing iron absorption data for different cereal grains, is the nature of the test meal. In the majority of published studies other foods were added to the cereal-based test meal, many of them reduce or enhance iron absorption. In the earlier review, the studies included in the survey were limited to those in which the cereal food was the main component of the test meal. Nevertheless, results obtained with meals containing potent inhibitors such as tea or coffee or strong enhancers such as ascorbic acid were included; this undoubtedly accounts for some of the wide differences reported from different laboratories. We eliminated this variable in the present investigation by performing baseline studies with meals containing only added sucrose and salt, neither of which influence absorption. The use of a standardized test meal allowed us to focus on the effect of the cereals per se.

Fortification iron was added to the test meal in several previous reports depending on whether the emphasis was on the use of the cereal grain as a food staple or as an infant weaning food. Because our interest was in the latter, we added  $\text{FeSO}_4$  to all meals in our initial comparison, which accounted, in part, for the low absorption observed in studies 1 and 2. The native iron content of our test meals ranged from  $< 0.2$  mg Fe for rice and maize to  $> 2$  mg Fe for bitter quinoa. It should be emphasized that the absolute amount of iron absorbed from cereals that contained no fortifying iron was negligible with or without ascorbic acid, ranging from only 0.01 to 0.04 mg Fe. However, when the iron content of the meal was increased 3- to 10-fold, there was a relatively modest and consistent inhibiting effect averaging 30–40% for most cereals except quinoa. Because this decrease was modest even with cereals containing a high native iron content, it is clearly beneficial to fortify infant cereals regardless of the cereal grain used for their preparation.

A similar constancy was observed for the enhancing effect of ascorbic acid on the cereals. The relative increase in iron absorption was nearly threefold and similar for the four cereals tested, although absorption from an ascorbate-containing quinoa remained lower than from wheat, rice, or maize. Thus, with the exception of quinoa, we again saw no obvious advantage of one cereal over another with regard to the enhancing effect of ascorbate. Although we did not test the effect of adding both iron and ascorbic acid to the test meals, it is reasonable to assume that the combined effect would markedly increase the absolute amount of iron absorbed from the test meals.

Studies performed over the past decade leave little doubt that the phytate content of cereal foods is one of the most important

determinants of food iron availability. A significant early observation of this effect was the dose-related inhibition of iron absorption that occurred when increasing amounts of bran were added to a wheat-based meal (19). The nature of this inhibition was shown in later studies to be due mainly to the phytate content of bran (6). A characteristic feature of the inhibiting effect of phytate is the small amounts required to produce an effect. In one recent study, we observed that the phytic acid content of soy protein must be reduced to < 10 mg per meal to significantly reduce the inhibitory effect (7), although in other investigations, a dose-related inhibition was demonstrated over a much broader range of phytate concentrations (20). One of the more convincing studies of the marked inhibition of iron absorption by small quantities of phytate was performed to explain a threefold higher iron absorption from rolls baked with wheat starch than with rice starch (21). When a revised, more sensitive method of phytate analysis was used, the difference in iron absorption was shown to result from an absence of detectable phytate in the wheat-based meal compared with a low but measurable phytate content in rolls prepared from rice starch. In a recent study from this laboratory, the inhibitory effect of adding varying amounts of sodium phytate to meals containing different types of protein was shown to be independent of the protein source or basal iron absorption from the test meal (8).

The differences that were observed in the present study in iron absorption from different cereals almost certainly reflect differences in phytate content of the test meals. A striking example is the dramatic difference in iron absorption from different lots of maize that differed 10-fold in phytic acid content. Presumably, differences in phytate content also explain the relatively low iron absorption observed with wheat cereal in the present study compared with the 10-fold higher values reported previously from rolls prepared with 55% extraction flour (22). The close correlation between iron absorption and the phytate content of the cereals observed in the present study, regardless of the type of cereal (Figure 3), is further evidence that the cereal used for infant feeding is important mainly in regard to its phytate content. In many cases, the latter is less an inherent property of the cereal than an effect of the method of processing it. For example, when iron absorption rates from polished and unpolished rice with widely different phytate contents were compared, a close reciprocal relation was observed between phytate content and iron absorption (21). It is obviously an advantage to use degermed and debranned maize flour when preparing infant cereal. In future efforts to modify the composition of infant cereals to improve their influence on iron balance, attention should be focused on the milling and processing methods used to reduce their content of phytate rather than on the particular cereal grain used. ■

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