

**NUTRITIONAL SIGNIFICANCE OF INTERACTIONS
BETWEEN IRON AND FOOD COMPONENTS^{1,2}**

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SUMMARY

Most food iron in the gut enters into two "common pools" that behave quite differently in terms of absorption. Heme iron present in hemoglobin and myoglobin, is well absorbed and is relatively unaffected by diet composition. Non-heme iron, the form of iron present in vegetables and in man's staples, generally is poorly absorbed and is greatly affected by enhancing or inhibiting substances in the diet. In experiments employing intrinsically-labeled hemoglobin as a tracer, absorption of a dry hemoglobin concentrate added to milk, a rice cereal and wheat cookies, was uniformly good, relatively constant and quite independent from the type of food. In contrast, absorption of iron salts decreases markedly when given with food.

The presence or absence of inhibiting or enhancing factors of non-heme iron absorption is determinant in the possibility of obtaining required iron for most people in the world whose diet contains little heme iron. Meat and ascorbic acid are the main enhancers of non-heme food iron absorption. Common inhibitors include carbonates, oxalates, phytate, bran, tea and egg yolk. The enhancing effect of ascorbic acid on the absorption of fortification iron in milk and the effect of tea, eggs or meat on the absorption of bread iron from common Chilean meals are discussed as examples of interactions of food components with non-heme iron.

INTRODUCTION

Iron is an abundant element in nature and exists in relatively large amounts in most foods consumed by man. Thus, it is a paradox that today, iron deficiency continues to be one of the most prevalent nutritional deficiencies in the world. Explanation for this phenomenon can be found in the fact that man has great difficulty in absorbing iron through the intestinal mucosa, a fact that is largely related to interactions that occur between the element and other food constituents.

In the past two decades, knowledge concerning the factors affecting the biological availability of iron has advanced tremendously with the use of precise radioisotopic techniques. It is well known that absorption is influenced by the iron nutrition status of the individual and by the total amount of iron present in the diet. However, of greater importance is the chemical form in which iron is presented to the intestinal cell. Several studies (1, 2) have demonstrated that most food iron in the gut enters into two "common pools" that behave quite differently in terms of

absorption, the so called heme-iron and non-heme iron pools. Heme iron, present in hemoglobin and myoglobin, is well absorbed and is relatively unaffected by diet composition (3, 4, 5). On the other hand, non-heme iron, the form of iron present in vegetables and in man's staples such as wheat, rice and maize, generally is poorly absorbed and is greatly affected by enhancing or inhibiting substances in the diet (5). Important exceptions to this two-pool model are ferritin and hemosiderin, which seem to conform a third iron pool that is very poorly absorbed (6). Also, some insoluble iron salts, such as ferric hydroxide and ferric oxide present in dirt, may contribute significantly to the iron in the diet but are essentially unavailable for absorption (7).

ABSORPTION OF HEME IRON

If soluble inorganic iron salts and hemoglobin are given in water solutions in the absence of food, absorption of the inorganic iron is higher. The better absorption of heme iron becomes apparent in the presence of food and is due to the fact that heme enters the mucosal cell as such, its iron being released within the cell, and is thus unaffected by intestinal secretions or other ingredients in the diet (8).

The independence of heme iron absorption from diet composition has been extensively documented and can be illustrated by studies performed in our laboratory in relation to the interest in the use of hemoglobin derived from bovine blood in food fortification. Dry hemoglobin concentrates intrinsically labeled with ^{55}Fe were used to fortify milk, a rice cereal and wheat cookies. Iron absorption was calculated from the radioactivity incorporated into circulating red cells. Results revealed that bio-availability of the hemoglobin iron was uniformly good, relatively constant and quite independent from food ingredients (Fig. 1).

BIO-AVAILABILITY OF NON-HEME FOOD IRON

In contrast, there is a ten fold decrease in the per cent absorption of ferrous sulphate iron when given with milk instead of water (Fig. 1). As previously mentioned, many factors present in food can profoundly influence the bio-availability of non-heme iron. The presence or absence of inhibiting or enhancing factors

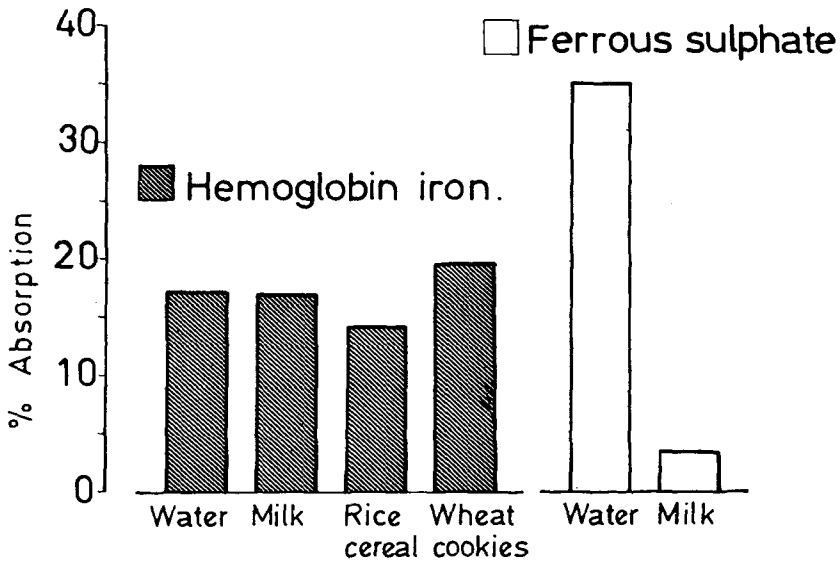


FIGURE 1

Absorption of heme and non-heme fortification iron given with different foods

of its absorption becomes determinant in the possibility of obtaining the required iron for the vast majority of people in the world whose diet contains very little or no heme iron.

The interaction of depressing and enhancing factors in a mixed diet is complex (9). The effects of ligands of dietary origin depend on factors such as the concentration of the ligand, its affinity for iron, the concentration of other ligands, the effectiveness of complexing in the gut lumen and the efficiency with which complexes are absorbed (10). A list of substances influencing non-heme food iron absorption is shown in Table 1.

The main enhancers of non-heme food iron absorption are meat (11, 12) and ascorbic acid (13, 14, 15). Thus, the presence of meat, fish or poultry in the diet is important in iron nutrition

TABLE 1
FACTORS AFFECTING THE BIO-AVAILABILITY OF NON-HEME
FOOD IRON

<i>Enhancing</i>	<i>Depressing</i>
Meat, fish, chicken	Carbonates, oxalates, phosphates
Ascorbic acid	Phytate
	Bran, vegetable fiber
	Tea
	Egg yolk

not only because of their heme iron contents, but also because they increase the absorption of non-heme iron, an effect that may be related to the amino acids released during digestion (11, 12).

Ascorbic acid is present in significant amounts in many commonly eaten foods. The importance of ascorbic acid rich foods on the availability of non-heme iron in a meal has been well demonstrated. Ascorbic acid acts as a reductant and a binder of iron to form a complex that is easily absorbed. Its effect is dose dependent (14).

We have studied the effect of ascorbic acid on the availability of fortification iron in infant milk formulas. As previously mentioned, milk has a marked inhibitory effect on the absorption of non-heme iron. When 15 mg per liter of iron, as ferrous sulphate, is added to milk, only 3 - 4% is absorbed. Ascorbic acid was added to fortified milk in concentrations ranging from 25 to 800 mg per liter (16). With doses of 100 and 200 mg per liter, absorption increased by a factor of 1.8 and 2.8 respectively (Figure 2). These results have important implications in the choice of iron-fortified formulas for the prevention of iron deficiency in infants. Other studies in our laboratory have shown that absorption of fortification iron in different formulas, depending on their ascorbic acid contents, can vary from about 3 to 12%.

Inhibitors of iron absorption form complexes with iron that make it poorly available. In addition to substances such as carbonates, oxalates, phosphates and phytates, whose adverse effect has been known for some time (9, 10, 17, 18), it has recently been demonstrated that when tea is given with various meals, insoluble iron tannates are formed and there is a marked reduction in

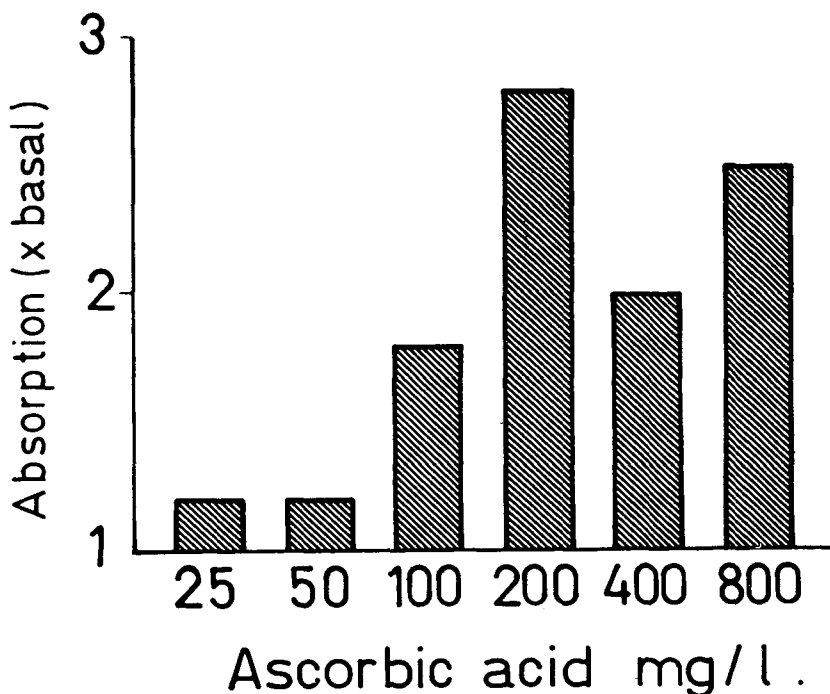


FIGURE 2

Effect of ascorbic acid on the availability of fortification iron in milk

absorption (19). Bran inhibits the absorption of iron from wheat bread (20), an effect that appears to be unrelated to its phytate content as dephytinized wheat bran still inhibits non-heme iron absorption (21). Absorption of iron from biologically-labeled eggs is very low, and the inclusion of eggs in meals decreases the absorption of non-heme iron (22). The poor availability of iron from egg yolk is due to the presence of phosvitin, a phosphoprotein which binds iron tightly (23).

Some of the aspects discussed about factors influencing the absorption of non-heme food iron are illustrated by recent studies conducted in our laboratory on the availability of iron from typical Chilean meals (Table 2). Wheat is the predominant staple in Chile. Most of the iron in the meals we studied came from the ferrous sulphate-fortified wheat flour that is used to make bread and

TABLE 2
AVAILABILITY OF NON-HEME IRON FROM COMMON CHILEAN MEALS

Meal	Iron content (mg)	Main source of iron	Other meal ingredients	Per cent absorption
Breakfast	2.9	Wheat bread	Tea, sugar	1.9
Lunch	3.4	Wheat bread	Meat, potatoes, pumpkin, apple	4.0
Dinner	4.9	Wheat bread, spaghetti	Eggs	1.8

pastas. Using an extrinsic tag of radio iron, absorption from this predominantly vegetable diet was studied in 30 healthy adults. Iron absorption was low, particularly from breakfast and dinner, which contained tea and eggs, both potent inhibitors of non-heme iron absorption. Absorption from lunch, which contained 80 g of meat and 23 mg of ascorbic acid, was two times higher.

Of the essential minerals for man, iron is probably the one for which we have a better understanding of the many food interactions that have nutritional importance. As we increase our knowledge of the nutrition of the other minerals, equally significant interactions become apparent.

RESUMEN

SIGNIFICADO NUTRICIONAL DE LAS INTERACCIONES ENTRE EL HIERRO Y LOS COMPONENTES DE LOS ALIMENTOS

La mayor parte del hierro alimentario entra a formar parte en el intestino de dos "pools" comunes ("common pools") que se comportan en forma del todo diferente desde el punto de vista de la absorción. El hierro hemínico que contiene la hemoglobina y la mioglobina se absorbe bien, y se ve poco afectado por la composición de la dieta. En cambio el hierro no hemínico, que los vegetales y los alimentos básicos del hombre contienen, por lo general se absorbe mal y es muy afectado por sustancias favorecedoras o inhibitoras

presentes en la dieta. En experimentos realizados utilizando hemoglobina marcada intrínsecamente como trazador, la absorción de un concentrado seco de hemoglobina agregado a leche, a un cereal de arroz o a galletas de trigo, fue uniformemente buena, relativamente constante e independiente del tipo de alimento. En contraste, la absorción de sales inorgánicas de hierro decrece notoriamente al administrarlas con alimentos.

La presencia o ausencia de factores inhibidores o favorecedores de la absorción de hierro no hemínico es un factor determinante de las posibilidades de obtener el hierro requerido por la mayoría de la población del mundo cuya dieta contiene hierro hemínico escaso. La carne y el ácido ascórbico son los principales favorecedores de la absorción del hierro no hemínico de los alimentos. Los carbonatos, oxalatos, fitatos, el salvado de trigo, el té y la yema de huevo son inhibidores corrientes. Como ejemplos de interacciones entre los componentes de los alimentos y el hierro no hemínico se discute el efecto favorecedor del ácido ascórbico sobre la absorción del hierro de fortificación en leche y el efecto del té, el huevo o la carne sobre la absorción del hierro del pan en comidas comunes en Chile.

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