NUTRITIONAL STUDIES ON THE BIOAVAILABILITY OF IRON FROM CEREALS AND PULSES

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THESIS
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DECLARATION

I hereby declare that the thesis entitled '**Nutritional studies on the bioavailability of iron from cereals and pulses'** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

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CERTIFICATE

Certified that the thesis entitled '**Nutritional studies on the bioavailability of iron from cereals and pulses**' is a record of research work done independently by **Ms.Jainita M. Mehta**, under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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INTRODUCTION

With the number of persons anaemic or iron deficient around the globe in the high range of over 2000 millions with devastating effects on the physical, social and economic fabric of society, iron deficiency is a problem of staggering dimensions (Ramalingaswamy, 1994). It is a major nutritional problem in the world affecting an estimated 2170 million persons of which 90 per cent may be found in the developing countries (WHO, 1992).

The magnitude of this problem is much greater in India than in other developed countries. It is now recognized that mild to moderate iron deficiency even without anaemia has adverse functional consequence although they are less obvious (Serimshow, 1990).

In India iron deficiency anaemia is caused primarily by dietary deficiency of iron. The main source of iron from a typical Indian diet is contributed by cereals and pulses. Both pulses and grains are fairly good sources of iron (2-10 mg per cent). The prevalence of iron deficiency anaemia therefore in the majority of Indians is paradoxical. Poor iron bioavailability has been extensively reported as the prime factor in considering the aetiology of iron deficiency anaemia especially in India (Rao, 1994 and Chiplonkar *et al.*, 1993).

A factor just as important as the total iron content of the diet is the bioavailability of iron ingested. The absorption of dietary iron is highly variable and depends on what other foods are eaten with the meal, especially on the balance between foods that promote and those that inhibit iron availability.

The staple food in Kerala consists mainly of cereals and absorption of iron from this diet is quite low. This is due to the presence of significant amounts of phytates (1-2 per cent by weight) and tannins which are potent inhibitors of iron absorption. The poor iron absorption (3-5 per cent) from cereal based, phytate, fiber and tannin rich diets is a contributory factor for the prevalence of higher incidence of anaemia in the State. Heme iron forms a relatively minor part of iron intake. Non heme iron in cereal based diets is thus the main source of dietary iron.

It is not practical to substitute part of the plant foods by animal foods (Heme iron) due to their higher cost and therefore alternative approaches of increasing the total bioavailable iron intake are necessary as strategies for combating iron deficiency anaemia (Kakade and Agte, 1997). For this it is essential to obtain basic information regarding the bioavailability of iron from local foods. Such information may be provided by the *in vitro* methods which would help in due course in controlling the prevalence of iron deficiency among various segments of population by suggesting modifications in the existing dietary pattern with locally available foods (raw and processed forms).

Hence the present study "Nutritional studies on the bioavailability of iron from cereals and pulses" is an attempt on these lines with the following objectives.

1. To evaluate the *in vitro* availability of iron from commonly consumed cereals and pulses.
2. To study the effect of different common methods of processing, cooking and cooking utensils on the bioavailability of iron.
3. To explore the possibility of improving the availability of iron from cereal and pulse based diets by supplementation or substitution of local foods.

Review of Literature

REVIEW OF LITERATURE

Iron in Human nutrition

The importance of iron in nutrition has been a topic of concern in third world countries as well as in maternal and child health care in developing countries (Forbes *et al.*, 1989).

A healthy subject with a normal iron status has a haemoglobin concentration that is optional for the individual with respect to age, sex and attitude. A certain amount of iron is usually present in the stored form as ferritin and hemosiderin (Hallberg and Rossander, 1991).

The total dietary iron intake of vegetarians who followed a balanced diet had been reported to be higher than that of non-vegetarians (Calkins *et al.*, 1984). There is a variety of plant foods that supply measurable amounts of iron for vegetarians. The major sources of dietary iron for vegetarians included whole grain and fortified cereals, legumes, dark-green vegetables, nuts, seeds and dried fruits (Craig, 1994).

The absorption of iron in foods varied anywhere from 1-40 per cent depending on the presence or absence of enhancers or inhibitors in the meal. Thus, increasing the levels of enhancers or lowering that of inhibitors may have a strong influence on the nutritional adequacy of the iron in the usual diets of the population (WHO/UNICEF/UNO, 1994).

Several studies have failed to demonstrate an association between iron status and intake of dietary iron. Body iron resources are fundamentally dependent on the intake of bioavailable dietary iron (Rao and Vijayasarathy, 1975).

Iron nutritional status of population at risk can be improved by providing foods fortified with suitable inorganic iron salts and by improving the availability of iron from the habitual diet (Rao and Vijayasarathy, 1975 and INACG, 1982). There is evidence that amino acid, mainly cysteine (Mortinez-Torres and Layrisse, 1970; Mortinez-Torres *et al.*, 1981) and ascorbic acid (Sayers *et al.*, 1973) when added at appropriate levels enhanced iron absorption from diets.

Iron balance in human adults were determined by the rate of iron loss or by the effectiveness of adaptive changes in the rate of its absorption from the diet. Dietary iron comprised a small readily absorbed fraction and a large non-heme component, the absorption of which varied widely depending on body iron stores and meal composition (Hallberg *et al.*, 1989).

Depending on the balance between enhancers and inhibitors, percentage absorption varied as much as 20 fold in the same individual. These findings have led to the assumption that the type of diet consumed by adults had a significant and independent influence on iron status that modified the effect of iron requirement (Cook *et al.*, 1991). Results of a study conducted by Brune *et al.* (1989) had revealed, no effect on iron stores when 2 g ascorbic acid/day was added to the diet of normal American volunteers for a period of 2 years. A more recent study indicated that ascorbic acid supplements increased dietary iron absorption in iron depleted women (Baynes and Bothwell, 1990).

Iron deficiency anaemia, its prevalence and its consequences

Iron deficiency is recognised as the most prevalent nutritional deficiency world wide, and children below 2 years of age are considered as one of the highest risk groups (Calve and Gnezz, 1990).

More than 500 million people are believed to have iron deficiency anaemia due to poor dietary absorption and parasite infestation. The prevalence of anaemia in United States has declined over the past decade because of the increased use of iron-fortified foods, the increased use of iron supplements, the increased intake of vitamin C and the use of birth control pills (Dallman, 1990).

Iron and zinc were poorly absorbed from legumes and cereals. Areas of the world that rely upon these foods as a staple part of the diet had the greatest prevalence of nutritional iron deficiency anaemia. Iron deficiency was less common in areas where meat was commonly eaten (INACG, 1982).

The magnitude of iron deficiency anaemia was much greater in India than in other developing countries. The Indian diets are based on cereals, pulses, green leafy vegetables, condiments and spices. Though the grains are fairly good source of iron, the majority of Indians are suffering from iron deficiency ananemia due to low availability of iron from cereal grain and also due to infestation of gastro-intestinal tract and other diseases which either enhanced or aggravated the condition (Rao and Prabhavathi, 1982 and Annapurani and Murthy, 1984).

Iron deficiency is more common in females (33%) than in males (5%). The Punjabi Indians consumed substantial quantities of spices and tea, which were high in tannins. The high prevalence of iron deficiency was suggested to be the result of high intakes of phytates and tannins that inhibited dietary iron absorption (Bindra and Gibson, 1986).

Iron deficiency anaemia is more common in both urban and rural population of India inspite of seemingly adequate intake of dietary iron. This may be due to poor absorption, caused by dietary inhibitors like phytates and tannins. Inter play of these inhibitors and enhancers like ascorbic acid determined the availability of iron from the diets (NIN, 1995).

Low serum ferritin concentration as well as iron-deficiency anaemia were reported in middle-aged East Indian immigrants to Canada who followed a lactovo vegetarian diet based on unleavened chapaties made from whole wheat flour (Bindra and Gibson, 1986).

Children who consumed a restricted macrobiotic diet commonly manifested iron deficiencies, where as children who consumed a balance lactovo vegetarian or vegetarian diets have an iron status similar to children who are omnevores. Iron deficiency has been reported in » 15 per cent of young macrobiotic children in Boston and in the Netherlands (Dwyer *et al.*, 1982 and Dagnelie *et al.*, 1989).

Several studies conducted by Hallberg and Rossander-Hulten (1991) strongly indicated that a low serum ferritin value is also pathogenic for iron deficiency because there are no other conditions that lead to low values. The ferritin values proposed to indicate iron-deficiency varied between 12 and 15 kg/l. Vegetarians have lower serum ferritin concentration and hence reduced iron stores compared with omnivores (Mc Endree, 1983, Locong, 1986, Helmon and Darnton-Hill, 1987, Lowik *et al.*, 1990, Reddy and Sanders, 1990). The total amount of storage iron can vary over a wide range without any apparent impairment of body functions. Reduced iron stores are associated with an increased risk of iron deficiency (Dallmon, 1986).

There are many deleterious effects of iron deficiency, including decreased capacity for work, greater tendency to fatigue, decreased athletic performance, impaired intellectual performance, decrease in attentiveness, behavioural abnormalities in small children, greater risk of premature delivery and low birth weight in neonates, complications of pregnancy, impaired immune function and increased risk of lead poisoning (Cook and Lynch, 1986, Dallman, 1989, 1990).

Iron deficiency is a widespread nutritional disorder in infants, children and women of reproductive age. It is associated with an impairment of several immune functions, such as skin responses to antigens and allergens, mitogenic response of human peripheral blood lymphocytes and bactericidal capacity of phagocytic cells (Kuvibidila *et al.*, 1990).

Iron stores are lower in premenopausal women, adolescent and young children, who therefore have higher risk of iron deficiency (Dallmon, 1990). Iron deficiency anaemia develops only after iron stores are seriously depleted and hemoglobin production slows until haemoglobin concentrations are below normal (Herbert, 1987).

One of the consequences of a lower iron status is an increased absorption of lead (Mahaffey, 1983) and cadmium (Flanagam *et al.*, 1978) thus increasing the biotoxicity of both metals.

Mechanism of absorption of iron, transport and storage

Iron absorption is defined as the percentage of ingested iron that after the digestion of food, has passed the mucosal cell and is taken up by the blood. Bioavailability is the percentage of ingested iron that becomes available for metabolic action. Bioavailability includes iron absorption, transport of iron to relevent body tissues, and conversion into its physiologically active forms. Utilization comprises one step more than bioavailability, thus including metabolism. During each stage, iron interact with other components of ingested food. These interactions influence absorption, bioavailability and utilization of iron positively or negatively (Van Dokkum, 1992).

Iron is efficiently recycled in the body and little is excreted. Adequate levels of iron is maintained by an intestinal absorptive system. Not all of the iron present in the diet is capable of being absorbed (Morck and Cook, 1981).

Food iron occurs in two forms with respect to the machanism of absorption - heme and non-heme iron (Hallberg and Bjorn-Rasmussen, 1972).

Heme, containing iron is a porphyrin ring structure, found in hemoglobin and myoglobin and accounts for nearly 40 per cent of the iron present in animal tissue, including fish and poultry (Monsen *et al.*, 1978). Because of the porphyrin complex, heme is more soluble in the neutral condition of the small intestine than in the acid conditions of the stomach. It is taken up by the mucosal cells as the intact metalloprotein, and iron is released once inside. Absorption of heme iron is high, averaging from 15 per cent for iron - replacement to 35 per cent in those lacking iron stores (Conred *et al.*, 1967).

Due to the high bioavailability of heme iron it provides nearly one third of the iron absorbed each day from mixed diets. Because of its unique absorptive mechanism and solubility at elevated pH, heme iron availability is unaffected by dietary components that either enhance or inhibit the availability of the nonheme iron present in the rest of the diet. Non-heme iron is present in foods of vegetable origin and also accounts for the remaining 60 per cent iron in animal tissues. To be absorbed, non-heme iron must reach the upper small intestinal mucosa in the soluble form (Bothwell *et al.*, 1975).

The absorption of iron from a diet is thus determined by the amounts of heme and non-heme iron present in the diets (Hallberg and Rossander, 1991).

Meat aids iron absorption by counteracting luminal factors that otherwise would intefere with the transport of iron to the mucosal cell surface. The exact mechanism by which animal tissues promote iron absorption is still unknown, but it has been suggested that amino acid and/or polypeptides arising from proteolytic digestion might chelate dietary non-heme iron, thereby facilitating its absorption (Morck and Cook, 1981).

Heme iron in meat is absorbed to 25 per cent, and the absorption is independent of iron status and meal composition. Moreover, meat has an enhancing effect on the absorption of non-heme iron (Cook, 1985, Hallberg and Rossander, 1991).

Heme iron is absorbed by a pathway distinct from that of non-heme iron. Although the availability of heme iron for absorption is high, the final true absorption (referring to the amount of iron of heme origin entering the circulation) is far from 100 per cent within the mucosal cell, the intact iron porphyrin complex is broken down, and the released iron enters the storage or transit pathway as non-heme iron. This means that iron of heme origin may either be transported across the cell, or sequestered and retained as ferritin and returned to the lumen and the gut through disquamation of the cell (Hazell, 1985).

There are other dietary constituents which aid or interfere with non-heme iron solubility and thus, absorption (Hodson, 1981). Studies conducted by Layrisse *et al.* (1975) indicated that although non-heme iron in meat was generally well absorbed, purified ferritin had low bioavailability when added to a vegetable meal due to chemical alteration during putrification.

Cook *et al.* (1973) had observed that solubility alone cannot accurately predict bioavailability of different iron compounds used for fortification.

Hallberg (1980) found that oxides and hydroxide of iron did not exchange with soluble radio iron salts used to measure food iron absorption in humans. Hence, the actual nutritional value of contaminant iron cannot be directly determined.

The strength of iron-chelating bond, the solubility of the complex, the environmental factor, such as pH and the presence of other (competing) chelating compounds, will determine the availability of iron by mucosal cell wall. The strength of a bond of a legand with iron may contribute to either enhancement or inhibition of iron availability (Mac Phail *et al.*, 1981).

The enhancing effect by legands is due to the formation of soluble chelates with non-heme dietary iron and thus preventing the formation of insoluble chelates with the inhibitory compound in the gut (Subba Rao and Narasinga Rao, 1983). The availability of dietary iron in the body is promoted if it is in the soluble form (Mudambi and Rajagopal, 1990).

Ascorbic acid maintains the normally ferric form of food iron in a more soluble ferrous state. Secondly, under acidic conditions in the stomach, ascorbic acid forms a complex with iron that remains soluble as the pH increases in the upper small intestine (Clydesdale, 1981, Nojeim and Clydesdale, 1988). Schricker and Miller (1982) stated that longer stomach retention and therefore, longer exposure to an acidic environment, may explain the high availability of reduced iron to human.

Particle size is an important determinant of elemental iron solubility and availability for absorption. Electrolytic iron has a higher bioavailability than hydrogen reduced iron of the same particle size, due to the greater surface area of its dentritic-crystal structure (Pannell *et al.*, 1975).

The larger the particles, for example, an iron-calcium phytate precipitate, the slower the precipitate will be dissolved. A neutral liquid containing a precipitate of an iron complex that is acidified may take as long as one hour to convert the iron from its crystalline form into a soluble form (Smith, 1983).

Iron deficiency occurs when iron absorption is not sufficient to meet the needs of the body (FAO/WHO, 1989). A lack of iron causes iron stores to decrease which is followed by a drop in serum ferritin concentration (Herbert, 1992).

The body carefully guards against iron losses and conserves iron when ever possible. Iron balance is precisely regulated mainly through change in the amount of iron absorbed (Finch and Cook, 1984).

Under normal conditions, iron absorption is » 10-15%, but it can vary greatly from as little as 1% to » 40% (Charlton and Bothwell, 1983).

The actual amount of iron absorbed from the gastrointestinal tract is determined by the iron content of the meal, the chemical form of the iron, the iron status of the individual, and the composition of ingested foods (Baynes and Bothwell, 1990).

Iron absorption occurs mainly in the duodenum and to some extent in the jejunum. The single most important factor that regulates iron absorption is iron status of the body. There is good evidence that the absorption of iron is influenced by the state of the body's iron stores. Dietary iron appears to pass into the epithelial cells of the intestinal lining as a chelate with carbohydrate such as fructose or sorbitol or with some amino acids. The rate at which iron is released from the epithelial cells to the general circulation depends upon the state of transferrin in the plasma. The bodys need for iron thus effects the absorption of the element from the gastrointestinal tract (Lloyel *et al.*, 1978).

The amount of iron that is absorbed is also markedly influenced by the body iron stores, if these stores are lowered, a higher percentage of the available iron is absorbed, and as the body iron content rises the percentage iron absorption falls (Bothwell *et al.*, 1979).

The bodys need for iron also controls the absorption of iron. If the body has an immediate need of iron, it passes directly from the intestine into the blood stream. If the supply of iron is more than what the body needs, it is stored in the mucosa of the intestinal cells as ferritin (Mudambi and Rajagopal, 1990).

Simpson (1996) suggested that the control of iron absorption by tissue oxygen acts through a mechanism independent of the control exerted by dietary or mucosal iron.

Regarding the oxidation state, the behaviour of iron with respect to availability is mainly related to a difference in solubility between ferric and ferrous iron (Van Dokkum, 1992).

The reduction of iron from the ferric (Fe^{3+}) to the ferrous (Fe^{2+}) form improves absorption (Bogort, 1966). Vitamin C and amino acid which reduce Fe^{3+} to Fe^{2+} forms also improves absorption. Phytic acid found in foods such as whole grain cereals decreased absorption by forming an insoluble iron compound (Mudambi and Rajagopal, 1990).

Due to limited bioavailability and lack of an excretory machanism for iron, its homeostasis in mammals is controlled at the site of absorption itself. The established iron related protein like transferrin, ferritin and lactoferrin have been implicated in the absorption machanism of dietary iron. A more recent hypothesis is that mucosal apotrasnferrin acts as a shutle protein for transporting iron between the luman and the mucosal cells. The mechanism of involvement of these protein either singly or in combination in iron absorption are not yet known. Results suggested that duodinal mucosal ferritin played a major role in the uptake of iron (NIN, 1995).

Factors influencing availability of iron from foods

Iron bioavailability varies within foods and depends on the countration of enhancers and inhibitors of iron absorption. Generally high iron bioavailability is observed from foods such as meat while low bioavailability is observed in cereals and legumes (Layrisse *et al.*, 1985).

Several studies attempted to define the quantitative importance of specific biochemical determinants such as ascorbic acid, phytate, polyphenols and proteins, both singly and in combination influencing iron absorption (Gillooly *et al.*, 1983; Hurrel *et al.*, 1988; Brune *et al.*, 1989; Hallberg *et al.*, 1989; Bajner *et al.*, 1990; Reddy and Cook, 1991).

Non-heme iron availability is influenced by a variety of enhancing and inhibiting substances released from foods during digestion (Hallberg and Bjorn-Resmussen, 1972; Hussain *et al.*, 1974; Bjorn-Rasmussen *et al.*, 1974; Cook and Monsen, 1976). If a meal is composed of food low in enhancing substances or high in inhibiting substances, non-heme iron availability from that meal may be low (Schricker and Miller, 1983).

Non-heme iron interacts and complexes with digestion products that can inhibit iron absorption. Heme iron is already in a stable complex so its absorption is independent of iron absorption inhibitors (Schricker and Miller, 1983).

Non-heme iron absorption is strongly influenced by many inhibitors and enhancing factors in the diet where as heme iron absorption is very little affected by other dietary components. The efficient absorption of heme iron is because of specific heme-binding sites in the intestinal tract (Baynes and Bothwell, 1990).

During digestion, non-heme iron may alter the valence state and rapidly form iron-chelate complexes (Van Dokkum, 1992).

Factors affecting iron absorption and retention are enhancers (vitamin C, meat, fish and pountry) or decreasers (egg yolk, coffee, tea, fibre, antacids and phytates) and the ionic forms of the iron (Mahoney and Hendrick, 1984).

Factors that inhibit iron absorption are phytates present in cereal bran, cereal grain, high extraction flour, legumes, nuts and seeds, iron binding phenolic compounds (tannins), tea, cocoa, coffee, herbal infusions, spices and some vegetables, Calcium in different forms, milk and milk products (WHO/UNICEF/UNO, 1994).

The absorption of iron from food is generally low, but is increased when the bodys stores are depleted and when needs are greatest as in growing children or menstruating or pregnant women (Buss and Robersion, 1978).

Bioavailability of iron in influenced by various factors such as iron solubility concentrate, pH, iron status, gastric emptying rate and distribution of added iron (Smith, 1983). Cereals, vegetable and starchy foods contribute for a large part to individual iron intake. These foods provide only non-heme iron which is therefore strongly influenced by the composition of the diet.

Factors enhacing the absorption of non-heme iron

Two factors of major nutritional significance that were shown to consistently increase iron availability were ascorbic acid and meat or animal tissue (Morck and Cook, 1981; Hallberg and Rossander, 1991; Hamdaovi *et al.*, 1995).

Ascorbic acid is a powerful promoter of non-heme iron absorption. About 75 mg ascorbic acid increased non-heme iron absorption three to four fold (Cook and Monsen, 1977; Monsen, 1988). When ascorbic acid was added to a meal, the increase in iron absorption was proportional to the dose of supplementation (Cook and Monsen, 1977; Lynch and Cook, 1980).

Macfarlane *et al.* (1990) demonstrated that even large amounts of ascorbic acid have only a moderate effect on iron absorption from soy.

According to Deehr *et al.*, (1990) ascorbic acid present in orange juice consistently increased non-heme iron absorption.

Lynch and Cook (1980) and Kenerva *et al.* (1987) had observed that ascorbate increased both the amount of iron retained in mucosal cells and that transferred across the serosa in isolated duodenal loops, possibly by increasing solubilization of membrane-bound iron.

Higher percentage of dietary ascrobic acid content in high socio-economic group when compared to the low socio-economic group might be one of the several factors which caused the higher availability of dietary iron and increased blood iron and haemoglobin in high socio-economic group than the low socio-economic group (Annapurani and Murthy, 1984).

Ascorbic acid is the best enhancer of non-heme iron absorption. The mechanism by which vitamin C promotes iron availability is by reducing ferric iron to its ferrous oxidation state and secondly ferric iron may form a ferric ascorbate complex at the low pH prevailing in the stomach. This iron-chelate remains stable and soluble at the higher pH in the duodenum, thus making iron available for absorption. This complexing, however, must be initiated at a low pH (Lynch and Cook, 1980; Clydesdale, 1981).

Ascorbic acid improved apparent iron absorption. Ascorbic acid also improved haemoglobin erythrocyte protoporphyrin and serum iron but not hematocrit, serum ferritin iron binding capacity or transferrin saturation. In iron depleted women consuming a diet with predicted poor iron availability, ascorbic acid supplementation enhanced body iron retention for 5.5 weeks (Hunt *et al.*, 1990).

The results of the study by Hunt *et al.* (1990) suggested that iron depleted women are capable of absorbing as much as 25 per cent of the iron from a diet with iron principally in a non-heme form and with low amounts of ascorbic acid and meat.

Annapurni and Murthy (1984) concluded that the rise in serum iron and Hb levels after supplementing sprouted green gram in the diet is due to an increase in the ascorbic acid content.

Iron is most readily absorbed from meat (up to 25%) (Buss and Robersion, 1978).

Not only does meat (meat, fish, poultry) contain a portion of its iron as heme iron, which is much better absorbed than non-heme iron, but meat enhances the absorption of non-heme iron as well (Monsen *et al.*, 1978; Taylor *et al.*, 1986).

Plant foods can make significant contributions of available iron in the diet (Zhang *et al.*, 1985).

Sugar (Amine and Hegsted, 1975) and ascorbic acid (Sayers *et al.*, 1968) may increase iron availability. Fruit juices, common breakfast meal items have been shown to enhance iron availability (Rossander and Hallberg, 1979).

An ability of EDTA to enhance iron absorption, had been shown in recent studies in which absorption of 5-50 mg iron as performed NaFe EDTA was two fold higher than when iron was added as ferrous sulphate (Layriss and Mortinez-Torres, 1977).

A similar response relative to ferrous sulphate was seen when this iron chelate was added to a milk-rice-sugar formula (Viteri *et al.*, 1978).

The effect of EDTA on iron absorption appears to depend on both the absolute amount of EDTA in the diet as well as the molar ratio of EDTA to iron. When this molar ratio is less than 1, absorption from the meal may be enhanced, especially when basal availability of food iron is low (Mac Phail *et al.*, 1981).

Citric acid also enhances iron absorption *in vivo* (Gillooly *et al.*, 1983; Carlson *et al.*, 1983) and *in vitro* (Mahansho *et al.*, 1987) although this has not been a constant finding (Hallberg and Rossander, 1984).

Both fructose and citric acid have been associated with enhanced iron availability for absorption through the formation of soluble chelate (Bates *et al.*, 1972; Hazell and Johnson, 1987).

Inorganic polyphosphate which are used extensively in food industry, have a very high iron chelating ability. These polyphosphate can keep iron completely in solution at pH 7.5 (Subba Rao and Rao, 1983).

The influence of food protein products on non-heme iron bioavailability is known to vary according to the protein product (Cook and Monsen, 1976, Cook and Monsen, 1989). Various amino acids are capable of dissolving metal phytate precipitates and hence making iron more available for absorption (Van Dokkum, 1992).

Ferrous glycine Sulphate (FGS) is an organic form of elemental iron and is supposed to have higher bioavailability and better tolerance. *In vitro* studies carried out with iron fortified salts revealed a higher availability of iron from FGS as compared to ferrous sulphate (NIN, 94 and NIN, 95).

Inhibition of non-heme iron absorption

Many compounds in foods are reported to inhibit the absorption of iron, among them are phytates, oxalates, phosphates, EDTA, polyphenols and soy products (NIN, 1990). Phosphates have been shown to reduce iron absorption (Giri *et al.*, 1981).

The components in cereals and vegetables responsible for reduced bioavailability of non-heme iron in foods are phytate, dietary fiber, polyphenols and saponins (Disler *et al.*, 1975). Low absolute available iron in soya bean when compared to green gram, peas, horse gram and field beans may be due to the methionine deficiency and excess amounts of intrinsic inhibitors (Annapurani and Murthy, 1984).

Some vegetable foods, whole grain cereals, other pulses, nuts, dark green vegetables, curry, cocoa and egg are apparently good sources of iron, but other constituents (like phytic acid) render most of the iron in these foods unavailable for absorption (Bingham, 1977).

According to Morck and Cook (1981) agents such as tannins, phytates, phosphates, oxalates and carbonates form insoluble precipitates and macro molecules with iron that have poor availability.

Tannins, phytic acid and EDTA added to the food was found to decrease (five per cent level) the absolute available iron (Murthi *et al.*, 1985).

Iron from vegetable origin was much more "Surrounded" by inhibitors, such as phytate, fibre, oxalate and phosphates, than iron from animal origin (Van Dokkum, 1992).

According to Hallberg and Rossander (1991) the important factors that decreased the bioavailability were inositol phosphate (eg. phytate); iron binding phenolic compounds and calcium (Hallberg *et al.*, 1991).

The potent inhibitors of non-heme iron absorption widely distributed in vegetable foods were phytates and polyphenols (Herbert, 1987).

Polyphenolics in some vegetables and herbal teas may also have an adverse effect on the uptake of iron (Hallberg, 1981).

Components such as bran (Ismail-Beigi and Faraji, 1977) and phytate appear to reduce iron availability.

Phytates in whole grain cereals, legumes, nuts and seeds could bind non-heme iron and greatly reduce its absorption (Hallberg, 1981).

Because wheat bran is high in phytate, this was proposed as the inhibitory compound in bran (Morck and Cook, 1981).

Phytic acid present as a constituent in many cereals reduce iron absorption by forming insoluble complex of ferric phytate which was made soluble during germination (Annapurani and Murthy, 1984).

Phytate content is not the component of wheat bran solely rosponsible for inhibition of iron absorption. It has been demonstrated that iron was bound by neutral detergent fibres and acid detergent fibre prepared from wheat and maize (Reinhold *et al.*, 1985). Iron binding of these fibres was found to be exhibited by ascorbic acid, citric acid, phytic acid and EDTA in low concentration (Camire and Clydesdale, 1982).

Another recent study implicated phytate as the inhibitory factor in wheat bran (Macfarlane *et al.*, 1990).

The solubility of non-heme iron in the small intestine is a major factor in determining its absorption. Polyphenols and phytates in plant foods are known to bind with non-heme iron and thus inhibit its absorption (Craig, 1994).

Fibre was responsible for the low iron bioavailability observed from cereals (Reinhold *et al.*, 1985; Gracia and Wyatt, 1985).

In a recent review of the effect of fibre on trace mineral balance in man, Kelsay (1981) concluded that iron absorption averaged 3 per cent from the high fibre meal, and twice that level was absorbed from the low fibre meal.

The effect of fibre on iron absorption may depend not only on the amount of fibre eaten but also on the source or type of fibre consumed (Fernandez and Phillips, 1982).

Under *in vitro* conditions, iron reportedly was bound by acid detergent fibres and neutral detergent fibres from wheat and maize (Reinhold *et al.*, 1985).

Disler *et al.* (1975) were the first to report the dramatic reduction in iron absorption when tea was drunk with a meal. A single cup of tea reduced absorption of ferric chloride from 22 to 6 per cent and even with a complex meal, tea caused iron absorption to fall from 11 to 2.5 per cent. Tannins in tea leaves water were shown to account for this inhibition. This effect is due to formation of insoluble iron-tannate complex in the gut that renders dietary iron unavailable for absorption (de Alascon *et al.*, 1979).

De Alarcon *et al.* (1978) reported that tea markedly reduced the absorption of non-heme iron from foods. Tannin was responsible for the low bioavailability of iron in many vegetable foods (Sayers *et al.*, 1975) and coconut milk (Teni-then *et al.*, 1978).

Even in the presence of supplemental ascorbic acid, coffee as well as tea inhibit iron absorption. Coffee had proved to be about two thirds as inhibitory as tea. Greater inhibition was seen with stronger coffee (Derman *et al.*, 1978).

Tannins added to $Fecl_3$ solution or red gram dhal (previously free of tannin) was shown to decrease ionisable iron (Rao and Prabhavathi, 1982).

When tannin was added to ferric chloride solution, there was an initial increase in ionisable iron at pH 7.5 to a molar ratio of 10:3 between iron and tannin. However, when the tannin concentration was increased beyond this, the ionisable iron gradually decreased to a ratio of 10:15 when all iron was bound by tannin and the ionisable iron tended towards zero, when tannin was added to food (Rao and Prabhavathi, 1982).

Tea was consumed by population in which iron deficiency anaemia was prevalent (Marhav *et al.*, 1988).

Many popular beverages such as tea and coffee also constitute an important source of iron binding phenolic group such as Tannin compounds. These compounds were considered to be responsible for the reduced bioavailability of non-heme iron from foods (Brown *et al.*, 1990).

Polyphenols in coffee and tea (one well known polyphenolic compound is tannin) are believed to have a strong inhibitory effect on the availability of iron for absorption (Disler *et al.*, 1975; Hallberg and Rossander, 1982; Srikendra, 1989). Compounds with a polyphenolic structure are considered responsible for the reduced availability of iron because of the formation of insoluble complex (Van Dokkum, 1992).

The addition of egg white to ferrous ascorbate reduced iron absorption from 33 to 14 per cent, added yolk dropped absorption even further to 3.9 per cent (Peters *et al.*, 1971). The vitellin fraction of yolk, high in phosphoprotein, was believed to account for this inhibition.

Studies by Monsen and Cook (1979) showed that doubling the quantity of egg albumen in the meal caused a drop in iron absorption from 2.3 to 1.4 per cent On the other hand, omitting it completely from the formulation increased iron absorption by nearly three fold. Taken together these studies showed that both the white and the yolk of hen's egg can inhibit the absorption of non-heme iron contributed by other foods eaten in the same meal.

Monsen and Cook (1976) demonstrated that, when a semi-purified meal was fed to humans, the addition of either calcium chloride or potassium phosphate alone did not affect iron absorption. However, when both were added simultaneously to the meal, iron absorption was reduced 53-73 per cent. These results may be explained by reports that both inorganic and protein bound phosphate formed an insoluble ferric phosphate complex that was unavailable for absorption.

Dietary $CaCl_2$ has been shown by Berton *et al.* (1983) to decrease iron absorption in iron deficiency, the effect being caused by the cation.

Mahansho *et al.* (1987) suggested that calcium exerts its antagonistic effects solely on the serosal transfer component of iron absorption.

A study by Deehr *et al.* (1990) had concluded that 500 mg calcium as milk had an antagonistic effect on iron absorption.

It might be anticipated that the bioavailability of iron from tofu could be significantly influenced by its high calcium content (Macfarlane *et al.*, 1990).

The inhibitory effect of calcium and iron absorption appeared to be equal for heme and non-heme iron (Hallberg *et al.*, 1991, 1993).

A significant inhibition in the absorption was observed when Na_2 EDTA was added to meals comprised of semipurified ingredients or common food items. When molar ratio for EDTA : iron were 1:1 and 2:1, non-heme iron absorption was decreased by 20 and 50 per cent, respectively (Cook and Monsen, 1976).

Zinc and copper may bind to thioneins forming the respective metallothioneins, but copper binds more strongly than zinc. Hence the transport of copper accross the cell is impaired and less copper enters the circulation. As may be the case with iron bound to ferritin in the mucosal cell, the copper-thionein complex is released into the lumen by desquamation of the cell. Because copper is involved in iron metabolism as ferroxides, a relatively high intake of zinc may therefore induce anaemia and hypocupremia (Porter *et al.*, 1977, Van Dokkum, 1992).

Antacids can inhibit non-heme iron absorption, the excessive use of antacids should be avoided (Monsen *et al.*, 1978).

Pectin, but not cellulose also exhibited high iron binding activity *in vitro* and reduce by 40 per cent the amount of iron absorbed by a group of iron overloaded patients with hemochromatosis (Monnier *et al.*, 1980).

Soy proteins or soy flour is known to reduce the absorption of non-heme iron in humans (Reddy and Cook, 1991).

Soy proteins have received considerable attention since the initial reports of Cook *et al.* (Cook *et al.*, 1981) from the University of Kensas Medical Centre showing an inhibitory effect of a variety of different types of soy protein products on iron absorption.

Studies were conducted by Cook *et al.* (1981) in adult males by providing a test meal containing one or more protein sources along with labelled iron. They found that when soy protein replaced egg albumin, casein or a portion of meat, iron absorption dropped dramatically but Morck *et al.* (1982) observed that, when 100 mg vitamin C was added to a soy protein containing meal, iron absorption improved considerably.

Based on studies using human subjects Cook and Morck and Cook (1981) reported a substantial inhibition of iron absorption associated with soy products. Full fat soy flour, textured soy flour and isolated soy protein reduced iron absorption by 82, 65 and 92 per cent respectively.

No adverse affects on iron status was observed due to feeding humans, moderate quantities of soy products daily for 6 months (Bodwell, 1983).

It has been suggested that iron bioavailability from soy is a function of the protein composition and of the rate and site of maximal protein digestion (Berner and Miller, 1985).

In vitro studies (Schricker *et al.*, 1982; Kane and Miller, 1984; Berner and Miller, 1985) suggested that the higher affinity of undigested or partially digested soy protein for iron in the gastrointestinal tract may lower iron absorption.

Iron trapped within large peptide aggregates after *in vitro* digestion of soy was described by Schneph and Setterlee (1985).

Bioavailability of iron in single foods

A number of studies demonstrated that bioavailability of iron from soy alone was extremely poor (Ashworth *et al.*, 1973; Bjorn-Rasmussen *et al.*, 1973; Morck *et al.*, 1982; Lynch *et al.*, 1984; Derman *et al.*, 1987).

In vitro evidence indicated an inhibitory role for the soy protein complex (Schricker *et al.*, 1982; Kane and Miller, 1984; Berner and Miller, 1985; Thompson, 1988) and the differences in the nature of this complex are responsible for the varied inhibitory potentials of different soy products (Morris *et al.*, 1987).

Macfarlane *et al.*, 1990 suggested that it is the protein that is responsible for the low iron absorption from soy.

Reinhold *et al.* (1975) and Reinhold *et al.* (1981) led to the hypothesis that fibre rather than phytate is responsible for the low availability of iron from cereal products.

According to Annpurani and Murthy (1984), wheat, ragi, jowar and bajra may be preferred as a better source of iron than rice as they contained higher concentration of total and absolute available iron.

Forbes *et al.* (1989) observed that the dializable iron values in cereals were low and variable. The low values were presumably due to inhibitory substances in cereals that bind iron and prevent its dialysis.

The relative bioavailability of iron from mature winged bean (*Psophocarpus tetragonalobus*) flour was determined by Hettiarachchy and Erdman (1984) and the results indicated that iron from winged bean was 89 per cent as bioavailable iron from ferrous sulphate.

Absorption of iron from a variety of commonly eaten legumes (lentils, split peas, mung beans, black beans and soy beans) prepared as soup was observed to be only » 1-2 per cent (Lynch *et al.*, 1984).

Studies conducted at NIN (1994 and 1995) revealed that the total iron content in seven varieties of whole pulses ranged between 5.7-6.4 mg/100 g but the per cent ionisable iron varied widely from 3.4 to 35.6. The per cent ionisable iron in split pulses was found to be significantly higher. There was no difference in the values of phytate between whole and split pulses but the tannin content was found to be low in split pulses.

Tannins, which are defined as high molecular weight polyphenolic compounds are present in a wide variety of foods including sorghum, horse beans (Martin-Tanguy *et al.*, 1977), finger millets (Ramachandra *et al.*, 1977) and cowpea (Hagerman and Butler, 1978), but rarely in cereals.

Among cereals and millets only ragi and red varieties of sorghum contain significant amount of tannins. Most of the legumes with seed coat contain fairly high levels of tannins, kidney beans having the highest content (Rao and Prabhavathi, 1982).

Iron from corn and cooked beans is approximately 50 per cent less available than $FeSO_4$ (Garcia and Wyatt, 1985).

Iron absorption from wheat bread may depend on its bran content because bran is rich in phytates (Bjorn-Rasmussan, 1974; Hallberg *et al.*, 1987). Baynens and Bothwell, 1990 commented that phytate inhibited iron absorption, whereas fibre does not. Kelsay *et al.* (1979) proved that the iron balance of volunteers who consumed a high fibre diet was not adversely affected.

Murthy *et al.* (1985) also observed a very high total iron content in amaranth when compared to cereals and pulses but the absolute available iron content was very low when compared to the total iron content. This may be due to the presence of inhibitors of iron absorption such as phytates, phosphate and oxalates.

The low availability of iron from green vegetables, such as spinach is partly owing to its oxalic acid content (Oke, 1968).

Vegetable contain oxalic acid which inhibits iron absorption (Amine and Hegsted, 1975).

Although spinach contains nearly as much iron as beef, at least ten times the weight of spinach would have to be eaten for the same amount of iron to be absorbed (Bingham, 1977).

Green leafy vegetables had low total iron content but higher ionisable iron (35%) when compared to pulses (NIN, 1994 and 1995).

Fruits and vegetables are important sources of vitamin C which enhanced iron absorption (Baynes and Bothwell, 1990; Hallberg, 1981).

Small amounts of citric, malic and tartaric acid, found in fruits and vegetables and lactic acids found in Sauerkraut (Baynes and Bothwell, 1990; Gillooly *et al.*, 1983) can substantially enhance iron absorption. The effect of citric acid on iron absorption is additive to that produced by ascorbic acid alone (Ballot *et al.*, 1987).

Although egg contain approximately 1 mg of iron, the iron is poorly available to humans and the egg yolk further inhibits absorption of other dietary iron (Callender *et al.*, 1970; Hallberg, 1981; Baynes and Bothwell, 1990). Cook and Monsen (1976) used a semi-purified diet containing egg albumen in students to assess the effect of various animal proteins on iron absorption. Powdered egg produced the same level of iron absorption as whole milk, cheese or the unsubstituted basal diet, indicating that not all animal derived protein enhance iron absorption.

Egg has an adverse effect on absorption of dietary iron. Yolk phosphates of egg, binds ionic iron and reduces its solubility, thus decreasing its availability to mucosal cells (Halkett *et al.*, 1980).

Egg is mostly taken in breakfast as a source of good quality protein and iron. However, it has an adverse effect on absorption of inorganic iron (Narula and Wordsworth, 1980).

Most of the iron in egg yolk is bound by phosvitin. Heating whole egg or yolk in a double boiler does not release this iron. Only EDTA released (approx 50%) iron from phosvitin without heating (Allsright *et al.*, 1984).

Lactose has been shown to enhance iron absorption (Amine and Hegsted, 1975).

A study was undertaken by Tidehag *et al.* (1995) to determine whether milk with its high calcium content adversely affects the absorption of non-heme iron from the diets as a single meal and found that there was no decrease in apparent iron absorption during the milk diet period.

Because of its heme iron content and of the amino acid composition, meat is superior to vegetable products regarding iron availability. Monsen *et al.* (1978) concluded that 1 g of meat was roughly equivalent to 1 mg of ascorbic acid in its enhancing effect.

Tannins are known to be potent inhibitors of iron absorption as demonstrated in case of tea (Disler *et al.*, 1975).

Tannins in tea and coffee form iron tannate complexes that substantially reduce non-heme iron absorption (Disler *et al.*, 1975; Rossander and Hallberg, 1979; Brune *et al.*, 1989; Gillooly *et al.*, 1983).

Tamarind, turmeric and chillies were rich sources of tannins. These condiments, although used in small quantities, may contribute significantly in the total tannin content in the diet which inhibit iron absorption (Rao and Prabhavathi, 1982).

The bioavailability of iron from diets depends on the interaction of the promoters and inhibitors of iron absorption present in the meal or consumed immediately after eating (Hallberg, 1981).

Bioavailability of iron from diets - Effect of supplementation or substitution of foods on iron absorption

Studies on iron absorption from different meals clearly showed that the variation in the bioavailability is very great and that from most typical meals the bioavailability may be in the range of 5-15% in subjects with small but not fully absent iron stores (FAO/WHO, 1988).

According to Hallberg and Rossander-Hulten (1991) the iron status of the subject and the composition of the diet were the two main physiological factors influencing the amount of iron absorption from the diet.

Vegetarian diets can be constructed to be of high iron bioavailability. For the vegetarian, a diet high in vitamin C rich fruits and vegetables can provide adequate amounts of iron so long as the diet also contains a variety of whole grains, legumes, nuts and seeds rich in iron. A well balanced vegetarian diet is compatable with a healthy nutritional status (Havala and Dwyer, 1988).

Morck and Cook (1981) stated that meal could be classified as having low, medium or high iron availability depending on the quantity of meal and ascorbic acid. Estimates can then be made of the amount of heme and non-heme iron that would be absorbed by people having different levels of iron stores.

Number of diets were formulated to be typical of low or high income consumers in different regions of India. It was concluded that tannins as well as phytates, may be responsible for the low absorption of iron from typical Indian diet (Rao and Prabhavathi, 1982).

Some of the commonly used condiments and spices eg. tamarind, chillies, turmeric and coriander contain a fairly high concentration of tannins and although used in small quantities they may contribute significant amounts of tannin to the diet. Analysis of diets consumed in different regions in India indicated that the daily intake of tannin may vary from 1500 to 2500 mg (Rao and Prabhavathi, 1982).

The bioavailability of vegetarian diets may vary considerably depending on their content of especially ascorbic acid, phytate and iron binding phenolic compounds. The bioavailability of iron in western type vegetarian diets probably ranges from 5 to 12 per cent (Brune *et al.*, 1991, Brune *et al.*, 1989).

The estimated mean values of the iron absorption from heme and non-heme iron in a complete diet was 1.69 mg. Breakfast, provided 6 per cent of the absorpted iron, the main meals 73 per cent and the lunch and evening meals 21 per cent (Hallberg and Rossander Hulten, 1991).

The absorption of iron has been assessed at 12 per cent based on the average Dutch food pattern with a heme iron/non-heme iron ratio 1:3. However, for a diet without meat, iron absorption has been set at 8 per cent, which implies that the recommendations for an adequate intake of iron should be higher for vegetarians than for the global Dutch populations (OCDE, 1985).

Cook *et al.* (1991) indicated that in the context of a varied western diet, non-heme iron bioavailability is less important than absorption studies with single meal would suggest.

Studies on humans who were given constant lacto-vegetarian, vegetarian and mixed diets, with different amount of fibre and phytate concluded that an increasing intake of these inhibitors runs parallel with an increasing intake of iron. The net effect does not necessarily influence iron balance (Van Dokkum, 1992).

An iron salt may exhibit high availability when fed alone but when added to a meal such as maize, wheat or black beans, the level of iron absorption reduced considerably (Cook *et al.*, 1972).

Senchak *et al.* (1973) reported that adding food either as a substitute or as a supplement to a diet/food alters the absorption of iron significantly. He studied that iron absorption was highest when diet was high in rice and low in wheat concentration.

Ready to eat cereals are the most common at home breakfast choice. Breakfast cereals are an important source of iron in the U.S. diet (Gravani, 1976).

Ninety per cent of the enrichment iron used in the U.S. is added to breakfast cereals and flour based products (Davidson and Russo, 1976).

Rossander and Hallberg (1979) reported that iron absorption was lower from a cereal-milk meal than from meals containing orange juice or bacon but higher than that from meals containing tea or chocolate milk.

Studies conducted by Martinez *et al.* (1981) have shown an enhancement of iron absorption from maize, black beans and soy beans when cysteine was added after cooking the test meal.

According to Ranhotra *et al.* (1983) more haemoglobin was synthesised on milk supplemented (83 mg/mg iron) and soy supplemented (85 mg/mg iron) bread diets than on gluten supplemented (59 mg/mg iron) bread diets. Thus the study proved that, protein quality affected iron utilization.

Absolute available iron of diets based on rice (idlis), wheat (chapathi), sorghum (uppuma) and ragi (uppuma) showed that diets with iron fortified salts showed 8, 12, 21 and 43 per cent increase of absolute available iron and with tannins showed 6, 20, 34 and 24 per cent decrease of absolute available iron. They also observed that rice based diets (idli) were having high absolute available iron and sorghum based diet showed low value.

Bioavailability of iron from rice was highest in diets containing starch and lactose (Reddy and Reddy, 1985).

The results of an *in vitro* study conducted by Turnland *et al.* (1990) revealed that absorption of iron from cereal based diets is neither enhanced nor inhibited by the addition of milk.

Bjorn-Rasmussen (1974) revealed that iron absorption was reduced in direct proportion to the amount of bran added to a meal. More than half of the iron in wheat bran is present as monoferric phytate which was soluble at neutral pH and its iron had relatively high bioavailability.

Sondstead *et al.* (1978) found that addition of corn and wheat bran to the diet had no effect on iron balance of man (Sondstead *et al.*, 1978).

Simpson *et al.* (1985) revealed that addition of wheat bran to high or low iron bioavailability diets decreased iron absorption (Simpson *et al.*, 1985).

The addition of soy to a mixed diet inhibited the overall iron bioavailability (Cook *et al.*, 1981; Hallberg and Rossander, 1982).

A 50-60 per cent decrease was observed when textured soy flour was added to ground beef in a hamberger meal (Mork and Cook, 1981).

The relative bioavailability of iron from soy flour, freeze-dried soy beverage and soy concentrate was determined by Picciano *et al.* (1984). The relative iron bioavailability from soy concentrate (92%) and soy flour (81%) were not different from the reference standard, where as that from soy beverage (66%) it was significantly less (Picciano *et al.*, 1984).

Studying iron absorption from liquid formula meals that contained a number of soy protein isolates with different phytate contents observed a four to five fold increase in iron absorption when phytic acid was essentially removed from the soy protein isolates. They noted that the phytic acid content of the soy protein isolate had to be reduced to low amounts to increase in iron absorption (Hurrell *et al.*, 1992).

Ascorbic acid intake enhanced the iron absorption. It serves as a vehicle not only to counteract the inhibiting effect of egg in the diet but also improve the iron absorption from a normal diet. The reason may be, besides its role in the reduction of iron to more soluble ferrous state, it forms an iron ascorbate chelate thus improving iron absorption in the body (Callender *et al.*, 1970, 1980).

Callender *et al.* (1970) found that a acid intake enhanced iron absorption from a miner diet. The addition of orange juice containing 40-50 mg ascorbic acid to a breakfast meal of bread, egg and tea or coffee was found to increase iron absorption from 3-7 to 10.4 per cent .

Bingham (1977) has demonstrated that iron absorption from a breakfast of egg and toast was increased when a glass of citru fruits was taken at the same time. Meat itself also enhanced absorption from these foods.

The marked effect of vitamin C is well illustrated by Rossander and Hallberg (1979) who found that a glass of orange juice containing 70 mg ascorbic acid increased non-heme iron absorption 2.5 times from a continental type of breakfast with coffee and three times from the same breakfast with tea.

A bread meal with fruit juice as a drink and a limited amount of coffee and tea, or no coffee and tea at all, will certainly improve iron availability for absorption, because ascorbic acid reverses the strong inhibitory effect of polyphenols (Lynch and Cook, 1980).

WHO/UNICEF/UNU (1994) recommended the addition of orange or fruit juice or other sources of ascorbic acid to the meal such as potato, cabbage and cauliflower.

Ascorbic acid was shown to account for the seven fold increase in iron absorption from maize porridge when papaya was included in the meal (Layrisse *et al.*, 1974).

When ascorbic acid was given in divided doses i.e., 100 ml in breakfast and 100 ml after dinner, three fold increase in iron absorption was observed (Rathee and Pradhan, 1980).

The enhancement of non-heme iron absorption by ascorbic acid is thought to occur only when it is consumed with a meal (Monsen, 1988).

The absorption of non-heme dietary iron in humans varied widely depending on the nature of the meal. A dramatic 3 fold increase in iron absorption was observed when ascorbic acid was added to a meal (Forbes *et al.*, 1989).

The addition of nuts to a meal can produce a substantial inhibitory effect on iron absorption. Macfarlane *et al.* (1990) demonstrated that a modest addition of vitamin C to a meal will overcome the inhibitory effect of the nuts.

The supplementation of a diet with ascorbic acid enhanced the bodys retention of iron on an ongoing basis over a period of 5.5 weeks (Hunt *et al.*, 1990).

Addition of ascorbic acid or an equimolar amount of L-ascorbyl-6-palmatate to bread increased iron absorption from 5-7 per cent to 9.2 per cent (Morck *et al.*, 1980).

As the concentration of iron added to wheat bran was increased, less of the total added iron was bound. Ascorbic acid was found to inhibit binding of ferrous iron to wheat bran (Camire and Clydesdale, 1982).

Cook *et al.* (1984) investigated whether ongoing ascorbic acid supplementation with meals would affect serum ferritin as indicator of body iron stores. These healthy, free living subjects had no change in serum ferritin after ingesting 2 g ascorbic acid/day with meals for 16 weeks which suggested that body iron stores were not effected.

Tuntawiron *et al.* (1991) reported that ascorbic acid added to a typical south east Asian meal with increased content of iron-binding phenolic group and a bread meal with increased phytate content counteracted the inhibitory effect of these compounds on non-heme iron absorption and improved the bioavailability of iron from these meals.

Vitamin C has shown to improve iron absorption from soy to varying degree (Morck *et al.*, 1982; Derman *et al.*, 1987).

Martinez-Torres and Layrisse (1970) observed a two fold increase in iron absorption when 100 g fish was added to a meal of black beans.

The addition of beef to a meatless meal increased iron absorption and the addition of 100 mg ascorbic acid to the control meal increased absorption nearly four fold (Morch and Cook, 1981).

Iron absorption from vegetable food is enhanced when the food is administered with meat (Layrisse *et al.*, 1975).

Other workers have shown increased iron absorption when beef, fish, chicken or calf thymus was added to a maize meal, but they noted no response for egg white, cystine or water extract of beef (Bjorn-Rasmussen and Hallberg, 1979).

The bioavailability of heme iron in meals containing meat is about 25 per cent and the bioavailability of heme iron without meat has a maximum absorption of about 10 per cent, decreasing with increasing dose to a 5 per cent (Hallberg, 1980).

The lower bioavailability of iron in the Swedish diets can be explained by the lower meat intake in Sweden compared with that in both France and the United States and by the lower intake of fruits and vegetable with meals (OCDE, 1985).

Argentina is a country with the highest beef consumption to the world, with an iron availability representing 140 per cent of recommended intake (Calve and Gnazzo, 1990).

Drinking tea with meals contributed to the development of iron deficiency if the diets were primarily vegetable based. There is considerable evidence from human studies that tea inhibited the absorption of iron from meals (Disler *et al.*, 1977).

Kojima *et al.* (1981) found that tea and coffee acted differently on iron absorption when added to a suspension of cooked pinto beans. Tea reduced the amount of soluble iron by 88 per cent. Coffee, on the other hand, did not decrease the amount of iron in solution but was responsible for oxidizing all to the ferric state.

Rao and Prabhavathi (1982) studied the effect of adding tea to a breakfast meal, as normally used in south India. The results indicated that the inclusion of one cup of tea in a breakfast reduced ionisable iron by nearly 50 per cent.

With tea a marked decrease in iron absorption from 7.45 per cent to 1.23 per cent was also observed by (Reddy and Cook, 1991).

Separate tea-drinking from meal time. One or two hour later, the tea will not inhibit iron absorption, since most of the food would have left the stomach (WHO/UNICEF/UNU, 1994).

Hamdaovi *et al.* (1995) showed that tea decoction (100 mg/ml) reduced non-heme iron absorption from traditional Tunisian meal (Coyscous) by 50 per cent. In contrast, administration of 20 mg ascorbic acid increased non-heme iron absorption from the meal by more than 100 per cent. Administration of ascorbic acid (20 mg) in a tea decoction (100 mg/ml) completely countracted the inhibiting effect of tea and significantly improved the non-heme iron absorption from coyscous.

Supplementing the bread dough by calcium containing additives caused 50 per cent reduction in the availabile quantities of soluble (free) iron (Zemel and Shelef, 1982).

A study by Kochanowslei and Mc Mahan (1990) demonstrated that calcium inhibited iron absorption when the two minerals were present together but that when separated by one hour, there was no inhibition. This suggested that calcium has to be present in the same meals as iron to interfere with its absorption.

Supplemental $CaCO_3$ has been shown to inhibit iron absorption in humans when it was consumed together with food (Cook *et al.*, 1991).

$CaCO_3$ supplements depressed iron availability when consumed with meals. Both the cation and the anion in $CaCO_3$ contributed to the iron absorption-depressing action of this salts (Prather and Miller, 1992).

About 30-50 per cent more iron was absorbed when no milk or cheese was served with lunch or dinner. A reasonable separation of calcium and iron intakes would improve iron nutrition (Gleerup *et al.*, 1995).

Sayers *et al.* (1974) added iron mixed with salt and ascorbic acid to maize perridge and found no significant difference in absorption by humans between ferrous sulphate and ferric or the phosphate. Disler *et al.* (1975a) found that iron availability from maize porridge fortified with $FePO_4$ was several fold greater if the $FePO_4$ were added before rather than after cooking.

Orally administered iron has been found to be better absorbed when taken on an empty stomach. When ferrous sulphate in a dosage of 20-30 mg iron was administered together with a light meal the absorption was reduced to about one half compared to fasting condition (Reizensteir *et al.*, 1975). A similar reduction was found when 60 mg of iron as ferrous sulphate in solution was given together with a meal, containing vegetables with or without meal (Grebe *et al.*, 1975). A still more marked reduction in the absorption was observed when a much smaller dose of iron (0.25 mg) was administered together with a complete meal (Reizenstein *et al.*, 1975).

Iron fortification has resulted in increased intakes of food iron, some sources of iron used in fortification are of low bioavailability (Rios, 1975).

An eight fold reduction was found with rapdily disintegrating iron tablets and a three fold reduction with the slow-release tablets. Under fasting condition the rapidly disintegrating tablets were significantly better absorbed than the slow release tablets, where as the reverse was found when the tablets were given with a metal (Ekenved *et al.*, 1976).

In a human study Bjorn-Rasmussen *et al.* (1977) found a positive correlation between iron absorption from different hydrogen reduced iron preparations.

Hallberg and Rossander (1982) observed that citric acid or malic acid present in iron tablets provided some enhancement of iron absorption from the breakfast meal.

Most compounds used for iron fortification are only partially soluble and are thus only partially available for absorption in the gastro intestinal tract. Iron derived from contamination of foods with extraneous iron is also only partly available (Hallberg *et al.*, 1983).

Tripolyphosphate, Trimetaphosphate and Tetrasodium pyrophosphate when added to foods increased ionizable iron 3-7 folds. These polyphosphates when added to wheat flour served as potential promoters of food iron (Subba Rao and Rao, 1983).

Iron compounds that are used for food fortification varied considerably in bioavailability (WHO, 1989).

Processing, cooking and cooking utensils on iron bioavailability

Verma *et al.* (1977) found that the form of iron compounds, the composition of the meal and processing conditions can dramatically alter iron availability from diets.

Food processing, such as heat treatment, milling, fermentation or the action of enzymes, contribute to either enhanced or reduced availability. New compounds may be formed, the food environment may be altered, and new external factors may be introduced. This meant that the bioavailability of iron in processed or cooked foods may not reflect the bioavailability of the original food iron or an addėd iron source (Yetley and Glinsmann, 1983).

Disler *et al.* (1975a) found that ferric orthophosphats were poorly available if added to maize porridge after cooking or when added to biscuts prior to backing but was highly available if added to porridge before cooking.

Under some condition, thermal processing apparently affected iron availability. Wood *et al.* (1978) found that heat and pressure processing of chick diets fortified with various iron phosphate salts increased iron availability.

Lee and Clydesdale (1981) have stated that food processing such as germination, cooking, roasting and milling showed two to four fold increase in biologically available iron. Satwardhar *et al.* (1981) proved that the resultant significant increase in absolute available iron was also due to decrease in polyphenols after cooking to about 20-50 per cent.

It was found that boiling for one hour in a boiling water bath had no effect on the destruction of phytic acid in wheat bran, where as toasting for one hour at 178°C (350°F) and boiling for one hour in hydrochloric acid had a significant effect (Camire and clydesdale, 1982).

Schricker *et al.* (1982) showed that heating meat and red blood cells in a boiling water bath increased the amount of non-heme iron in these preparation. He also suggested that these increases in non-heme iron may be due to release of iron from the heme iron complex by oxidation charge of the porphyrin ring.

Conversions of heme to non-heme iron caused by heat or chemical processing reduced the availability of meat iron.

Four cooking procedures were evaluated to determine the changes in non-heme iron concentration occured as a result of common cooking practices. Braising meat resulted in significantly higher non-heme iron levels in the surface portion compared with before cooking levels and with the center portion after cooking. Roasting meat products resulted in high levels of non-heme iron after cooking compared with before cooking. The micro wave methods did not significantly alter the distribution of non-heme iron to total iron before and after cooking. The braising and roasting methods cooked the meat to a higher internal temperature and resulted in higher non-heme iron levels than the microwave method (Schricker and Miller, 1983).

Heating food and storing cooked foods easily distroyed ascorbic acid and therefore significantly dicreased iron availability for absorption. Prolonged storage of canned products increased the iron content of foods (Manriksen *et al.*, 1985). Reduced heme iron absorption has been observed after over cooking of meal, causing denaturation of the heme (Martinez-Torres *et al.*, 1986).

Disler *et al.* (1975a) showed that the iron in sugar fortified with ferric orthophosphate and ascorbic acid was much more available to human subjects if it was added to maize porridge before, rather than after cooking.

Ranhotra *et al.* (1979) in a study showed a decrease in iron availability of $FeSO_4$ as a result of baking.

Addition of 2-ascorbyl-6-palmatate to dough before baking gave iron absorption from final bread of 7.0 per cent indicating that its effect on absorption was largely in affected by the baking process (Morck *et al.*, 1980).

According to Schricker and Miller (1982) the baking process had little effect on relative availability of iron from a meal regardless of the iron source incorporated. A reduction in available iron was observed as a result of baking with the complex meals but not with the bread meals.

Non-heme iron concentrations were higher in ascorbic acid containing baked samples compared with sample baked without ascorbic acid (Schricker and Miller, 1983).

Comparison of 5 types of Iranian flat-breads with dough showed that the baking process appreciably improved the bioavailability of iron in berbari, toftoon and sengak breads and decreased it in lauast and village breads (Ranhotra *et al.*, 1983).

Coccodrilli *et al.* (1981) found that elemental iron sources generally have a good bioavailability even after processing.

Comparison among meals containing cereals that were similar except for type of processing showed that processing may effect iron bioavailability (Carlson and Miller, 1983).

Rao and Prabhavathi (1982) revealed that the proportion of ionisable iron increased significantly in legume seeds when seed-coat were removed. The phytin phosphate content, however, was only marginally reduced following decortication of seeds (Rao and Prabhavathi, 1982).

Percentage total and absolute available iron (mg/100 g) content of dehulled and milled pulses increased whereas roasted and cooked bengal gram showed per cent decrease of total iron and per cent increase of absolute available iron (NIN, 1995). In the case of peas roasted sample showed high percentage increase of both total and absolute available iron.

Germinated seeds were analysed before and after decortication. During germination the tannin content decreased by 20-30 per cent, while ionisable iron nearly doubled. Decorticated seed samples which had low tannin and high ionisable iron did not show any improvement at different stages of germination. The phytate content of the seeds decreased and ascorbic acid conent increased during germination. A reduction in tannin content of the whole seed during germination is responsible for the observed improvement in ionisable iron (Rao and Prabhavathi, 1982).

Ragi is a staple cereal food for certain regions of developing countries but it has low iron bioavailability when ragi was germinated for 48 hours, bioavailability of iron improved slightly from 17.0 to 23.7 (Reddy, 1985).

Bajra, ragi and jower showed 27 and 102 per cent increase of absolute available iron respectively after 48 hours of germination and no difference between 48 hours and 72 hours germination. In the case of bajra, germination can be done for 48 or 72 hours. The per cent increase of absolute available iron after 48 hours of germination when compared to the pulses showed that green gram had the highest percentage of increase of absolute available iron followed by peas, horse gram, field bean, soya bean, cowpea and bengal gram had the least increase (Annapurani and Murthy, 1984).

Polyphenolic content of red gram was determined after subjecting it a sprouting, cooking and dehulling. All these methods of processing helped in reducing the levels of polyphenols (Parmajyothi and Mulimani, 1996).

Morck and Cook (1981) stated that the iron content of the diet also can be increased by contamination during harvesting, processing, cooking or storing food. Under the acidic conditions occurring in fermentation of maize and sorghum beer, iron was extracted from cast-iron drums and was shown to be well absorbed from the beer (Derman *et al.*, 1980).

The modification of soy protein by food processing can influence the availability of iron. Absorption of iron from tempha was shown by Lynch *et al.* (1984) to be slightly improved whereas iron absorption from tofu was increased three fold.

Macfarlane *et al.* (1990) showed that when compared with a soy flour meal containing an equal amount of protein, iron absorption was found to be significantly improved with silken tofu, natto, tempeh, rice miso, barley miso and soy bean meso. This improvement could be explained with reference to a change in the protein composition of the product due to fermentation.

Macfarlane *et al.* (1990) found that Iron absorption from tofues (a fermented soy product) that was precipitated by calcium salts was no better than that from soy flour because of its high calcium content. Calcium is known to inhibit iron absorption.

Contamination with iron during milling showed wide variation from 47 to 154 per cent. But the increase in ionisable iron after milling was less than one per cent indicating that the contamination iron, acquired during milling is poorly ionised. The iron thus derived may not be available for assimilation presumably due to large particle size (Prabhavathi and Rao, 1981).

The bioavailability of iron formed by the corrosion of low carbon steel (99% Fe) in contact with red delicious apple was measured in a rat model using a depletion-repletion experiment. The percentage of ingested iron converted to haemoglobin iron was 74, 57 and 56 per cent respectively for daily doses of 110, 190 and 280 kg of this iron. When compared with $FeSO_4$ = 100, the relative biological value of the iron was found to range from 93-153. Ingestion of one red delicious apple that has been exposed to eight large iron nails for 24 hours could provide 10-15 mg iron having good bioavailability (Rosanoff and Kennedy, 1982).

Contamination iron usually have a very low bioavailability. One exception is the iron derived from cooking pots (WHO, 1989).

Addition of iron to foods due to preparation in iron cookware has often been cited as being significant (Burroughs and Chan, 1972).

According to Devadas *et al.* (1982) intake of food exposed to iron cookware can produce a significant rise in haemoglobin values in humans.

Addition of iron to foods due to preparation in iron cookware has often been cited as being significant. Although the possible role of iron cookware in iron nutrition has been debated, some studies have shown that intake of food exposed to iron cookware can produce a significant raise in hemoglobin values in humans. However, no biological studies for such nutritional iron have been found in the literature (Rosenoff and Kennedy, 1982).

Iron content of raw apples in contact with steel (99% iron) can increase by several milligrams over a days exposure time (Rosanoff and Kennedy, 1982).

The possible role of iron cookware in iron nutrition has been debated (Sharon, 1982).

Apples show a particularly high rate of iron intake when in contact with reduced iron (Moore, 1985).

Curing meat decreases the bioavailability by iron by up to 25 per cent (Mahony and Handrick, 1984).

In a study conducted by Tidehag *et al.* (1995) it was showed that iron absorption from low fibre diets measured from the morning meals to be almost 80 per cent greater than the average iron absorption measured from all meals during the same 2 days.

Cooking of egg white increases iron absorption (Bothwell *et al.*, 1982).

Materials and Methods

MATERIALS AND METHODS

The investigation on 'Nutritional studies on the bioavailability of iron from cereals and pulses' was undertaken to

1. evaluate the *in vitro* availability of iron from commonly consumed cereals and pulses
2. find out the effect of different common methods of processing, cooking and cooking utensils on the bioavailability of iron
3. improve the availability of iron from cereal and pulse based diets by supplementation or substitution of local foods.

The first part of the study consisted of evaluating the bioavailability of iron using *in vitro* techniques from selected cereals [rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.) and ragi (*Eleusine coracona* Gaertn.)] and pulses [bengal gram (*Cicer arietimum* Linn.), black gram (*Phaseolus mungo* L.), green gram (*Phaseolus aureus* Roxb.), horse gram (*Dolichos biflorus* Roxb.), cowpea (*Vigna sinensis* Sari.) and soy bean (*Glycine max*. (L) Merr.]. The above food materials were selected because they are the common components of South Indian diets. Estimation of ionisable iron was done by the method of Rao and Prabhavati (1978). Briefly the technique involved digestion of food samples under simulated gastric conditions viz., Pepsin-HCl buffer (pH 1.35) and changing the pH to 7.5 and estimating iron in the supernatant after centrifigation. Total iron in the food sample was estimated by Wang's method as described in the manual of Laboratory technique by NIN (1983). The food materials were dry ashed in muffle furnace at 550°C. Prepared acid extract using conc. H_2SO_4 and colourimetric determination of iron using potassium thiocyanate at 540 nm.

Ionizable iron at pH 7.5 (jejunal and duodenal pH) was taken as a measure of iron +-availability since the site of iron absorption is the duodenum. The values are expressed as ionisable iron per 100 units of total iron in a food. Then absolute available iron was calculated as follows

$$\text{Absolute available iron} = \frac{\text{Per cent ionisable iron at pH 7.5}}{100} \times \text{Total iron}$$

Bioavailability of iron was evaluated after processing such as parboiling, milling, dehulling, puffing, germination and fermentation of the selected food materials. Common household cooking methods such as boiling, steaming, frying and roasting was also done for evaluating the *in vitro* iron bioavailability. The effect of common cooking vessels such as aluminium, steel, iron, mud pots and tufflon coated vessels were also evaluated for changes in the bioavailability of iron.

Estimation of phytin phosphorus, tannins and crude fibre was done in the raw and processed samples which had an adverse effect on the iron absorption and also ascorbic acid (vitamin C) in germinated samples which enhanced iron bioavailability.

The second part of the study was concentrated on evaluating the *in vitro* availability of iron from the actual diets commonly consumed by adults and modifications of local diets for enhanced iron bioavailability.

Samples of cereals and pulses were purchased in one lot from the local market for all the experiments in this study. Raw and processed samples of the selected cereals and pulses were dried and made into flours which passed a sieve mesh of 60 mm and they were stored separately in air tight plastic containers with proper labels and used for evaluation of *in vitro* iron availability.

Methods of processing

1. Parboiling

Five kg of paddy was parboiled by cold water soaking method as suggested by Bhattacharya and Subha Rao (1966).

2. Handpounding

Hundred gram of both raw and parboiled rice was handpounded (Bhattacharya and Subha Rao, 1966).

3. Milling

Hundred gram of both raw and parboiled rice was milled by process suggested by Swaminathan (1974).

4. Dehulling

Hundred gram of the pulses were soaked in water for half an hour and washed to remove the seed coat (NIN, 1982).

5. Puffing

Hundred gram of raw rice was puffed by the method suggested by Rajalekshmi (1984).

6. Germination

Hundred gram of the selected cereals (Ragi) and pulses were washed with distilled water and were soaked for 4 hours. The soaked seeds were then spread on a wet filter paper on a layer of water saturated sterilised cotton pad on a sterilised petridish and allowed to germinate with enough moisture at room temperature (27°C) in the dark for 24 hours, 48 hours and 72 hours (Victor and Wall, 1980). After germination for each period, healthy seedlings containing cotyledons were collected and dried in an oven for 5-6 hours at 60°C. The dried seeds were powdered to pass a 50 mm mesh and used for analysis.

7. Fermentation

Hundred gram of parboiled rice and 30 g of black gram dhal was soaked separately in distilled water for 4 hours. The soaked rice and dhal was then ground to a fine paste separately by adding sufficient distilled water in a mixi. The two pastes were then mixed thoroughly to get a uniform idli batter and was kept for natural fermentation at room temperature for 12 hours.

Methods of cooking

All the cooking methods were carried out using glass vessels.

1. Roasting

Heat treatments were given for the dry cereals and pulses for about a short period of one to two minutes, powdered to pass a 60 mm mesh and used for estimation. Roasting was also done to dehulled pulses.

2. Frying

Heat treatments were given for the dry cereals and pulses by rubbing with little coconut oil for a short period of one to two minutes, powdered the fried samples to pass a 60 mm mesh and used for estimation. Frying was also done to dehulled pulses.

3. Boiling

Both parboiled and milled rice were cooked in excess water till the grains become soft and drain off excess water. Parboiled and milled rice were also cooked with sufficient water using a pressure cooker.

Whole grams were soaked for 8 hours and cooked in sufficient water till it became soft. Soaked whole grains were also subjected to pressure cooking.

4. Steaming

The fermented idli batter prepared from rice pulse mix was poured in glass moulds and was steamed in idli cooker.

Cooking vessels

All the above cooking methods with cereals and pulses were repeated using aluminium, steel, iron, mud and tufflon coated vessels.

Estimation of phytin phosphorus

Estimation of phytin phosphorus was done in the whole grams, dehulled pulses and germinated pulses since high phytin phosphorus content in pulses has an adverse effect on the iron absorption. Phytin phosphorus content was estimated by the method of Peach and Tracy (1955) where 1 g of the sample was extracted with 0.5 N HCl, centrifuged and pH adjusted to 2. 4 ml of 0.1 per cent Ferric chloride was added and heated for 40 mts and cooled and centrifuged. Precipitate was dissolved in 0.5 ml of 0.6 N NaOH and made up to 10 ml with distilled water. 5 ml of this was taken and digested with con. H_2SO_4 for 1 hour. After complete digestion it was made up to 10 ml the aliquort was taken for estimation of phosphorous by Fiske Subba Rao method as described in the Manual of Laboratory techniques by NIN (1983). Phytin phosphorus was also estimated in daily diets and modified diets.

Estimation of Tannins

Since tannins have a strong inhibitory effect on the availability of iron for absorption, it was estimated in ragi and whole grams and also in dehulled pulses and germinated ragi and pulses by Vannilin hydrochloric acid method (Burns, 1971). Tannins was also estimated in the whole days diet and modified diets.

Estimation of crude fiber

Dietary fiber is also claimed as an inhibitor of iron absorption. Hence crude fiber in selected cereals and pulses both processed and unprocessed was estimated by acid and alkali digestion as per the method described in the Manual of Laboratory Techniques by NIN (1983). Fiber in the daily diet and modified diets were also estimated.

Estimation of ascorbic acid

Ascorbic acid is the best enhancer of nonheme iron absorption. Ascorbic acid content if germinated ragi and pulses were estimated by dye method as described in the Manual of Laboratory Techniques by NIN (1983). Ascorbic acid in the whole days diet and modified diets were also estimated.

Collection of cooked food samples

Local dietary pattern of adults were observed for a period of 10 days. Then one day weighment survey was conducted to find out the actual quantity of raw food stuffs consumed by the individual. Ten per cent of the food item actually consumed for breakfast, lunch, tea and dinner were collected for analysis. These were pooled and homogenised in a blender and 5.0 g was taken for evaluating the absolute available iron by Pepsin-HCl method of Narasinga Rao and Prabhavathi (1978). Food was first weighed and given to the subjects. Plate wastes were weighed. From this quantities consumed were calculated. Iron availability in whole days diet was found out for 3 days randomly and identified as Diet I, II and III, the composition and quantity of raw food equivalents of which is given in Appendix-I.

Rice based diets with high levels of iron availability

The above 3 dietary patterns were kept as a standard and these diets were modified by substituting and supplementing with foods which improve iron absorption and also by using processed foods which reduced the iron absorption inhibitors composition of the modified diets are given in Appendix-II. Modified diets were also evaluated for absolute available iron by Pepsin-HCl method of Rao and Prabhavathi (1978).

Results

RESULT

The results of the research project entitled "Nutritional studies on the bioavailability of iron from cereals and pulses are projected under the following headings.

1. Total and ionisable iron content of selected cereals and pulses
2. Effect of different methods of processing, cooking and cooking untensils on the total and ionisable iron content of selected cereals and pulses
3. Iron absorption enhancers and inhibitors in selected cereals and pulses and the effect of processing
4. Total iron, ionisable iron and absolute available iron from local diets
5. Iron absorption enhancers and inhibitors in local diets
6. Iron absorption enhancers and inhibitors in the modified diets
7. Total iron, ionisable iron and absolute available iron in modified diets

1 Total and ionisable iron content of selected cereals and pulses

Table 1 projects the total iron, ionisable iron at pH 1.35 and 7.5 and absolute available iron of selected cereals.

Table 1. Total iron, ionisable iron and absolute available iron in cereals

Cereals	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5	
Raw rice (milled)	2.98 ± 1.3	10.25 ± 1.3	9.20 ± 0.03	0.274 ± 0.01
Wheat (flour)	4.42 ± 0.28	40.64 ± 0.33	14.17 ± 0.004	0.63 ± 0.04
Ragi	6.79 ± 0.02	10.78 ± 0.02	7.31 ± 0.04	0.49 ± 0.001

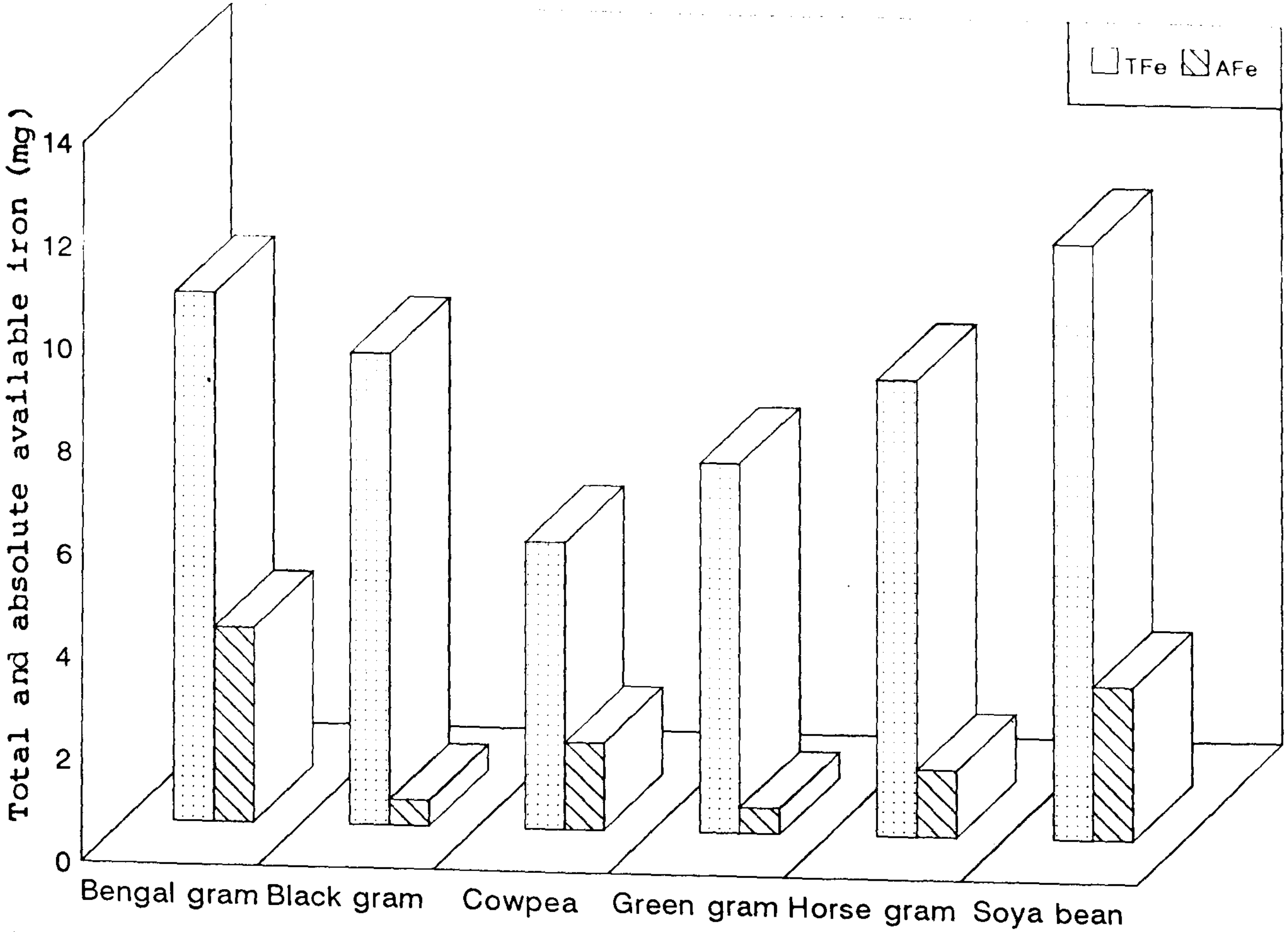
As depicted in Table 1, total iron content among cereals was highest in ragi (6.79 mg/100 g) followed by wheat (4.42 mg/100 g). Total iron was least in raw rice (2.98 mg/100 g). Ionisable iron at pH 1.35 was maximum for wheat (40.64%) followed by raw rice (10.25%) and ragi (10.78%). Ionisable iron at pH 7.5 was also highest in wheat (14.17%), then raw rice (9.2%) and lastly ragi (7.31%). Regarding absolute available iron maximum availability of iron was found from wheat (0.63 mg %) followed by ragi (0.49 mg %). Availability of iron from raw rice was found to be the least (0.274 mg %).

Total iron, ionisable iron and absolute available iron was estimated in selected pulses and is presented in Table 2.

Table 2. Total iron, ionisable iron and absolute available iron in pulses (whole)

Pulses	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5	
Bengal gram	10.32 ± 0.004	39.20 ± 0.01	36.5 ± 0.03	3.80 ± 0.005
Black gram	9.20 ± 0.008	37.80 ± 0.03	5.9 ± 0.004	0.50 ± 0.0008
Cowpea	5.60 ± 0.008	66.30 ± 0.2	30.7 ± 0.02	1.70 ± 0.06
Green gram	7.10± 0.004	37.80 ± 0.008	8.2 ± 0.02	0.60 ± 0.002
Horse gram	8.90 ± 0.03	28.89 ± 0.06	14.8 ± 0.004	1.31 ± 0.005
Soya beans	11.60 ± 0.01	21.90 ± 0.11	26.02 ± 0.05	3.00 ± 0.078

As revealed in the table among pulses maximum total iron was observed for soyabeans (11.6 mg/100 g) followed by bengal gram (10.32 mg/100 g) and black gram (9.2 mg %). Horse gram contained 8.9 mg/100 g whereas green gram



TFe - Total iron AFe - Absolute available iron

Fig.1. Total iron and absolute available iron in pulses (whole)

was found to contain 7.1 mg/100 g. The lowest value for total iron was observed for cowpea (5.6 mg 100 g).

Regarding ionisable iron at pH 1.35 maximum ionisable iron was shown by cowpea (66.3%) followed by bengal gram (39.20%); black gram and green gram showed the same values for ionisable iron at pH 1.35 (37.8%). The values for horse gram and soyabeans were found to be 28.89 and 21.9 per cent respectively.

At pH 7.5 ionisable iron was found to be more in bengal gram (36.5%) followed by cowpea (30.7%). Ionisable iron at pH 7.5 was 26.02 per cent for soyabeans. Low values were observed for black gram (5.9%) and green gram (8.2%). For horse gram the ionisable iron at pH 7.5 was found to be 14.8 per cent.

Among pulses absolute available iron was more in bengal gram (3.8 mg per cent) and soyabeans (3.0 mg per cent). Iron from cowpea showed the next highest availability (1.7 mg per cent) followed by horse gram (1.31 mg per cent). Iron availability was found to be least from black gram (0.5 mg per cent) and green gram (0.6 mg per cent) (Fig.1).

2 Effect of different methods of processing, cooking and cooking utensils on the total and ionisable iron content of selected cereals and pulses

Total iron, ionisable iron and absolute available iron in rice subjected to various processing methods are presented in Table 3.

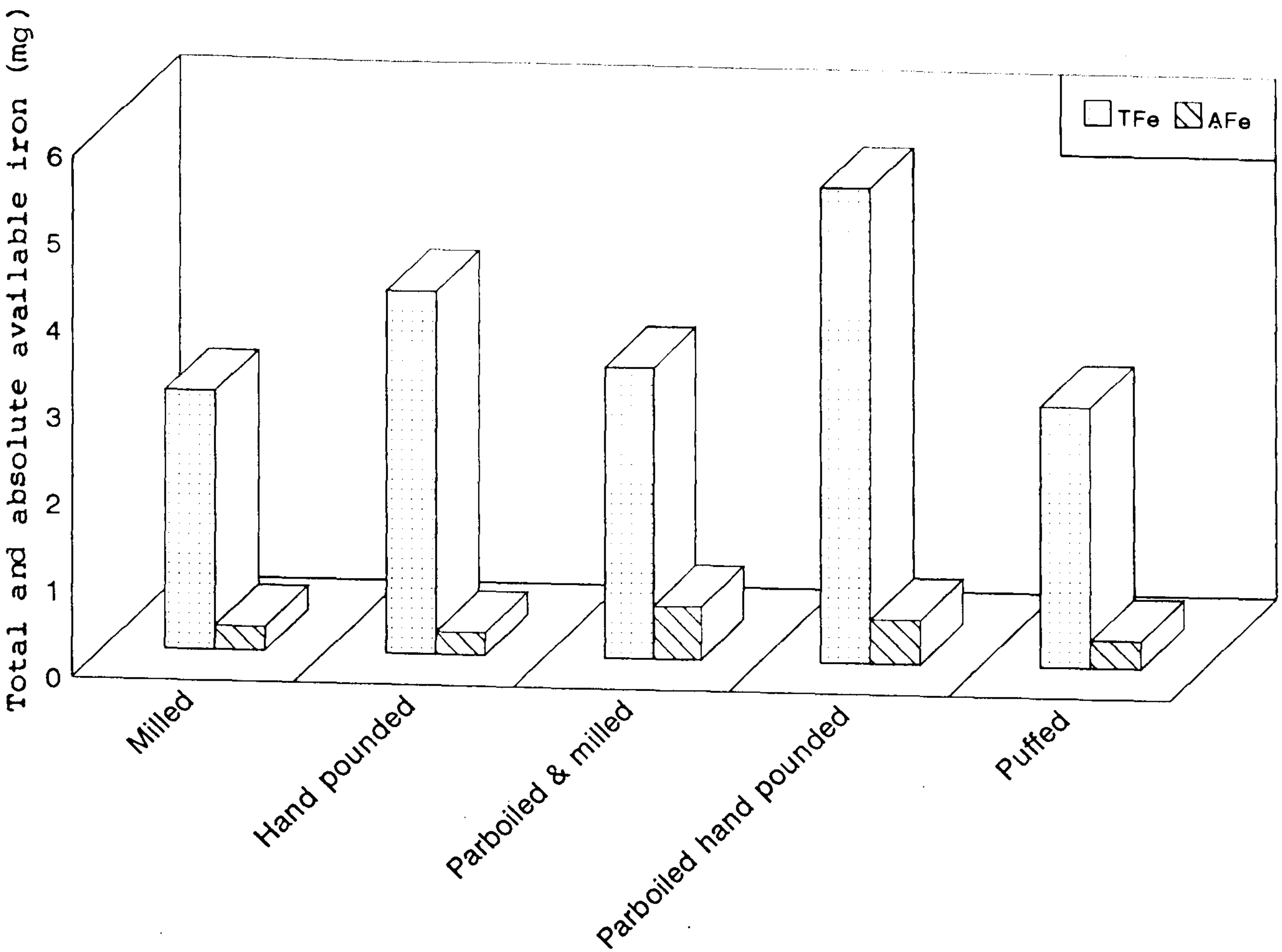
Table 3. Total iron, ionisable iron and absolute available iron in processed rice

Cereals	Processing methods	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
			pH 1.35	pH 7.5	
Raw rice	Milled	2.98 ± 1.3	10.25 ± 1.3	9.20 ± 0.03	0.274 ± 0.01
Raw rice	Hand pounded	4.18 ± 0.07	20.51 ± 0.33	6.26 ± 0.17	0.260 ± 0.003
Rice	Parboiled and milled	3.35 ± 0.1	30.95 ± 0.1	18.16 ± 0.06	0.608 ± 0.02
Rice	Parboiled and hand pounded	5.47 ± 0.13	30.61 ± 0.66	9.41 ± 0.28	0.510 ± 0.03
Rice	Puffed	3.00 ± 0.04	12.01 ± 0.004	10.95 ± 0.004	0.320 ± 0.005

With regard to different processing methods in rice total iron content was found to be more in parboiled and hand pounded rice (5.47 mg per cent) followed by hand pounded raw rice (4.18 mg per cent). Total iron content of raw rice, milled, was 2.98 mg per cent while that of parboiled rice milled was 3.35 mg per cent. For puffed rice the total iron content was 3.0 mg per cent.

Ionisable iron at pH 1.35 of these processed rice products revealed that parboiled and milled rice had got the maximum value ie. 30.95 per cent followed by parboiled hand pounded rice (30.61%).

For raw rice milled it was 10.25 per cent and for raw rice hand pounded it was 20.51 per cent. Ionisable iron at pH 1.35 for puffed rice was found to be 12.01 per cent.



TFe - Total iron   AFe - Absolute available iron

Fig.2. Total iron [redacted] and absolute available iron in processed rice

Ionisable iron at pH 7.5 revealed that among these processing methods of rice, parboiling and milling of rice resulted in maximum ionisable iron (18.16%), followed by puffing (10.95%). Parboiling and hand pounding of rice resulted in 9.41 per cent whereas raw rice milled showed 9.2 per cent. The lowest value for ionisable iron at pH 7.5 was shown by raw hand pounded rice (6.26%).

As depicted in Fig.2, the absolute available iron content of rice subjected to various processing methods, maximum available iron was found in rice parboiled and milled (0.608 mg per cent) followed by rice parboiled and hand pounded (0.51 mg per cent). Absolute available iron for raw rice milled was 0.274 mg per cent whereas that of raw rice hand pounded it was 0.26 mg per cent. For puffed rice it was 0.32 mg per cent.

Total iron, ionisable iron and absolute available iron in wheat and ragi subjected to processing methods are presented in Table 4.

Table 4. Total iron, ionisable iron and absolute available iron in processed wheat and ragi

Cereals	Processing methods	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
			pH 1.35	pH 7.5	
Wheat flour	(whole)	4.42 ± 0.28	40.64 ± 0.33	14.17 ± 0.04	0.63 ± 0.04
Wheat flour	(refined)	2.51 ± 0.25	39.12 ± 0.69	27.06 ± 0.42	0.68 ± 0.05
Ragi	(whole)	6.79 ± 0.02	10.78 ± 0.02	7.31 ± 0.002	0.49 ± 0.001
Ragi powder	(milled)	6.87 ± 0.02	10.01 ± 0.005	7.11 ± 0.004	0.48 ± 0.004

From the above table it was clear that total iron was more in milled ragi (6.87 mg per cent) when compared to whole ragi (6.79 mg per cent). In the case of wheat, whole wheat flour had higher total iron value (4.42 mg per cent) when compared to refined wheat flour.

Considering the ionisable iron at pH 1.35, whole wheat flour had the highest value (40.64%), when compared to refined wheat flour (39.12%) whole ragi (10.78%) and milled ragi powder (10.01%).

Ionisable iron at pH 7.5 showed that refined wheat flour had the highest value (27.06%) followed by whole wheat flour (14.17%). For whole ragi the value was 7.31 per cent and for ragi powder it was 7.11 per cent.

The absolute available iron was found to be maximum in refined wheat flour (0.68 mg/100 g) followed by whole wheat flour (0.63 mg/100 g), whole ragi (0.49 mg/100 g) and ragi powder (0.48 mg/100 g).

Table 5 indicated the effect of dehulling on total, ionisable and absolute available iron content of bengal gram and black gram.

Table 5. Effect of dehulling on total iron, ionisable iron and absolute available iron of bengal gram and black gram

Pulses	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5	
Bengal gram				
Whole	10.32 ± 0.004	39.20 ± 0.01	36.5 ± 0.03	3.8 ± 0.005
Dehulled	12.40 ± 0.012	78.00 ± 0.12	78.0 ± 0.004	9.7 ± 0.01
Black gram				
Whole	9.20 ± 0.008	37.80 ± 0.03	5.9 ± 0.004	0.5 ± 0.0008
Dehulled	9.50 ± 0.004	13.90 ± 0.009	15.4 ± 0.004	1.5 ± 0.0004

Total iron content increased after dehulling from 10.32 mg per cent to 12.4 mg per cent in bengal gram and from 9.2 mg per cent to 9.5 mg per cent in black gram.

There was a decrease in ionisable iron at pH 7.5 when compared to the ionisable iron at pH 1.35 (39.20% to 36.5%) in the case of whole bengal gram but with dehulling no change was observed (78%) in pH 1.35 and 7.5 but due to dehulling the ionisable iron at both pH had a higher value when compared to the whole bengal gram. The absolute available iron content of the bengal gram was also increased from 3.8 mg per cent to 9.7 mg per cent due to dehulling.

With regard to black gram also total iron content increased from 9.2 to 9.5 mg/100 g with dehulling. The ionisable iron at pH 1.35 was found to be decreasing (13.9%) when compared to the whole gram (37.8%); but at pH 7.5 the ionisable iron increased from 5.9 to 15.4 per cent after dehulling. The absolute available iron also increased after dehulling ie. from 0.5 to 1.5 mg per cent.

Table 6 presents the effect of dehulling on total, ionisable and absolute availoable iron content of green gram and soyabean.

Table 6. Effect of dehulling on toal iron, ionisable iron and absolute available iron of green gram and soya bean

Pulses	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5	
Green gram				
Whole	7.10 ± 0.004	37.80 ± 0.008	8.20 ± 0.02	0.60 ± 0.002
Dehulled	7.32 ± 0.007	38.62 ± 0.5	9.22 ± 0.1	0.67 ± 0.009
Soya bean				
Whole	11.60 ± 0.01	21.90 ± 0.11	26.02 ± 0.05	3.00 ± 0.078
Dehulled	11.84 ± 0.32	21.87 ± 0.09	26.88 ± 0.1	2.59 ± 0.07

As revealed in table total iron content increased after dehulling in both green gram (7.1 to 7.32 mg/100 g) and soyabean (11.6 to 11.84 mg %). Ionisable iron at pH 1.35 increased from 37.8 to 38.62 per cent and at pH 7.5 this increase was from 8.2 to 9.22 per cent in green gram due to dehulling. An increase in absolute available iron was also observed from 0.6 to 0.67 mg per cent in green gram after dehulling.

In soyabeans after dehulling ionisable iron at pH 1.35 was found to be decreasing from 21.9 to 21.87 per cent but at pH 7.5 it was increasing from 26.02 to 26.88 per cent. Absolute available iron was also found to be decreasing from 3 to 2.59 mg per cent after dehulling.

Table 7 projects the effects of germination of ragi on total, ionisable and absolute available iron content.

Table 7. Effects of germination of ragi on total, ionisable and absolute available iron

Sample	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5	
1) Ragi	6.79 ± 0.02	10.78 ± 0.02	7.31 ± 0.02	0.49 ± 0.001
2) Ragi - germinated				
24 hours	8.05 ± 0.048	26.21 ± 0.16	18.17 ± 0.01	1.51 ± 0.006
48 hours	12.08 ± 0.04	36.40 ± 0.01	25.07 ± 0.01	3.03 ± 0.01
72 hours	13.18 ± 0.06	61.57 ± 0.02	20.17 ± 0.012	2.65 ± 0.01

As depicted in the table total iron content increased in ragi due to germination and that also a gradual increase was noted with the period of germination from 24 hours to 72 hours (from 6.79 > 8.05 > 12.08 > 13.18 mg per cent). There was an increase in ionisable iron at pH 1.35 in ragi due to germination, the maximum being observed at 72 hours of germination (61.57%) for 48 hours of germination it was 36.4 per cent and for 24 hours of germination it was 26.21 per cent. Ionisable iron at pH 7.5 also increased due to germination, but the maximum ionisable iron was observed during 48 hours of germination (25.07%). For 72 hours of germination it decreased to 20.17 per cent and for 24 hours germination the value was least ie. 18.17 per cent.

Absolute available iron in ragi also increased due to germination; the maximum bioavailability was observed in 48 hours of germination (3.03 mg/100 g). At 72 hours of germination the bioavailability was 2.65 mg per cent and at 24 hours of germination the absolute available iron was minimum ie. 1.51 mg per cent.

Table 8 presents the effect of germination of pulses on the total iron content.

Table 8. Effect of germination on total iron content of pulses

Pulses	Total iron in raw pulses (mg/100 g)	Total iron (mg/100 g) with period of germination		
		24 hours	48 hours	72 hours
Bengal gram	10.32 ± 0.004	11.4 ± 0.004	11.40 ± 0.004	12.7 ± 0.008
Green gram	7.10 ± 0.004	8.6 ± 0.004	11.10 ± 0.01	13.0 ± 0,01
Horse gram	8.9 ± 0.03	8.6 ± 0.004	10.20 ± 0.004	11.8 ± 0.004
Cowpea	5.60 ± 0.008	5.9 ± 0.004	8.81 ± 0.004	9.5 ± 0.02
Soya bean	11.60 ± 0.01	13.3 ± 0.009	17.60 ± 0.004	17.6 ± 0.02

Above table revealed that in general there was an increase in the total iron content due to germination of pulses. For bengal gram the total iron content increased from 10.32 to 11.4 mg during 24 hours of germination and there was no change in the value for 48 hours of germination (11.4 mg/100 g) and further increased to 12.7 mg for 72 hours of germination. For green gram there was a steady increase in total iron as the period of germination progressed from 24, 48 and 72 hours (8.6 > 11.1 > 13.0 mg/100 g).

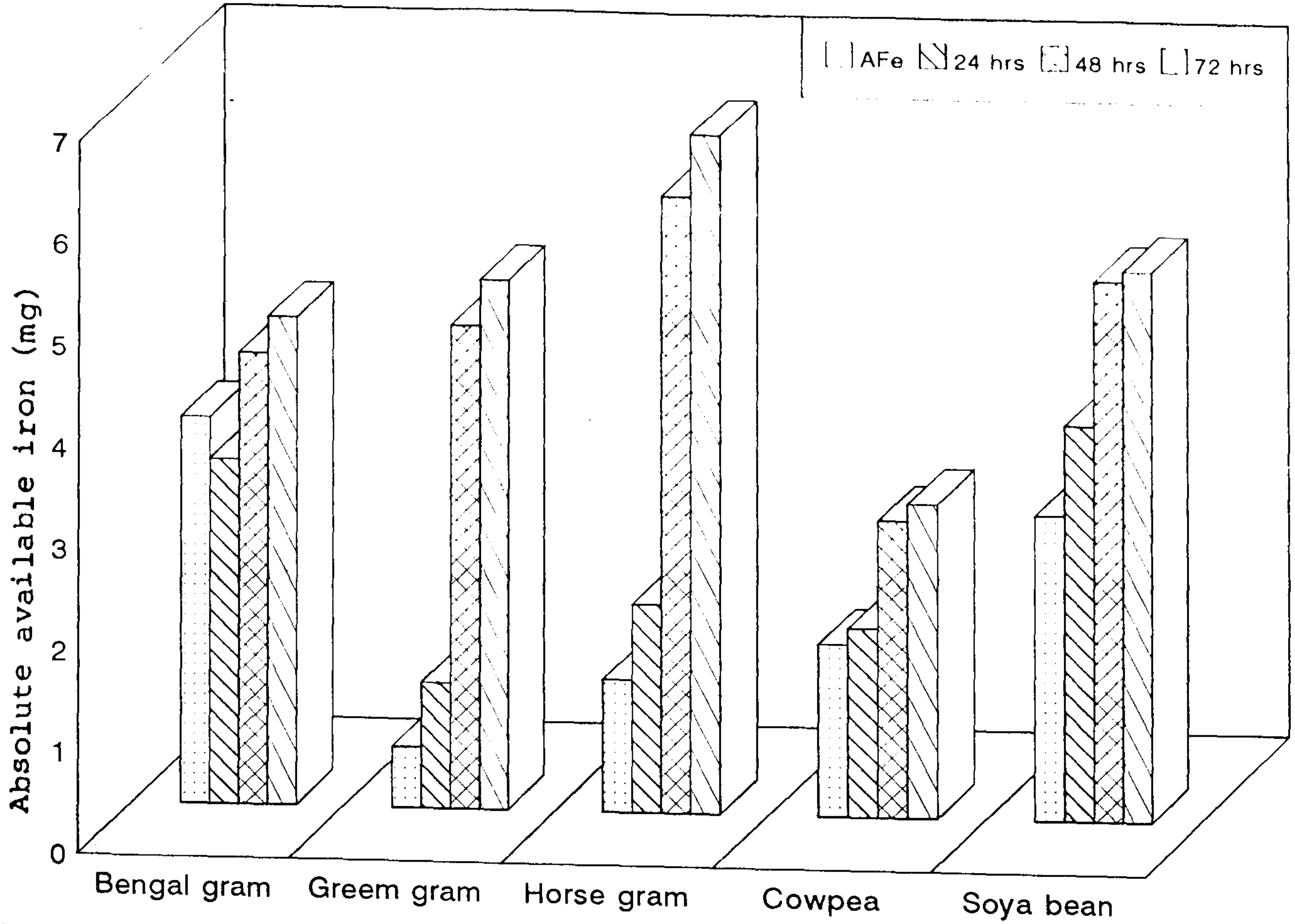
For horse gram there was a decrease in the total iron content during 24 hours of germination from 8.9 to 8.6 mg but increased to 10.2 and 11.8 mg for 48 and 72 hours of germination respectively.

For cowpea also there was a gradual increase in total iron content as the period of germination increased (5.6 > 5.9 > 8.81 > 9.5 mg/100 g). For soyabeans total iron increased from 11.6 to 13.3 mg during 24 hours of germination and then to 17.6 mg for 48 hours of germination, but there no further increase in total iron was observed during 72 hours of germination (17.6 mg/100 g).

Table 9 reveals the effect of germination of pulses on the absolute available iron.

Table 9. Effect of germination on absolute available iron in pulses

Pulses	Absolute available iron (mg/100 g)	Absolute available iron (mg/100 g) with period of germination		
		24 hours	48 hours	72 hours
Bengal gram	3.80 ± 0.005	3.39 ± 0.049	4.44 ± 0.029	4.80 ± 0.23
Green gram	0.60 ± 0.002	1.24 ± 0.009	4.76 ± 0.35	5.21 ± 0.23
Horse gram	1.31 ± 0.005	2.05 ± 0.016	6.07 ± 0.08	6.68 ± 0.29
Cowpea	1.70 ± 0.06	1.86 ± 0.016	2.92 ± 0.05	3.09 ± 0.07
Soya beans	3.00 ± 0.078	3.89 ± 0.009	5.31 ± 0.05	5.41 ± 0.13



AFe - Absolute available iron

Fig.[redacted]3Effect of germination on absolute available iron in pulses

As projected in the table, absolute available iron in pulses increased during germination. For bengal gram there was a decrease in the absolute available iron from 3.8 to 3.39 mg during 24 hours of germination but for 48 hours and 72 hours it increased to 4.44 and 4.8 mg respectively.

For green gram a steady increase was observed in absolute available iron as the period of germination progressed (0.6 > 1.24 > 4.76 > 5.21 mg). For horse gram also the absolute available iron increased from 1.31 to 2.05 during 24 hours of germination and reached a peak (6.68 mg) during 72 hours of germination. For 48 hours of germination the observed absolute available iron was 6.07 mg/100 g.

For cow pea (1.7 > 1.86 > 2.92 > 3.09) and soya beans also (3.0 > 3.89 > 5.31 > 5.41) the same trend was observed with the absolute available iron (Fig.3).

The effect of fermentation on total iron, ionisable iron and absolute available iron is presented in Table 10.

Table 10. Effect of fermentation on total iron, ionisable iron and absolute available iron from idli batter

Sample	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5	
Unfermented batter	4.79 ± 0.02	60.42 ± 0.09	51.11 ± 0.01	2.45 ± 0.009
Fermented batter	4.77 ± 0.02	60.66 ± 0.03	52.13 ± 0.01	2.49 ± 0.009
Idli prepared	4.77 ± 0.02	60.72 ± 0.3	53.74 ± 0.1	2.56 ± 0.018

Table 11. Effect of roasting of rice and wheat flour on total iron, ionisable iron and absolute available iron

Sample	Total iron (mg/100 g)		Ionisable iron (%)				Absolute available mg/100 g	
	W.R*	R*	pH 1.35		pH 7.5		W.R	R
			W.R	R	W.R	R		
Milled raw rice	2.98 ± 1.3	3.31 ± 1.20	10.25 ± 1.3	10.71 ± 1.30	9.20 ± 0.03	9.36 ± 0.003	0.274 ± 0.01	0.31 ± 0.001
Wehat flour (unprocessed)	4.42 ± 0.28	4.67 ± 0.004	40.64 ± 0.33	40.91 ± 0.004	14.17 ± 0.02	15.13 ± 0.002	0.63 ± 0.04	0.71 ± 0.0004
Wheat flour (refined	2.51 ± 0.25	2.54 ± 0.24	39.12 ± 0.69	39.85 ± 0.004	27.06 ± 0.004	27.41 ± 0.41	0.68 ± 0.05	0.70 ± 0.004

* W.R. = Without roasting
* R = Roasted

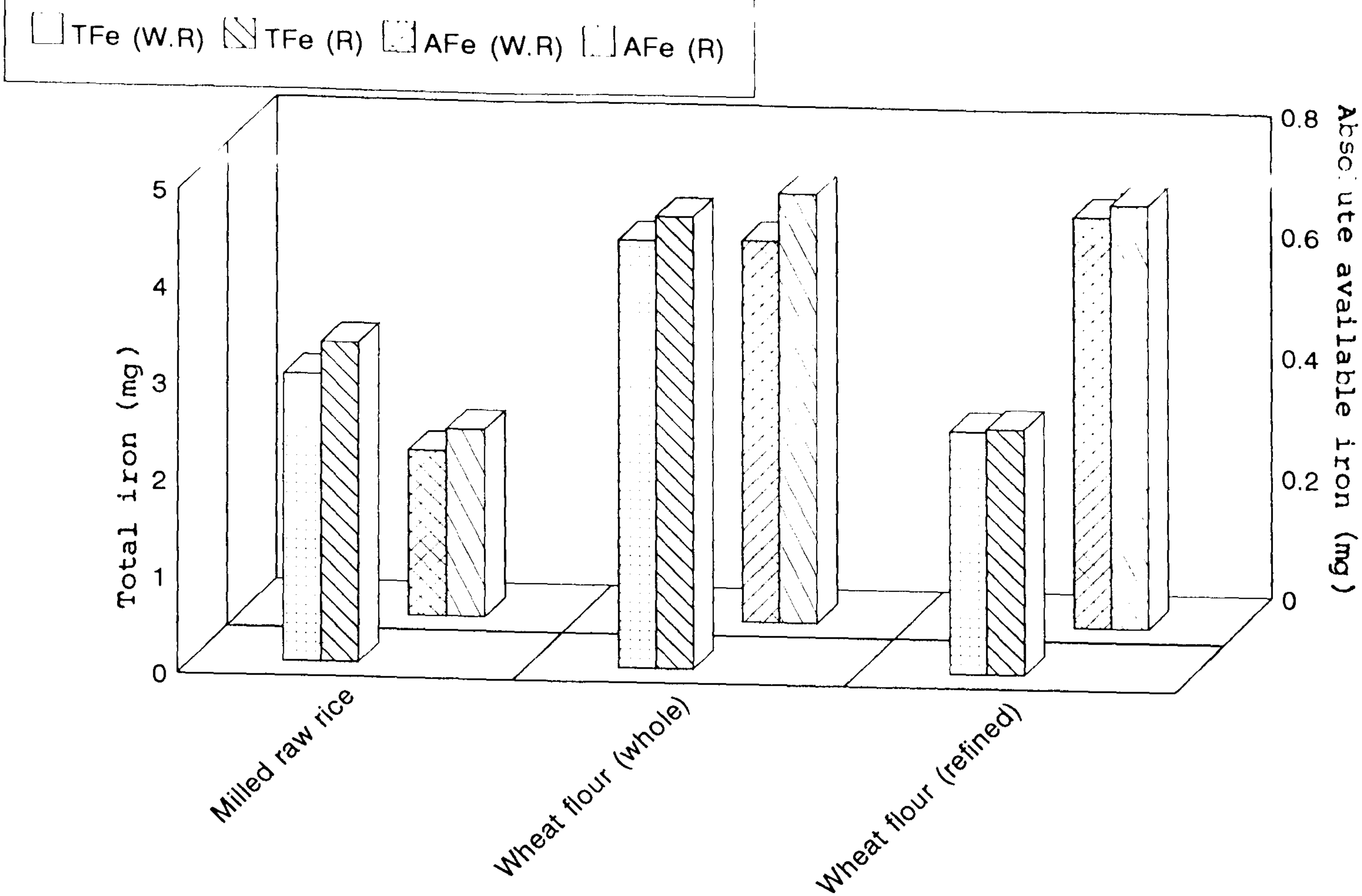


Fig. 4 [redacted]. Effecti[redacted] of roasting of rice and wheat flour on total iron and absolute available iron

TFe (W.R) - Total iron (without roasting) TFe (R) - Total iron (roasted)

AFe (W.R) - Absolute available iron (without roasting) AFe (R) - Absolute available iron (roasted)

The above table reveals that the total iron content decreased when the batter was fermented from 4.79 to 4.77 mg per cent, but then no change was observed in the total iron content when idli was prepared with the fermented batter (4.77 mg per cent). The ionisable iron at pH 1.35 steadily increased (60.42 > 60.66 > 60.72 %). The same trend was also observed with ionisable iron at pH 7.5 (51.11 > 52.13 > 53.74 %). Absolute available iron was found to be more in the prepared sample (2.56 mg/100 g). In fermented batter it was 2.49 mg per cent and for unfermented butter the least value was observed ie. 2.45 mg per cent.

Cooking methods such as roasting, frying boiling and steaming were done to find out its effect on total iron, ionisable iron and absolute available iron in cereals and pulses and all the cooking were done in glass vessels.

Table 11 projects the effect of roasting of cereals on the total iron, ionisable iron and absolute available iron.

Cooking procedure such as roasting enhanced the total iron, ionisable iron at pH 1.35 and 7.5 and also the absolute available iron. As depicted in the table after roasting total iron content of milled raw rice flour increased from 2.98 to 3.31 mg/100 g. Ionisable iron at pH 1.35 also increased from 10.25 to 10.71 per cent and at pH 7.5 the increase was from 9.2 to 9.36 per cent. Absolute available iron increased from 0.274 to 0.31 mg/100 g.

Unprocessed wheat flour showed an increase in total iron from 4.42 to 4.67 mg/100 g after roasting. Ionisable iron at pH 4.35 increased from 40.64 to 40.9[illegible] per cent and at pH 7.5 the increase was from 14.17 to 15.13 per cent. Absolute available iron also increased with roasting (0.71 mg/100 g).

Table 12. Effect of germination and roasting on total iron, ionisable iron and absolute available iron of ragi

Sample	Total iron (mg/100 g)		Ionisable iron (%)				Absolute available mg/100 g	
			pH 1.35		pH 7.5			
	W.R*	R*	W.R	R	W.R	R	W.R	R
Ragi	6.79 ± 0.02	6.90 ± 0.01	10.78 ± 0.02	10.51 ± 0.004	7.31 ± 0.01	7.81 ± 0.004	0.49 ± 0.001	0.54 ± 0.001
<u>Ragi germinated and roasted</u>								
24 hours	8.05 ± 0.048	8.08 ± 0.04	26.21 ± 0.16	26.58 ± 0.008	18.17 ± 0.01	18.19 ± 0.01	1.51 ± 0.006	1.57 ± 0.001
48 hours	12.08 ± 0.04	12.41 ± 0.04	36.40 ± 0.01	36.90 ± 0.008	25.07 ± 0.008	25.81 ± 0.08	3.03 ± 0.01	3.20 ± 0.01
72 hours	13.18 ± 0.06	13.90 ± 0.02	61.57 ± 0.02	61.59 ± 0.01	20.17 ± 0.012	20.39 ± 0.04	2.65 ± 0.01	2.83 ± 0.009

* W.R. = Without roasting
* R = Roasted

Roasting of refined wheat flour also revealed an increase in total iron (2.54 mg/100 g). Ionisable iron at ph 1.35 increased from 39.12 to 39.85 per cent and at pH 7.5 this increased from 27.06 to 27.41 per cent after roasting. There was also an increase in absolute available iron (0.70 mg/100 g) after roasting (Fig.4).

Table 12 shows the effect of germination and roasting of ragi on total iron, ionisable iron and absolute available iron.

As revealed in the table total iron of germinated ragi was found to increase with roasting. Maximum total iron was observed in germinated ragi for 72 hours after roasting (13.18 mg/100 g) but ionisable iron at pH 7.5 was found be maximum in roasted ragi after 48 hours of germination (25.81 per cent) where as it was only 20.39 per cent in the case of roasted ragi germinated for 72 hours. Absolute available iron was also found to be highest in roasted ragi after 48 hours of germination (3.2 mg per cent) followed by roasted ragi for 72 hours (2.83 mg per cent) and roasted ragi after 24 hours of germination (1.57 mg per cent)

Table 13 projects the effect of roasting on total, ionisable and absolute available iron of bengal gram and green gram.

Table 13. Effect of roasting on total, ionisable and absolute available iron of bengal gram and green gram

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
<u>Bengal gram</u>				
Whole	10.32 ± 0.004	39.20 ± 0.01	36.50 ± 0.03	3.80 ± 0.005
Roasted	9.60 ± 0.004	22.50 ± 0.02	78.00 ± 0.02	7.44 ± 0.004
<u>Green gram</u>				
Whole	7.10 ± 0.004	37.80 ± 0.008	8.20 ± 0.02	0.60 ± 0.002
Roasted	8.09 ± 0.004	88.45 ± 0.004	80.12 ± 0.16	6.48 ± 0.004

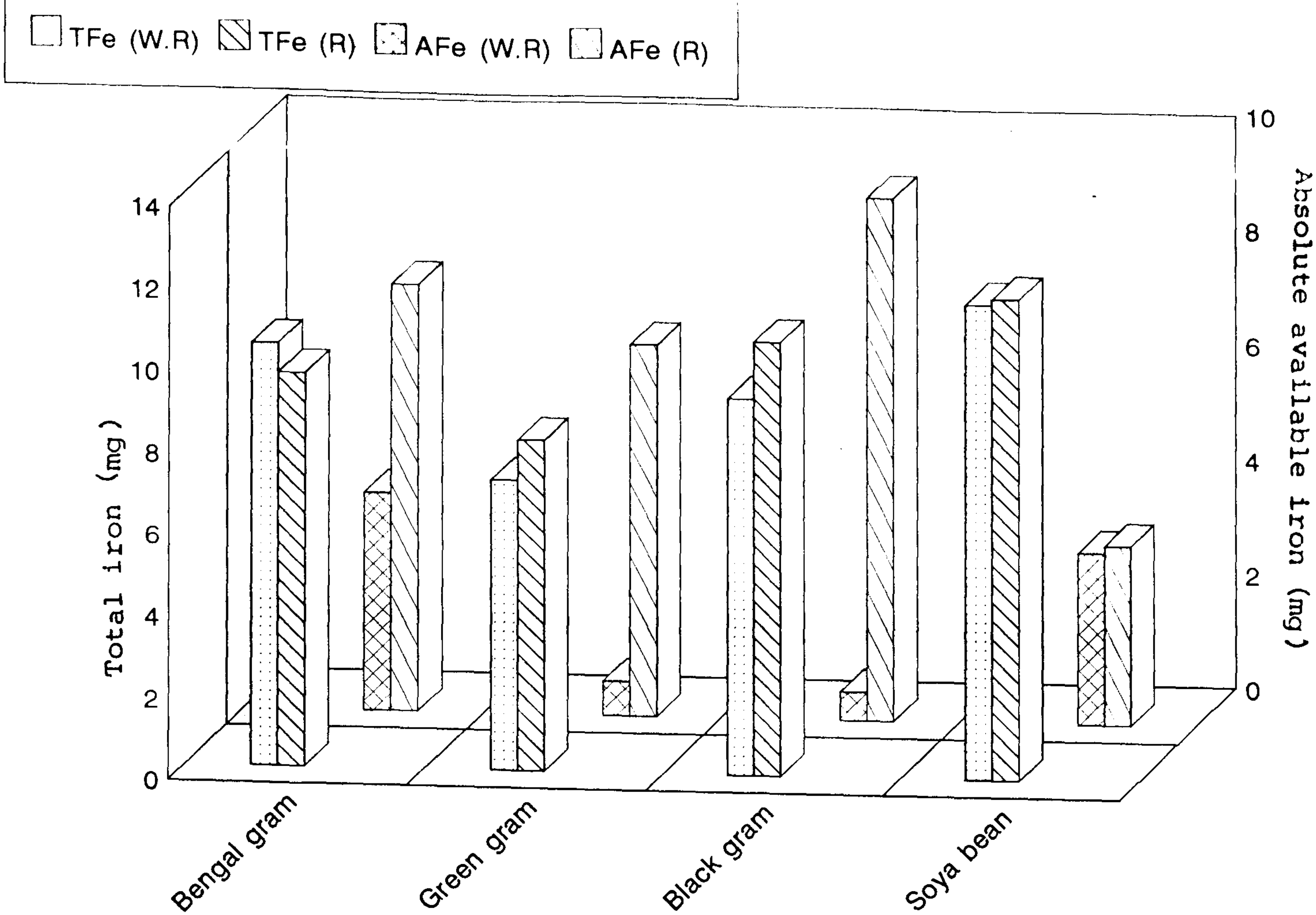


Fig.5. Effect of roasting on total and absolute available iron of pulses

TFe (W.R) - Total iron (without roasting) TFe (R) - Total iron (roasted)
AFe (W.R) - Absolute available iron (without roasting) AFe (R) - Absolute available iron (roasted)

As depicted in the table after roasting the total iron content of bengal gram reduced slightly from 10.32 to 9.60 mg/100 g. Ionisable iron at pH 1.35 also showed a reduction from 39.20 to 22.50 per cent but at pH 7.5 there was on increase from 36.5 to 78.0 per cent. The absolute available iron increased from 3.8 to 7.44 mg/100 g.

The total iron content of green gram increased from 7.10 to 8.09 mg/100 g on roasting. The ionisable iron at pH 1.35 increased from 37.8 to 88.45 per cent and at pH 7.5 it increased from 8.20 to 80.12 per cent on roasting. The absolute available iron increased from 0.60 to 6.48 mg/100 g on roasting as shown in Fig.5.

Table 14 projects the effect of roasting on total iron, ionisable and absolute iron of black gram and soya bean.

Table 14. Effect of roasting on total, ionisable and absolute available iron of black gram and soya bean

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Black gram				
Whole	9.20 ± 0.008	37.80 ± 0.030	5.90 ± 0.004	0.50 ± 0.0008
Roasted	10.60 ± 0.008	92.11 ± 0.004	86.00 ± 0.004	9.12 ± 0.0080
Soya bean				
Whole	11.60 ± 0.01	21.90 ± 0.11	26.02 ± 0.05	3.00 ± 0.078
Roasted	11.75 ± 0.02	21.81 ± 0.10	26.67 ± 0.05	3.13 ± 0.080

As seen in the table, there is a slight increase in the total iron of black gram on roasting (10.6 mg/100 g) when compared to whole (9.2 mg/100 g). An increase in the ionisable iron was seen from 37.8 to 92.11 per cent at pH 1.35. At pH 7.5 there was an increase from 5.9 to 86 per cent. The absolute available iron was shown to increase from 0.5 to 9.12 mg/100 g when roasted.

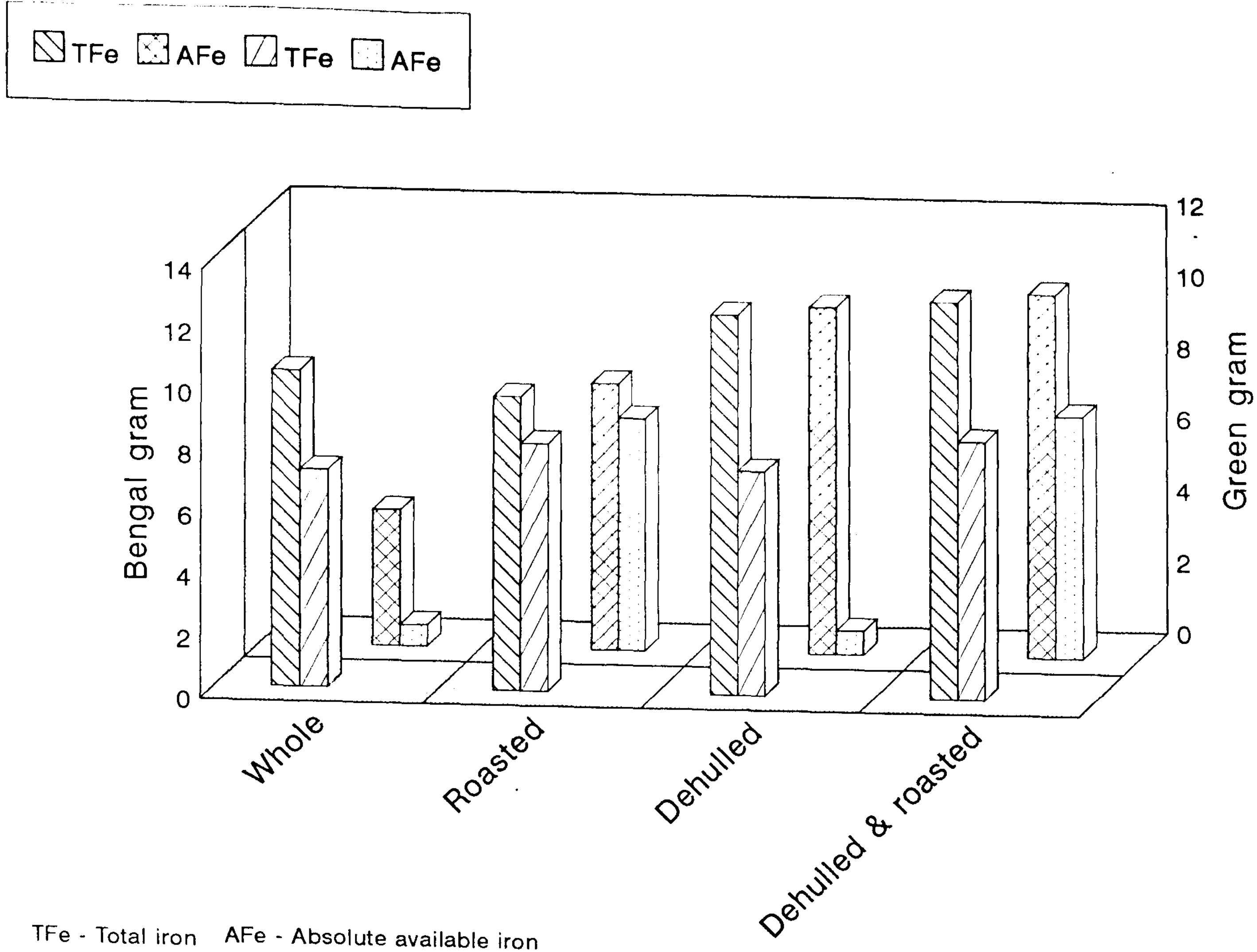
In the case of soya bean there was a slight increase in the total iron from 11.6 mg/100 g to 11.75 mg/100 g on roasting. The ionisable iron at pH 1.35 also showed only a slight increase from 21.9 to 21.81 per cent and at pH 7.5 on increase from 26.02 to 26.67 per cent as observed in Fig.5.

The absolute available iron also showed a marginal increase from 3.0 to 3.13 mg/100 g.

Table 15 shows the effect of dehulling and roasting on total, ionisable and absolute available iron of bengal gram and green gram.

Table 15. Effect of dehulled and roasting on total, ionisable and absolute available iron of bengal gram and green gram

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
<u>Bengal gram</u>				
Whole	10.32 ± 0.004	39.20 ± 0.01	36.50 ± 0.03	3.80 ± 0.005
Roasted	9.60 ± 0.010	22.50 ± 0.01	78.00 ± 0.12	7.44 ± 0.010
Dehulled	12.40 ± 0.012	78.00 ± 0.12	78.00 ± 0.04	9.70 ± 0.010
Dehulled & roasted	12.95 ± 0.012	80.45 ± 0.16	78.51 ± 0.12	10.17 ± 0.004
<u>Green gram</u>				
Whole	7.10 ± 0.004	37.80 ± 0.008	8.20 ± 0.02	0.60 ± 0.002
Roasted	8.09 ± 0.004	88.45 ± 0.004	80.12 ± 0.16	6.48 ± 0.004
Dehulled	7.32 ± 0.07	38.62 ± 0.05	9.22 ± 0.1	0.67 ± 0.009
Dehulled & roasted	8.41 ± 0.04	88.64 ± 0.06	80.51 ± 0.06	6.77 ± 0.002



TFe - Total iron AFe - Absolute available iron

Fig.6. Effect of dehulling and roasting on total and absolute available iron of Bengal gram and Green gram

As seen in Fig.6, in bengal gram the total iron increased on dehulling (12.4 mg/100 g) and dehulling and roasting (12.95) when compared to roasting (9.6 mg/100 g) as revealed from the table. The ionisable iron at pH 1.35 showed an increase to 78 per cent on dehulling. On dehulling and roasting ionisable iron increased to 80.45 per cent when compared to whole (39.20 per cent) and roasted (22.50 per cent). Ionisable iron at pH 7.5 showed only a slight increase (78.51 per cent) when compared to roasted (78 per cent) and dehulled (78 per cent). The absolute available iron was shown to increase on roasting (7.44 mg/100 g), dehulling (9.7 mg/100 g) and dehulling and roasting (10.17 mg/100 g).

As showin in the table, a slight reduction was seen in the total iron of dehulled green gram (7.32 mg/100 g) when compared to roasted green gram (8.09 mg/100 g). But on dehulling an roasting there was an increase in the total iron (8.41 mg/100 g). The ionisable iron at pH 1.35 showed a reduction on dehulling (38.62 per cent) when compared to roasting (88.45 per cent). While on dehulling and roasting an increase to 88.64 per cent was seen. At pH 7.5 a reduction of ionisable iron was seen on dehulling (9.22 per cent) when compared to dehulling and roasting an increase was seen (80.51 per cent). The absolute available iron was shown to reduce on dehulling (0.67 mg/100 g) when compared to roasting (6.48 mg/100 g) and dehulling and roasting 6.77 mg/100 g).

Table 16 projects the effect of dehulling and roasting on total ionisable and absolute available iron of black gram and soya bean.

Table 16. Effect of dehulling and roasting on total, ionisable and absolute available iron of black gram and soya bean

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Black gram				
Whole	9.20 ± 0.008	37.80 ± 0.030	5.90 ± 0.004	0.50 ± 0.0008
Roasted	10.60 ± 0.004	92.11 ± 0.004	86.00 ± 0.004	9.12 ± 0.0040
Dehulled	9.50 ± 0.004	13.90 ± 0.009	15.40 ± 0.004	1.50 ± 0.0004
Dehulled & roasted	10.73 ± 0.007	92.87 ± 0.004	86.54 ± 0.004	9.28 ± 0.0040
Soya bean				
Whole	11.60 ± 0.10	21.90 ± 0.11	26.02 ± 0.05	3.00 ± 0.078
Roasted	11.75 ± 0.21	21.81 ± 0.08	26.67 ± 0.05	3.13 ± 0.080
Dehulled	11.84 ± 0.32	21.87 ± 0.09	26.88 ± 0.10	2.59 ± 0.070
Dehulled &	12.44 ± 0.22	24.85 ± 0.08	27.01 ± 0.05	3.36 ± 0.078

As depicted in the table, in the case of black gram an increase was seen in the total iron on dehulling (9.5 mg/100 g) and dehulling and roasting (10.73 mg/100 g) when compared to whole black gram (9.2 mg/100 g). On roasting the total iron was 10.6 mg/100 g. The ionisable iron at pH 1.35 was maximum in roasted (92.11 per cent) and dehulled and roasted (92.87 per cent) when compared to whole (37.8 per cent) and dehulled (13.9 per cent). The ionsable iron at pH 7.5 was 86 per cent in roasted and 86.54 per cent in dehulled and roasted. On dehulling the ionisable iron was 15.4 per cent and in whole black gram it was 5.9 per cent. The absolute available iron increased from 0.5 mg/100 g in whole to 9.12 in roasted black gram. On dehulling a reduction was seen to 1.5 mg/100 g while on dehulling and roasting an increase was seen to 9.28 mg/100 g).

In the case of soya bean only a slight increase in the total iron was observed from whole (11.6 mg/100 g) to 11.75 mg/100 g on roasting. An increase was seen on dehulling (11.84 mg/100 g) and on dehulling and roasting (12.44 mg/100 g). The ionisable iron at pH 1.35 was maximum (24.85 per cent) in dehulled and roasted when compared to whole (21.9 per cent), roasted (21.81 per cent) and dehulled (21.87 per cent). Similarly, the ionisable iron at pH 7.5 was also more for dehulling and roasting (27.01 per cent) when compared to whole (26.02 per cent), roasted (26.67 per cent) and dehulled (26.88 per cent). The absolute available iron increased on roasting (3.13 mg/100 g) and dehulling and roasting (3.36 mg/100 g) when compared to whole (3.0 mg/100 g) or dehulled soya bean (2.59 mg/100 g).

Table 17. presents the effect of frying of rice and wheat flour on total iron, ionisable iron and absolute available iron.

Table 17. Effect of frying of rice and wheat flour on total iron, ionisable iron and absolute available iron

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Milled raw rice	2.98 ± 1.3	10.25 ± 1.3	9.20 ± 0.03	0.274 ± 0.01
Milled raw rice (fried)	3.01 ± 1.1	10.34 ± 1.24	9.31 ± 0.003	0.280 ± 0.01
Wheat flour (whole)	4.42 ± 0.28	40.64 ± 0.33	14.17 ± 0.02	0.630 ± 0.04
Wheat flour (whole fried)	4.53 ± 0.23	40.74 ± 0.32	14.71 ± 0.02	0.641 ± 0.0004
Wheat flour (refined)	2.51 ± 0.25	39.12 ± 0.69	27.06 ± 0.41	0.680 ± 0.05
Wheat flour (refined fried)	2.53 ± 0.24	39.47 ± 0.004	27.31 ± 0.40	0.691 ± 0.004

As seen in the table there is an increase in the total iron of milled raw rice on frying (3.01 mg/100 g) when compared to milled raw rice (2.98 mg/100 g). A slight increase in total iron was observed in fried wheat flour (4.53 mg/100 g) when compared to whole wheat flour (4.42 mg/100 g). However, only a marginal increase in the total iron was observed in the case of fried refined wheat flour (2.53 mg/100 g) and refined wheat flour (2.51 mg/100 g).

Considering the ionisable iron at pH 1.35 a slight increase on frying was observed in the case of milled raw rice from 10.25 per cent to 10.34 per cent (fried). Similarly whole wheat flour also showed an increase on frying from 40.64 per cent to 40.74 per cent. The same was noted in the case of refined wheat flour which showed an increase from 39.12 per cent to 39.47 per cent on frying.

At pH 7.5 the ionisable iron was found to increase in milled raw rice (9.2 per cent) on frying (9.31 per cent). The ionisable iron at pH 7.5 was 14.17 per cent for whole wheat flour and 14.71 per cent for fried whole wheat flour. Refined wheat flour showed at increase from 27.06 per cent to 27.31 per cent on frying.

The absolute available iron showed a slight increase from 0.274 mg/100 g on frying, milled raw rice. The absolute available iron increased for whole wheat flour from 0.63 mg/100 g to 0.641 mg/100 g on frying. Similarly, the absolute available iron increased in the case of refined wheat flour from 0.68 mg/100 g to 0.691 mg/100 g on frying.

The effect of frying on total, ionisable and absolute available iron of bengal gram and green gram are depicted in Table 18.

Table 18. Effect of frying on total, ionisable and absolute available iron of bengal gram and green gram

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Bengal gram				
Whole	10.32 ± 0.004	39.20 ± 0.01	36.50 ± 0.03	3.80 ± 0.005
Fried	10.33 ± 0.003	28.50 ± 0.01	70.00 ± 0.03	7.23 ± 0.004
Green gram				
Whole	7.10 ± 0.004	37.80 ± 0.008	8.20 ± 0.02	0.60 ± 0.002
Fried	8.01 ± 0.004	45.43 ± 0.004	8.24 ± 0.02	0.66 ± 0.001

As shown in the table, the total iron is maximum in the case of fried bengal gram (10.33 mg/100 g) when compared to whole bengal gram (10.32 mg/100 g), whole green gram (7.1 mg/100 g) and fried green gram (8.01 mg/ 100 g).

Ionisable iron at pH 1.35 was maximum for fried green gram (45.43 per cent) when compared to whole green gram (37.8 per cent), whole bengal gram (39.2 per cent) and fried bengal gram (28.5 per cent).

At pH 7.5 the ionisable iron was maximum for fried green gram (8.24 per cent) when compared to whole green gram (8.2 per cent), whole bengal gram (36.5 per cent) and fried bengal gram (70 per cent).

Regarding the absolute available iron, the maximum was seen in fried bengal gram (7.23 mg/100 g) and fried green gram (0.66 mg/100 g) when compared to whole bengal gram (3.8 mg/100 g) and whole green gram (0.6 mg/100 g).

Table 19 indicated the effect of frying on total, ionisable and absolute available iron of black gram and soya bean.

Table 19. Effect of frying on total, ionisable and absolute available iron of black gram and soya bean

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Black gram				
Whole	9.20 ± 0.008	37.80 ± 0.03	5.90 ± 0.004	0.50 ± 0.0008
Fried	10.10 ± 0.007	39.80 ± 0.004	8.90 ± 0.004	0.89 ± 0.0007
Soya bean				
Whole	11.60 ± 0.01	21.90 ± 0.11	26.02 ± 0.05	3.00 ± 0.078
Fried	11.64 ± 0.01	21.76 ± 0.12	26.53 ± 0.05	3.09 ± 0.08

The table indicates that the total iron was maximum in the case of fried soya bean (11.64 mg/100 g) closely followed by whole soya bean (11.60 mg/100 g) fried black gram (10.1 mg/100 g) and whole black gram (9.2 mg/100 g).

At pH 1.35 the ionisable iron was found to be maximum in fried black gram (39.8 per cent) when compared to whole black gram (37.8 per cent), whole soya bean (21.9 per cent) and fried soya bean (21.76 per cent).

The ionisable iron at pH 7.5 was highest in the case of fried soya beans (26.53 per cent) when compared to 26.02 per cent for whole soya beans. In the case of whole black gram it was 5.9 per cent where as it increased to 8.9 per cent after frying.

The absolute available iron of fried black gram increased from 0.5 to 0.89 mg where as for soya beans it increased from 3 to 3.09 mg/100 g.

Table 20 depicts the effect of dehulling and frying on total, ionisable and absolute available iron of bengal gram and green gram.

Table 20. Effect of dehulling and frying on total, ionisable and absolute available iron of bengal gram and green gram

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Bengal gram				
Whole	10.32 ± 0.004	39.20 ± 0.01	36.50 ± 0.03	3.80 ± 0.005
Whole fried	10.33 ± 0.003	28.50 ± 0.01	70.00 ± 0.03	7.23 ± 0.07
Dehulled	12.40 ± 0.012	78.00 ± 0.12	78.00 ± 0.04	9.70 ± 0.01
Dehulled & fried	12.53 ± 0.004	73.00 ± 0.01	70.01 ± 0.03	8.77 ± 0.05
Green gram				
Whole	7.10 ± 0.004	37.80 ± 0.008	8.20 ± 0.02	0.60 ± 0.002
Whole fried	8.01 ± 0.004	45.43 ± 0.004	8.24 - 0.02	0.66 ± 0.001
Dehulled	7.32 ± 0.07	38.62 ± 0.05	9.22 ± 0.1	0.67 ± 0.009
Dehulled & fried	7.38 ± 0.004	38.11 ± 0.05	9.10 ± 0.1	0.67 ± 0.008

It was observed that in the case of bengal gram, dehulling and frying had the maximum value of 12.53 mg/100 g when compared to whole (10.32 mg/100 g), fried (10.33 mg/100 g) and dehulled (12.4 mg/100 g) bengal gram.

Green gram fried had the highest value of 8.01 mg/100 g when compared to dehulled (7.32 mg/100 g) and dehulled and fried green gram (7.38 mg/100 g). The total iron of whole green gram was 7.1 mg/100 g.

The ionisable iron at pH 1.35 was maximum for dehulled bengal gram (78 per cent) followed by dehulled and fried (73 per cent), whole (39.2 per cent) and fried bengal gram 28.5 per cent.

In the case of green gram the maximum ionisable iron at pH 1.35 was observed for fried green gram (45.43 per cent) when compared to whole green gram (37.8 per cent), dehulled (38.62 per cent) and dehulled and fried (38.11 per cent).

The ionisable iron at pH 7.5 for bengal gram was high in the case of frying (70 per cent), dehulled (78 per cent) and dehulled and roasted (8.24 per cent) when compared to whole bengal gram (36.5 per cent).

The ionisable iron at pH 7.5 for green gram was maximum for fried green gram (79.87 per cent) when compared to whole (8.2 per cent), dehulled (9.22 per cent) and dehulled and fried green gram (9.10 per cent).

In case of bengal gram the absolute availableiron was maximum for dehulled bengal gram (9.7 mg/100 g) followed by dehulling and roasting (8.77 mg/100 g) frying (7.23 mg/100 g) and whole bengal gram (3.8 mg/100 g).

The absolute available iron was maximum in fried green gram (0.66 mg/100 g) when compared to dehulled and fried (0.67 mg/100 g), whole green gram 0.6 mg/100 g and dehulled green gram (0.67 mg/100 g).

Table 21 potrays the effect of dehulling and frying on total, ionisable and absolute available iron of black gram and soya bean.

Table 21. Effect of dehulling and frying on total, ionisable and absolute available iron of black gram and soya bean

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Black gram				
Whole	9.20 ± 0.008	37.80 ± 0.03	5.90 ± 0.004	0.50 ± 0.008
Whole fried	10.10 ± 0.007	39.80 ± 0.004	8.90 ± 0.004	0.89 ± 0.008
Dehulled	9.50 ± 0.004	13.90 ± 0.009	15.40 ± 0.004	1.50 ± 0.07
Dehulled & fried	9.87 ± 0.008	14.11 ± 0.009	15.90 ± 0.004	1.60 ± 0.008
Soya bean				
Whole	11.60 ± 0.01	21.90 ± 0.11	26.02 ± 0.05	3.00 ± 0.078
Whole fried	11.64 ± 0.01	21.76 ± 0.12	26.53 ± 0.05	3.09 ± 0.08
Dehulled	11.84 ± 0.32	21.87 ± 0.09	26.88 ± 0.1	2.59 ± 0.07
Dehulled & fried	11.98 ± 0.31	21.99 ± 0.11	27.01 ± 0.1	3.24 ± 0.07

As revealed in the table in black gram dehulling and frying resulted in an increase in total iron from 9.5 to 9.87 mg per cent, but total iron was maximum for whole fried black gram (10.1 mg per cent). The ionisable iron at pH 1.35 was maximum for black gram fried (39.8%) followed by whole black gram (37.8%), dehulled and fried (14.11%) and dehulled black gram (13.9%). The ionisable iron at pH 7.5 was maximum for dehulled and fried black gram (15.9 per cent) followed by dehulled black gram (15.4%) and fried black gram (8.9%). Absolute available iron also increased from 1.5 to 1.6 mg per cent when dehulled samples were fried.

For soya beans also dehulling and frying resulted in an increase in total iron from 11.84 to 11.98 mg per cent. Absolute available iron also showed an increase from 2.59 to 3.24 mg per cent after the dehulled samples were subjected to frying. While the ionisable iron at pH 1.3 increased froj 21.87 to 21.99 per cent and at pH 7.5 it increased from 26.88 to 27.01 per cent.

Table 22. portrays the effect of boiling rice (excess water methods) on total iron, ionisable iron and absolute available iron.

Table 22. Effect of boiling of rice (excess water method) on total, ionisable and absolute available iron

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Parboiled milled rice (uncooked)	3.35 ± 0.01	30.95 ± 0.06	18.16 ± 0.06	0.608 ± 0.02
Parboiled milled rice (boiled)	3.41 ± 0.01	30.99 ± 0.1	18.74 ± 0.05	0.64 ± 0.01
Raw milled rice (uncooked)	2.98 ± 1.3	10.25 ± 1.3	9.20 ± 0.03	0.274 ± 0.01
Raw milled rice (cooked)	3.11 ± 1.2	11.11 ± 1.01	9.50 ± 0.02	0.30 ± 0.01

The total iron was found to increase on boiling parboiled milled rice from 3.35 mg/100 g (uncooked) to 3.41 mg/100 g. The total iron increased from 2.98 mg/100 g in uncooked raw milled rice to 3.11 mg/100 g in boiled raw milled rice.

The ionisable iron at pH 1.35 was more for boiled parboiled milled rice (30.99 per cent) when compared to uncooked parboiled milled rice (30.95 per cent).Similarly, a slight increase was seen on boiling raw milled rice (11.11 per cent) when compared to uncooked milled rice (10.25 per cent).

The ionisable iron at pH 7.5 increased to 18.74 per cent on boiling parboiled milled rice when compared to 18.16 per cent in uncooked parboiled milled rice. An increase was also observed in cooked raw milled rice (9.5 per cent) when compared to 9.2 per cent in uncooked raw milled rice.

The absolute available iron was maximum in the case of parboiled milled rice (boiled) (0.64 mg/100 g) followed by uncooked parboiled milled rice (0.608 mg/100 g), boiled raw rice (0.30 mg/100 g) and raw milled rice (uncooked) 0.274 mg/100 g.

Table 23 depicts the effect of boiling (pressure cooking) of rice on total iron, ionisable iron and absolute available iron.

Table 23. Effect of boiling (pressure cooking) of rice on total, ionisable and absolute available iron

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Parboiled milled rice (boiled excess water)	3.41 ± 0.01	30.99 ± 0.1	18.74 ± 0.05	0.64 ± 0.01
Parboiled milled rice (pressure cooked)	3.54 ± 0.02	31.87 ± 0.14	18.94 ± 0.04	0.67 ± 0.02
Raw milled rice (boiled excess water)	3.11 ± 1.2	11.11 ± 1.02	9.50 ± 0.02	0.30 ± 0.01
Raw milled rice (pressure cooked)	3.21 ± 1.04	11.85 ± 1.01	9.85 ± 0.01	0.32 ± 0.02

The total iron was maximum for parboiled milled rice (pressure cooked) (3.54 mg/100 g) when compared to parboiled milled rice (boiled in excess water) (3.41 mg/100 g). This was followed by raw milled rice (pressure cooked) (3.21 mg/100 g) and raw milled rice (boiled in excess water) (3.11 mg/100 g).

At pH 1.35 the ionisable iron was more (31.87 per cent) for parboiled milled rice (pressure cooked) when compared to 30.99 per cent for parboiled milled rice (boiled in excess water. Similarly, the ionisable iron was more (11.85 per cent) for raw milled rice (pressure cooked) when compared to raw milled rice boiled in excess water (11.11 per cent).

The ionisable iron at pH 7.5 was more for parboiled milled rice (pressure cooked) (18.94 per cent) when compared to parboiled milled rice boiled in excess water (18.74 per cent). The ionisable iron at pH 7.5 was more for pressure cooked raw milled rice (9.85 per cent) when compared to raw milled rice (boiled in excess water) (9.5 per cent).

The absolute available iron was more for pressure cooked parboiled milled rice (0.67 mg/100 g) followed by parboiled milled rice (boiled in excess water (0.64 mg/100 g), raw milled rice (pressure cooked) (0.32 mg/100 g) and raw milled rice (boiled in excess water (0.30 mg/100 g).

Table 24 portrays the effect of soaking and boiling of pulses on the total, ionisable and absolute available iron.

Table 24. Effect of soaking and boiling of pulses on total, ionisable and absolute available iron

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Bengal gram (raw)	10.32 ± 0.004	39.20 ± 0.01	36.50 ± 0.03	3.80 ± 0.005
Bengal gram (soaked and boiled)	10.60 ± 0.004	41.04 ± 0.01	39.64 ± 0.02	4.20 ± 0.004
Green gram (raw)	7.10 ± 0.004	37.80 ± 0.008	8.20 ± 0.02	0.60 ± 0.002
Green gram (soaked and boiled)	7.41 ± 0.003	38.54 ± 0.006	19.42 ± 0.01	1.44 ± 0.002
Cowpea (raw)	5.60 ± 0.008	66.30 ± 0.2	30.70 ± 0.02	1.70 ± 0.06
Cowpea (soaked and boiled)	6.01 ± 0.006	69.84 ± 0.3	38.10 ± 0.02	2.30 ± 0.04
Horse gram (raw)	8.90 ± 0.03	28.89 ± 0.06	14.80 ± 0.004	1.31 ± 0.005
Horse gram (soaked and boiled)	9.0 ± 0.03	30.74 ± 0.05	14.91 ± 0.004	1.34 ± 0.004

As depected in the table, an increase in the total iron was observed from 10.32 mg/100 g in raw bengal gram to 10.6 mg/100 g in soaked and boiled bengal gram.

Green gram also showed an increase from 7.1 mg/100 g (raw) to 7.41 mg/100 g on soaking and boiling.

Soaked and boiled cowpea showed a total iron of 6.01 mg/100 g when compared to 5.6 mg/100 g for raw cowpea.

Horse gram, showed an increase from 8.9 mg/100 g in raw horse gram to 9.0 mg/100 g on soaking and boiling.

The ionisable iron at pH 1.35 increased from 39.20 per cent in raw bengal gram to 41.04 per cent on soaking and boling.

In the case of green gram the ionisable iron at pH 1.35 increased from 37.8 per cent (raw) to 38.54 per cent on soaking and boiling.

The ionisable iron at pH 1.35 increased to 69.84 per cent on soaking and boiling cowpea when compared to raw cowpea (66.3 per cent).

An increase from 28.89 per cent to 30.74 per cent was seen in horse gram on soaking and boiling.

The ionisable iron at pH 7.5 increased to 39.64 per cent on soaking and boiling bengal gram when compared to 36.5 per cent in raw bengal gram.

In green gram, there was an increase from 8.2 mg/100 g to 19.42 mg/100 g on soaking and boiling.

In cowpea the ionisable iron at pH 7.2 increased from 30.7 per cent to 38.1 per cent on soaking and boiling.

Similarly for horse gram an increase in the ionisable iron at pH 7.2 was seen from 14.8 to 14.91 an soaking and cooking.

An increase in the absolute available iron was observed on soaking and boiling bengal gram (4.2 mg/100 g), green gram (1.44 mg/100 g), cowpea (2.3 mg/100 g) and horse gram (1.34 mg/100 g) when compared to raw bengal gram (3.8 mg/100 g), green gram (0.6 mg/100 g), cowpea (1.7 mg/100 g) and horse gram (1.31 mg/100 g).

The effect of soaking and pressure cooking of pulses on the total iron, ionisable and absolute available iron is shown in Table 25.

Table 25. Effect of soaking and boiling (by pressure cooking) of pulses on total, ionisable and absolute available iron

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Bengal gram	10.65 ± 0.005	43.01 ± 0.01	41.63 ± 0.02	4.43 ± 0.004
Green gram	7.53 ± 0.003	39.85 ± 0.004	34.48 ± 0.01	2.60 ± 0.002
Cowpea	6.13 ± 0.004	71.10 ± 0.3	45.47 ± 0.02	2.78 ± 0.04
Horse gram	9.14 ± 0.03	33.48 ± 0.04	15.89 ± 0.004	1.45 ± 0.004

As depected in the table the total iron content for bengal gram was maximum (10.65 mg/100 g) followed by horse gram (9.14 mg/100 g), green gram (7.53 mg/100 g) and cowpea (6.13 mg/100 g).

The ionisable iron at pH 1.35 was maximum in cowpea (71.10 per cent) followed by bengal gram (43.01 per cent), greem gram (39.85 per cent) and horse gram (33.48 per cent).

At pH 7.5 the ionisable iron is maximum in the case of cowpea (45.47 per cent) followed by bengal gram (41.63 per cent), green gram (34.48 per cent) and horse gram (15.89 per cent).

The absolute available iron for bengal gram is 4.43 mg/100 g, followed by cowpea (2.78 mg/100 g), green gram (2.6 mg/100 g) and horse gram (1.45 mg/100 g).

Table 26 depicts the effect of steaming on total, ionisable and absolute available iron from idli batter.

Table 26. Effect of steaming on total, ionisable and absolute available iron from idli batter

Sample	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Idli batter	4.77 ± 0.02	60.66 ± 0.03	52.13 ± 0.01	2.49 ± 0.009
Idli steamed	4.77 ± 0.02	60.72 ± 0.3	53.74 ± 0.1	2.56 ± 0.018

Table 27. Effect of roasting of rice flour with different cooking vessels on total, ionisable and absolute available iron

	Milled raw rice flour			
Type of vessel	Total iron mg/100 g	Ionisable iron %		Absolute available iron mg/100 g
		pH 1.35	pH 7.5	
Glass vessel	3.31 ± 1.20	10.71 ± 1.30	9.36 ± 0.003	0.31 ± 0.001
Aluminium vessel	2.98 ± 1.2	10.54 ± 1.2	9.31 ± 0.002	0.28 ± 0.002
Steel vessel	3.30 ± 1.1	10.74 ± 1.2	9.43 ± 0.003	0.31 ± 0.001
Iron vessel	3.42 ± 1.3	10.74 ± 1.3	9.0 ± 0.003	0.31 ± 0.001
Mud vessel	3.31 ± 1.2	10.70 ± 1.30	9.36 ± 0.03	0.31 ± 0.001
Tufflon coated vessel	3.30 ± 1.2	10.71 ± 1.28	9.29 ± 0.03	0.31 ± 0.001

The total iron was maximum when rice flour was roasted in iron vessels (3.42 mg/100 g) followed by rice flour roasted in glass vessels and mud vessel (3.31 mg/100 g), steel and tefflon coated vessel (3.30 mg/100 g). The total iron was least for rice flour roasted in aluminium vessel (2.98 mg/100 g).

The ionisable iron at pH 1.35 was 10.74 per cent steel and iron vessels followed by glass vessel and tufflon coated vessel (10.71 per cent). The ionisable iron at pH 1.35 was 10.70 per cent for rice roasted in muc vessel and 10.54 in the case of aluminium vessel.

The ionisable iron at pH 7.5 was highest in the case of rice flour roasted in steel vessel (9.43 per cent) followed by glass vessel and mid vessel (9.36 per cent). The ionisable iron at pH 7.5 for rice roasted in aluminium vessel was 9.31 per cent and that for iron and tefflon coated vessel was 9.0 per cent and 9.29 per cent respectively.

The absolute available iron was found to be the same for rice roasted in glass vessel, steel vessel, iron vessel, mud vessel and tufflon coated vessel (0.31 mg/100 g) but was less in the case of aluminium vessel (0.28 mg/100 g).

Table 28. shows the effect of roasting of wheat flour with different cooking vessels on total, ionisable and absolute available iron.

The total iron was more in the case of wheat flour roasted in iron vessel (4.74 mg/100 g) followed by glass vessel (4.67 mg/100 g), tufflon coated vessel (4.66 mg/100 g), steel and mud vessel (4.65 mg/100 g) and least in the case of aluminium vessel (4.60 mg/100 g).

Table 28. Effect of roasting of wheat flour with different cooking vessels on total, ionisable and absolute available iron

Type of vessel	Whole wheat flour roasted			Absolute available iron (mg/100 g)
	Total iron	pH 1.35	pH 7.5	
Glass vessel	4.67 ± 0.004	40.91 ± 0.004	15.13 ± 0.002	0.71 ± 0.0004
Aluminium vessel	4.60 ± 0.003	40.51 ± 0.004	15.00 ± 0.02	0.69 ± 0.0004
Steel vessel	4.65 ± 0.004	40.87 ± 0.004	15.15 ± 0.02	0.70 ± 0.0004
Iron vessel	4.74 ± 0.003	40.95 ± 0.002	14.88 ± 0.002	0.70 ± 0.0003
Mud vessel	4.65 ± 0.004	40.88 ± 0.002	15.21 ± 0.002	0.71 ± 0.0003
Tufflon coated vessel	4.66 ± 0.003	40.92 ± 0.001	15.21 ± 0.002	0.71 ± 0.0004

At pH 1.35 the ionisable iron was maximum in the case of wheat flour roasted in iron vessel (40.95 per cent) when compared to tufflon coated vessel (40.92 per cent), glass vessel (40.92 per cent), mud vessel (40.88 mg/100 g), iron vessel (40.87 per cent) and aluminium vessels (40.91 per cent).

The ionisable iron at pH 7.5 was maximum when wheat flour was roasted in mud vessel and tufflon coated vessel (15.21 per cent) while less in the case of steel vessel (15.15 per cent), glass vessel (15.13 per cent) and aluminium vessel (15.0 per cent). The ionisable iron at pH 7.5 was least in the case of iron vessel (14.88 per cent).

The absolute available iron showed a maximum of 0.71 mg/100 g when wheat flour was roasted in glass vessel, mud vessel and tufflon coated vessel while it reduced in the case of iron and steel vessel (0.70 mg/100 g) and was leasted in the case of aluminium vessel (0.69 mg/100 g).

Table 29 portrays the effect of roasting of bengal gram and green gram using different vessels on total, ionisable and absolute available iron.

The total iron was maximum for bengal gram roasted in iron vessel (9.75 mg/100 g) followed by glass vessel and mud vessel (9.60 mg/100 g). The total iron was 9.59 mg/100 g for bengal gram cooked in tufflon coated vessel and 9.58 mg/100g for bengal cooked in steel vessel. It was least in the case of aluminium (9.21 mg/100 g).

In the case of green gram the total iron was maximum for green gram roasted in iron vessel (8.11 mg/100 g) while it was 8.09 mg/100 g in the case of

Table 29. Effect of roasting of bengal gram and green gram using different vessels on total, ionisable and absolute available iron

Type of vessel	Bengal gram roasted				Green gram roasted			
	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5			pH 1.35	pH 7.5	
Glass vessel	9.60±0.004	22.50±0.02	78.00±0.02	7.48±0.004	8.09±0.004	88.45±0.004	80.12±0.16	6.48±0.004
Aluminium vessel	9.21±0.002	22.00±	75.10±0.01	6.92±0.003	8.01±0.003	88.11±0.003	79.40±0.14	6.36±0.002
Steel vessel	9.58±0.003	22.84±0.01	77.60±0.02	7.43±0.004	8.08±0.002	88.36±0.004	79.53±0.13	6.43±0.004
Iron vessel	9.75±0.004	22.56±0.02	75.40±0.01	7.35±0.003	8.11±0.001	88.46±0.004	79.40±0.14	6.43±0.003
Mud vessel	9.60±0.003	22.54±0.02	78.00±0.01	7.48±0.002	8.09±0.004	88.51±0.004	80.01±0.15	6.47±0.004
Tufflon coated vessel	9.59±0.003	22.51±0.02	77.99±0.01	7.48±0.001	8.08±0.003	88.45±0.004	80.10±0.16	6.47±0.004

glass vessel and mud vessel. The total iron 8.08 mg/100 g for green gram roasted in tufflon coated and steel vessel and 8.01 mg/100 g in the case of aluminium vessel.

Regarding the ionisable iron at pH 1.35, bengal gram roasted in steel vessel was 22.84 per cent followed by that of iron vessel (22.56 per cent), mud vessel (22.54 per cent), tufflon coated vessel (22.51 per cent), glass vessel (22.50 per cent) and least in the case of aluminium vessel (22.0 per cent).

In the case of green gram the ionisable iron at pH 1.35 was maximum for green gram roasted in mud vessels (88.51 per cent) followed by green gram roasted in iron vessel, tufflon coated and glass vessel (88.45 per cent), steel (88.36 per cent) and least in the case of aluminium vessel(88.11 per cent).

At pH 7.5 the ionisable iron for bengal gram roasted mud vessels and glass vessels was the highest (78.00 per cent). This was closely followed by tufflon coated vessel (77.99 per cent), steel vessel (77.6 per cent), iron vessel (75.4 per cent) and aluminium vessel (75.1 per cent).

In green gram the ionisable iron at pH 7.5 was maximum for green gram roasted in glass vessel (80.12 per cent) closely followed by tufflon coated vessel (80.10 per cent) and mud vessel (80.01 per cent). The ionisable iron at pH 7.5 for green gram roasted in steel vessel was 79.53 per cent and that for iron and aluminium was 79.4 per cent respectively.

The absolute available iron for bengal gram roasted in glass vessels, mud vessel and tufflon coated vessel was maximum (7.48 mg/100 g) when compared to steel vessel (7.43 mg/100 g), iron vessel (7.35 mg/100 g) and aluminium (6.92 mg/100 g).

The absolute available iron for green gram roasted in glass vessels was maximum (6.48 mg/100 g) closely followed by mud vessel and tufflon coated vessel (6.47 mg/100 g), steel and iron vessel (6.43 mg/100 g) and aluminium vessel (6.36 mg/100 g).

Table 30 pictures the effect of dehulling and roasting of bengal gram and green gram using different vessels on total, ionisable and absolute available iron.

A slight difference was seen in the total iron of dehulled bengal gram roasted in iron vessels (12.98 mg/100 g), glass vessels, Mud vessels and tufflon coated vessels (12.95 mg/100 g), steel vessel (12.90 mg/100 g) and aluminium vessel (12.88 mg/100 g).

Similarly, the total iron for green gram dehulled and roasted in iron vessels (8.51 mg/100 g) was highest followed by glass, steel and tufflon coated vessel (8.41 mg/100 g), mud vessel (8.40 mg/100 g) and aluminium vessel (8.39 mg/100 g).

Regarding the ionisable iron at pH 1.35, bengal gram dehulled and roasted in iron vessel was maximum (81.01 per cent) closely followed by bengal gram cooked in glass vessel (80.45 per cent), mud and tufflon coated vessel (80.43 per cent), steel vessel (80.23 per cent) and aluminium vessel (80.12 per cent).

Regarding the ionisable iron at pH 1.3 for green gram on dehulling and roasting in tufflon coated vessel was 88.65 per cent, that for glass vessel was 88.64 per cent followed by mud vessel (88.63 per cent), steel vessel (88.59 per cent), iron vessel (88.58 per cent) and aluminium vessel (88.43 per cent).

Table 30. Effect of dehulling and roasting of bengal gram and green gram using different vessels on total, ionisable and absolute available iron

Type of vessel	Bengal gram dehulled and roasted				Green gram dehulled and roasted			
	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5			pH 1.35	pH 7.5	
Glass vessel	12.95±0.004	80.45±0.01	78.51±0.003	10.17±0.01	8.41±0.003	88.64±0.008	80.51±0.02	6.77±0.004
Aluminium vessel	12.88±0.003	80.12±0.02	78.13±0.003	10.06±0.01	8.39±0.002	88.43±0.007	80.31±0.02	6.73±0.004
Steel vessel	12.90±0.004	80.23±0.001	78.48±0.003	10.12±0.02	8.40±0.001	88.59±0.008	80.43±0.02	6.76±0.003
Iron vessel	12.98±0.001	81.01±0.01	78.00±0.003	10.12±0.02	8.51±0.002	88.58±0.007	79.50±0.02	6.76±0.004
Mud vessel	12.95±0.003	80.43±0.01	78.52±0.003	10.17±0.01	8.40±0.003	88.63±0.008	80.52±	6.77±0.004
Tufflon coated vessel	12.95±0.003	80.43±0.01	78.49±0.004	10.16±0.02	8.41±0.003	88.65±0.007	80.51±0.02	6.77±0.004

At pH 7.5 the ionisable iron for bengal gram dehulled and roasted in mud vessel had the highest value of 78.52 per cent when compared to glass vessel (78.51 per cent), tufflon coated vessel (78.49 per cent), steel (78.48 per cent), aluminium (78.13 per cent) and lowest in the case of iron (78.0 per cent).

The ionisable iron at pH 7.5 for green gram dehulled and roasted in mud vessel had a highest value of 80.52 per cent closely followed by glass and tufflon coated vessel (80.51 per cent), steel vessel (80.43 per cent), aluminium vessel (80.31 per cent) and lowest for iron vessel (79.50 per cent).

The absolute available iron for bengal gram dehulled and roasted in muc vessels and glass vessel was more (10.17 mg/100 g) when compared to tufflon coated vessel (10.16 mg/100 g), steel and iron vessel (10.12 mg/100 g) and aluminium vessel (10.06 mg/100 g).

The absolute available iron was more for green gram dehulled and roasted in mud vessels, tufflon coated vessel and glass vessel (6.77 mg/100 g) followed by green gram dehulled and roasted in steel and iron vessel ws (6.76 mg/100 g) and least for aluminium vessel (6.73 mg/100 g).

Table 31 gives a picture of the effect of roasting of black gram and soya beans using different vessels on total, ionisable and absolute available iron.

The total iron for black gram roasted in iron vessel was more (10.71 mg/100 g) when compared to mud and glass vessel (10.6 mg/100 g), tufflon coated vessel (10.59 mg/100 g), steel vessel (10.56 mg/100 g) and aluminium (10.53 mg/100 g).

Table 31. Effect of roasting of black gram and soyabeans using different vessels on total, ionisable and absolute available iron

Type of vessel	Bengal gram roasted				Green gram roasted			
	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5			pH 1.35	pH 7.5	
Glass vessel	10.60±0.008	92.11±0.004	86.00±0.004	9.12±0.004	11.75±0.02	21.81±0.10	26.67±0.05	3.13±0.077
Aluminium vessel	10.53 ±0.007	92.00±0.003	83.00±0.004	8.74±0.004	11.54±0.01	21.80±0.11	24.35±0.05	2.80±0.077
Steel vessel	10.56±0.008	92.10±0.003	84.50±0.004	8.92±0.003	11.69±0.02	21.80±0.10	26.56±0.05	3.10±0.076
Iron vessel	10.71±0.007	92.11±0.004	84.00±0.004	8.54±0.003	11.84±0.02	21.81±0.10	25.35±0.05	3.00±0.080
Mud vessel	10.60±0.007	92.11±0.004	86.01±0.004	9.12±0.004	11.74±0.02	21.80±0.11	26.65±0.05	3.13±0.080
Tufflon coated vessel	10.59±0.008	92.10±0.003	86.10±0.003	9.12±0.004	11.74±0.02	21.81±0.10	26.65±0.04	3.13±0.070

The total iron in the case of soya bean roasted in iron vessel was also more (11.84 mg/100 g) when compared to glass vessel (11.75 mg/100 g), mud and tufflon coated vessel (11.74 mg/100 g), steel vessel (11.69 mg/100 g) and aluminium vessel (11.54 mg/100 g).

Regarding the ionisable iron at pH 1.35 for bengal gram roasted in iron, mud and glass vessel was more (92.11 per cent) when compared to steel and tufflon coated (92.10 per cent) and aluminium vessel (92.0 per cent).

The ionisable iron at pH 1.35 for soya bean roasted in iron, tufflon coated and glass vessel was more (21.81 per cent), closely followed by mud, steel and aluminium vessel (21.80 per cent).

Regarding the ionisable iron at pH 7.5 for bengal gram roasted in tufflon coated vessel (86.1 per cent) was more when compared to mud (86.01 per cent) or glass vessl (86.0 per cent). This was closely followed by bengal gram roasted in steel vessel (84.5 per cent), iron vessel (84.0 per cent) and aluminium vessel (83 per cent).

The ionisable iron at pH 7.5 for soya bean roasted in glass vessel (26.67 per cent) was more followed by mud and tufflon vessel (26.65 per cent), steel vessel (26.56 per cent), iron vessel (25.35 per cent) and aluminium vessel (24.35 per cent).

The absolute available iron was maximum for bengal gram roasted in mud, tufflon coated and glass vessel (9.12 mg/100 g) when compared to steel vessel (8.92 mg/100 g), aluminium vessel (8.92 mg/100 g) and iron vessel (8.54 mg/ 100 g).

Table 32. Effect of dehulling and roasting of black gram and soyabeans using different vessels on total, ionisable and absolute available iron

Type of vessel	Black gram (dehulled and roasted)				Soyabean (dehulled and roasted)			
	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5			pH 1.35	pH 7.5	
Glass vessel	10.73±0.008	92.87±0.002	86.54±0.004	9.28±0.003	12.44±0.02	24.85±0.10	27.01±0.05	3.36±0.077
Aluminium vessel	10.53±0.007	92.33±0.003	84.53±0.003	8.90±0.004	11.98±0.02	24.33±0.10	25.02±0.04	3.00±0.078
Steel vessel	10.71±0.008	92.74±0.001	86.50±0.003	9.26±0.004	12.41±0.01	24.81±0.11	26.50±0.04	3.29±0.077
Iron vessel	10.85±0.008	92.53±0.001	83.24±0.004	9.03±0.003	12.58±0.02	24.82±0.11	26.00±0.03	3.27±0.077
Mud vessel	10.72±0.008	92.88±0.002	86.54±0.004	9.28±0.004	12.41±0.02	24.83±0.11	27.00±0.03	3.35±0.076
Tufflon coated vessel	10.71±0.008	92.87±0.002	86.53±0.003	9.27±0.003	12.43±0.03	24.85±0.11	27.00±0.05	3.36±0.007

The absolute available iron was maximum for soya bean roasted in mud, tufflon coated and glass vessel (3.13 mg/100 g) when compared to steel (3.10 mg/100 g), iron vessel (3.00 mg/100 g)and aluminium vessel (2.80 mg/100 g).

Table 32 shows the effect of dehulling and roasting of black gram and soya bean using different cooking vessels on total, ionisable and absolute available iron.

The total iron in black gram dehulled and roasted was more for iron vessel (10.85 mg/100 g), followed by glass vessel (10.73 mg/100 g), mud (10.72 mg/100 g). Steel and tufflon coated (10.71 mg/100 g) and aluminium (10.53 mg/100 g).

The total iron in the case of soya bean dehulled and roasted in iron vessel (12.58 mg/100 g) was more compared to glass vessel (12.44 mg/100 g), tufflon coated vessel (12.43 mg/100 g), steel and mud vessel (12.41 mg/100 g) and aluminium vessel (11.98 mg/100 g).

The ionisable iron at pH 1.3 was more in the case of black gram dehulled and roasted in mud vessel (92.88 per cent) closely followed by glass and tufflon coated vessel (92.87 mg/100 g), steel vessel (92.74 mg/100 g), iron vessel (92.53 mg/100 g) and aluminium vessel (92.33 mg/100 g).

The ionisable iron at pH 1.35 for soya bean dehulled and roasted in tufflon coated and glass vessel was more (24.85 per cent) when compared to mud (24.83 per cent), iron vessel (24.82 per cent), steel vessel (24.81 per cent) and aluminium (24.33 per cent).

Table 33. Frying of bengal gram and green gram using different vessels on total, ionisable and absolute available iron

Type of vessel	Bengal gram fried				Green gram fried			
	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5			pH 1.35	pH 7.5	
Glass vessel	10.33±0.003	28.50±0.01	70.00±0.03	7.23±0.002	8.01±0.004	45.43±0.004	8.24±0.02	0.66±0.001
Aluminium vessel	10.26±0.02	28.11±0.01	69.13±0.03	7.09±0.01	7.85±0.002	44.38±0.02	7.91±0.02	0.62±0.001
Steel vessel	10.29±0.2	28.49±0.02	70.10±0.02	7.21±0.002	7.99±0.002	45.41±0.03	8.11±0.03	0.65±0.002
Iron vessel	10.43±0.03	28.55±0.03	69.00±0.01	7.19±0.02	8.15±0.003	45.42±0.02	8.21±0.02	0.66±0.002
Mud vessel	10.32±0.3	28.50±0.02	70.00±0.01	7.22±0.03	8.00±0.002	45.42±0.01	8.23±0.01	0.66±0.001
Tufflon coated vessel	10.33±0.02	28.49±0.02	69.51±0.02	7.18± 0.004	8.01±0.004	45.43±0.01	8.23±0.01	0.66±0.001

At pH 7.5 the ionisable iron for black gram dehulled and roasted in mud and glass vessel (86.54 per cent) was more when compared to tufflon coated (86.53 per cent), steel vessel (86.50 per cent), aluminium vessel (84.53 per cent) and least in the case of iron vessel (83.24 per cent).

At pH 7.5 the ionisable iron for soya bean dehulled and roasted in glass vessel was more (27.01 per cent) closely followed by mud and tufflon coated vessel (27.0 per cent), steel (26.5 per cent), iron (26.0 per cent) and aluminium (25.02 per cent).

The absolute available iron for black gram dehulled and roasted in mud and glass vessel (9.28 mg/100 g) was more which was closely followed by tufflon coated vessel (9.27 mg/100 g), steel vessel (9.26 mg/100 g), iron vessel (9.03 mg/100 g) and least for aluminium vessel (8.90 mg/100 g).

The absolute available iron was more for soya bean dehulled and roasted in glass vessel and tufflon coated vessel (3.36 mg/100 g) followed by mud vessel (3.35 mg/100 g), aluminium vessel (3.0 gm/100 g), steel vessel (3.29 mg/100 g) and least in the case of iron vessel (3.27 mg/100 g).

Table 33 projects the effects of frying of bengal gram and green gram using different types of vessels on total, ionisable and absolute available iron.

As revealed in the table, frying of bengal gram in aluminium vessels resulted in a decrease in total iron (10.26 mg/100 g), ionisable iron at pH 7.5 (69.13%) and absolute available iron (7.09 mg/100 g). There was not much difference in the values for total iron, ionisable iron and absolute available iron in samples fried in steel, mud and tufflon coated vessels, but when the sample was

Table 34. Frying of dehulled bengal gram and green gram using different vessels on total, ionisable and absolute available iron

Type of vessel	Bengal gram dehulled and fried				Green gram dehulled and fried			
	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (%)		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5			pH 1.35	pH 7.5	
Glass vessel	12.53±0.004	73.00±0.01	70.01±0.02	8.77±0.004	7.38±0.002	38.11±0.02	9.10±0.002	0.67±0.004
Aluminium vessel	12.43±0.003	72.46±0.02	69.08±0.02	8.59±0.002	7.25±0.004	37.94±0.03	8.56±0.003	0.62±0.003
Steel vessel	12.51±0.001	73.01±0.02	70.00±0.03	8.76±0.004	7.34±0.001	38.10±0.02	8.95±0.002	0.66±0.003
Iron vessel	12.56±0.02	73.43±0.02	69.54±0.03	8.73±0.004	7.56±0.001	38.43±0.02	8.43±0.002	0.64±0.002
Mud vessel	12.53±0.03	73.01±0.01	69.98±0.03	8.77±0.004	7.39±0.001	38.10±0.04	9.11±0.004	0.67±0.004
Tufflon coated vessel	12.53±0.01	73.04±0.01	70.01±0.03	8.77±0.004	7.38±0.002	38.00±0.04	9.00±0.004	0.66±0.003

fried in iron vessel, total iron increased to 10.43 mg, but the absolute available iron decreased to 7.19 mg/100 g. When compared with the glass vessel (7.23 mg/100 g).

In case of green gram the total iron was maximum for green gram fried in iron vessel (8.15 mg/100 g) followed by glass and tufflon coated vessel (8.01 mg/100 g), mud vessel (8 mg/100 g), steel (7.99 mg/100 g) and aluminium (7.85 mg/100 g). The absolute available iron was least in the case of green gram fried in aluminium vessel (0.62 mg/100 g) and maximum for glass vessel, mud vessel, iron vessel, tufflon coated vessel (0.66 mg/100 g).

Table 34 reveals the effect of frying of dehulled bengal gram and green gram using different vessels on total, ionisable and absolute available iron.

Total iron was found to be maximum for dehulled bengal gram fried in iron vessels (12.56 mg per cent) but absolute available was less (8.73 mg per cent) when compared to samples fried in glass vessel (8.77 mg/100 g). Total iron was less in samples fried in aluminium vessel (12.43 mg per cent) but there was not much difference in total iron content with other vessels such as steel, mud and tufflon coated vessels.

Absolute available was also found to be least in samples fried in aluminium vessel (8.59 mg per cent) followed by iron vessel (8.73 mg per cent). All other vessels showed not much difference in the values for absolute available iron (8.77 mg/100 g).

The same trend was observed with green gram also.

Table 35. Frying of black gram and soya beans using different vessels on total, ionisable and absolute available iron

Type of vessel used	Black gram				Soya bean			
	Total iron (mg/100 g)	Ionisable iron %		Absolute available iron (mg/100 g)	Total iron (mg/100 g)	Ionisable iron %		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5			pH 1.35	pH 7.5	
Glass vessel	10.1 ± 0.007	39.8 ± 0.004	8.90 ± 0.004	0.89 ± 0.007	11.64 ± 0.01	21.76 ± 0.12	26.53 ± 0.13	3.09 ± 0.01
Aluminium vessel	9.8 ± 0.006	39.1 ± 0.004	8.23 ± 0.004	0.81 ± 0.0005	11.00 ± 0.01	20.73 ± 0.13	24.52 ± 0.13	2.70 ± 0.002
Steel vessel	10.0 ± 0.004	39.6 ± 0.003	8.81 ± 0.004	0.88 ± 0.007	11.63 ± 0.01	21.58 ± 0.13	26.51 ± 0.01	3.08 ± 0.004
Iron vessel	10.5 ± 0.006	39.0 ± 0.003	8.10 ± 0.004	0.85 ± 0.0006	11.83 ± 0.01	20.74 ± 0.13	23.44 ± 0.12	2.77 ± 0.004
Mud vessel	10.1 ± 0.006	39.8 ± 0.004	8.88 ± 0.004	0.89 ± 0.0007	11.63 ± 0.01	21.75 ± 0.01	26.52 ± 0.12	3.08 ± 0.002
Tufflon coated vessel	10.1 ± 0.006	39.78 ± 0.004	8.9 ± 0.004	0.89 ± 0.0007	11.64 ± 0.01	21.75 ± 0.12	26.51 ± 0.12	3.09 ± 0.01

Table 35 projects the effect of frying of blackgram and soya bean using different vessels on total, ionisable and absolute available iron.

As depicted in the table the total iron was maximum in the case of black gram cooked in iron vessel (10.5 mg/100 g) followed by that cooked in glass vessel, mud vessel and tufflon coated vessel (10.1 mg/100 g), steel vessel (10.0 mg/100 g) and least in the case of aluminium vessel (9.8 mg/100 g).

The ionisable iron at pH 1.35 was maximum for black gram cooked in glass vessel and mud vessel (39.8 per cent) followed by tufflon coated vessel (39.78 per cent), steel vessel (39.6 per cent), aluminium (39.1 per cent) and least for iron vessel (39.0 per cent).

Similarly, the ionisable iron at pH 7.5 was maximum for black gram cooked in glass and tufflon coated vessel (8.9 per cent) followed by mud vessel (8.88 per cent), steel vessel (8.81 per cent), aluminium vessel (8.23 per cent) and least in the case of iron vessel (8.10 per cent).

The absolute available iron was maximum for black gram cooked in glass, mud and tufflon coated vessel (0.89 mg/100 g) followed by steel vessel (0.88 mg/100 g), iron vessel (0.85 mg/100 g) and least in the case of aluminium vessel (0.81 mg/100 g).

On frying soya bean in different vessels it was observed that the total iron was maximum for soyabean fried in iron vessel (11.83 mg/100 g) while it was 11.64 mg/100 g in the case of glass and tufflon coated vessel and 11.63 mg/100 g in the case of mud and steel vessel, the total iron was least in the case of soya bean fried in aluminium vessel (11.0 mg/100 g).

At pH 1.35 the ionisable iron was maximum for soya bean fried in glass vessel (21.76 per cent) closely followed by mud vessel and tufflon coated vessel (21.75 per cent) and steel vessel (21.58 per cent) and least in the case of iron (20.74 per cent) and aluminium (20.73 per cent).

The ionisable iron at pH 7.5 was maximum for soya bean fried in glass vessel (26.53 per cent) followed by mud vessel (26.52 per cent) and steel and tufflon coated vessel (26.51 per cent). Soya bean fried in aluminium vessel had only 24.52 per cent ionisable iron value and it was least in the case of iron (23.44 per cent).

The absolute available iron was maximum in the case of soya bean fried in glass and tufflon coated vessel (3.09 mg/100 g) followed by mud and steel vessel (3.08 mg/100 g) and least in the case of iron (2.77 mg/100 g) and aluminium vessel (2.70 mg/100 g).

Table 36 shows the effects of frying of dehulled black gram and soya bean using different vessels on total, ionisable and absolute available iron.

As depicted in the table the total iron was found to be maximum for black gram dehulled and fried in iron vessel (9.98 mg/100 g) followed by glass, mud and tufflon coated vessel (9.87 mg/100 g), steel (9.85 mg/100 g) and least in the case of aluminium vessel (9.75 mg/100 g).

At pH 1.35 the ionisable iron was maximum in case of black gram dehulled and fried in glass and tufflon coated vessel (14.11 per cent) closely followed by mud vessel (14.1 per cent), steel vessel (14 per cent) and aluminium vessel (13.94 per cent) and least in the case of iron vessel (13.0 per cent).

Table 36. Frying of dehulled black gram and soya beans using different vessels on total, ionisable and absolute available iron

Type of vessel used	Black gram dehulled and fried				Soya bean dehulled and fried			
	Total iron (mg/100 g)	Ionisable iron %		Absolute available iron (mg/100 g)	Total iron (mg/100 g)	Ionisable iron %		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5			pH 1.35	pH 7.5	
Glass vessel	9.87 ± 0.008	14.11 ± 0.009	15.90 ± 0.004	1.57 ± 0.008	11.98 ± 0.31	21.99 ± 0.11	27.01 ± 0.1	3.24 ± 0.07
Aluminium vessel	9.75 ± 0.007	13.94 ± 0.008	13.92 ± 0.004	1.37 ± 0.007	11.53 ± 0.30	20.87 ± 0.11	25.01 ± 0.1	2.88 ± 0.06
Steel vessel	9.85 ± 0.008	14.00 ± 0.008	15.80 ± 0.003	1.56 ± 0.008	11.96 ± 0.31	21.98 ± 0.11	27.0 ± 0.1	3.23 ± 0.07
Iron vessel	9.98 ± 0.008	13.00 ± 0.004	14.01 ± 0.004	1.40 ± 0.007	12.0 ± 0.31	21.57 ± 0.11	25.73 ± 0.1	3.08 ± 0.07
Mud vessel	9.87 ± 0.008	14.10 ± 0.008	15.89 ± 0.004	1.57 ± 0.008	11.95 ± 0.31	21.98 ± 0.11	27.00 ± 0.1	3.23 ± 0.07
Tufflon coated vessel	9.87 ± 0.008	14.11 ± 0.008	15.9 ± 0.004	1.57 ± 0.008	11.98 ± 0.31	21.99 ± 0.11	27.01 ± 0.1	3.24 ± 0.007

The ionisable iron at pH 7.5 for black gram dehulled and fried was 15.9 per cent for glass vessel and tufflon coated vessel and 15.8 per cent for mud and steel vessel. For black gram dehulled and fried in iron vessel it was 14.01 per cent and that for aluminium was 13.92 per cent.

The absolute available iron was maximum for black gram dehulled and fried in glass, mud and tufflon coated vessel (1.57 mg/100 g) followed by steel vessel (1.56 mg/100 g), iron vessel (1.4 mg/100 g) and aluminium vessel (1.37 mg/100 g).

The total iron was maximum for soya bean dehulled and fried in iron vessel (12.0 mg/100 g) when compared to glass and tufflon coated vessel (11.98 mg/100 g), mud vessel (11.95 mg/100 g), steel vessel (11.96 mg/100 g) or aluminium vessel (11.53 mg/100 g).

The ionisable iron at pH 1.35 was maximum for soya bean dehulled and fried in glass and tufflon coated vessel (21.99 per cent) followed by steel and mud vessel (21.98 per cent), iron vessel (21.57 per cent) and aluminium vessel (20.87 per cent).

The ionisable iron at pH 7.5 for soya bean dehulled and fried in glass vessel, steel, mud and tufflon coated vessel was 27.01 per cent while that for iron vessel and aluminium vessel was 25.73 per cent and 25.01 per cent respectively.

The absolute available iron for soya bean dehulled and fried in glass and tufflon coated vessel (3.24 mg/100 g) was more when compared to steel and mud vessel (3.23 mg/100 g), iron vessel (3.08 mg/100 g) and aluminium vessel (2.88 mg/100 g).

Table 37 depicts the effect of boiling of parboiled and raw rice (excess water method) using different vessels on total, ionisable and absolute available iron.

As shown in the table the total iron was maximum in the case of parboiled rice boiled in iron vessel (3.48 mg/100 g) followed by glass vessel, steel and mud vessel (3.41 mg/100 g), tufflon coated vessel (3.4 mg/100 g) and aluminium vessel (3.15 mg/100 g).

In the case of raw rice also the total iron was maximum when raw rice was boiled in iron vessel (3.27 mg/100 g) followed by glass, steel and mud vessel (3.11 mg/100 g), tufflon coated vessel (3.10 mg/100 g) and aluminium vessel (3.05 mg/100 g).

The ionisable iron at pH 1.35 was maximum for parboiled rice boiled in glass vessel (30.99 per cent) followed by steel and mud vessel (30.98 per cent), iron and tufflon coated vessel (30.97 per cent) and least in the case of aluminium vessel (29.89 per cent).

The ionisable iron at pH 1.35 was maximum for raw rice boiled in glass and tufflon vessel (11.11 per cent) followed by that boiled in mud vessels (11.10 per cent), steel vessel (11.08 per cent) and iron and aluminium vessel (11.0 per cent).

The ionisable iron at pH 7.5 was more for parboiled rice boiled in steel vessel (18.75 per cent) when compared to glass and tufflon coated vessel (18.74 per cent), mud vessel (18.73 per cent), iron vessel (17.84 per cent) and aluminium vessel (17.64 per cent).

Table 37. Boiling of parboiled and raw rice (excess water method) using different vessels on total, ionisable and absolute available iron

Type of vessel used	Parboiled rice				Raw rice			
	Total iron (mg/100 g)	Ionisable iron %		Absolute available iron (mg/100 g)	Total iron (mg/100 g)	Ionisable iron %		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5			pH 1.35	pH 7.5	
Glass vessel	3.41 ± 0.01	30.99 ± 0.1	18.74 ± 0.05	0.64 ± 0.01	3.11 ± 1.2	11.11 ± 1.01	9.5 ± 0.02	0.30 ± 0.01
Aluminium vessel	3.15 ± 0.01	29.89 ± 0.1	17.64 ± 0.05	0.55 ± 0.01	3.05 ± 1.2	11.00 ± 1.01	8.9 ± 0.02	0.27 ± 0.02
Steel vessel	3.41 ± 0.01	30.98 ± 0.1	18.75 ± 0.05	0.64 ± 0.02	3.11 ± 1.15	11.08 ± 1.02	9.5 ± 0.01	0.30 ± 0.01
Iron vessel	3.48 ± 0.01	30.97 ± 0.2	17.84 ± 0.05	0.62 ± 0.02	3.27 ± 1.2	11.00 ± 1.02	9.0 ± 0.01	0.29 ± 0.01
Mud vessel	3.41 ± 0.01	30.98 ± 0.1	18.73 ± 0.04	0.64 ± 0.02	3.11 ± 1.2	11.10 ± 1.02	9.5 ± 0.01	0.30 ± 0.02
Tufflon coated vessel	3.40 ± 0.01	30.97 ± 0.1	18.74 ± 0.05	0.64 ± 0.01	3.10 ± 1.2	11.11 ± 1.01	9.5 ± 0.01	0.29 ± 0.01

The ionisable iron at pH 7.5 was maximum for raw rice boiled in glass vessel, steel, mud and tufflon coated vessel (9.5 per cent) when compared to iron vessel (9.0 per cent) or aluminium vessel (8.9 per cent).

The absolute available iron was 0.64 mg/100 g in the case of parboiled rice boiled in glass, steel, mud and tufflon coated vessel, while it was 0.62 mg/100 g for iron vessel and 0.55 mg/100 g for parboiled rice boiled in aluminium vessel.

The absolute available iron was 0.3 mg/100 g for raw rice boiled in glass vessels, steel vessel and mud vessel, while it was 0.29 mg/100 g for tufflon coated vessel and iron vessel and 0.27 mg/100 g for aluminium vessel.

Table 38 portrays the effect of soaking and boiling of bengal gram and green gram using different vessels on total, ionisable and absolute available iron.

As depicted in the table the total iron was maximum for bengal gram soaked and boiled in iron vessel (10.91 mg/100 g) followed by bengal gram cooked in mud vessels, glass vessels and tufflon coated vessels (10.6 mg/100 g), steel vessels (10.5 mg/100 g) and aluminium vessel (10.1 mg/100 g).

At pH 1.35 the ionisable iron was almost the same for bengal gram soaked and boiled in iron, steel and tufflon coated vessels (41.00 per cent), slightly more in mud vessels (41.03 per cent) and glass vessel (41.04 per cent) but less in the case of aluminium vessel (40.01 per cent).

The ionisable iron at pH 7.5 was almost the same for bengal gram soaked and boiled in glass vessel (39.64 per cent), steel vessel (39.62 per cent),

Table 38. Soaking and boiling of bengal gram and green gram using different vessels on total, ionisable and absolute available iron

Type of vessel used	Bengal gram				Green gram			
	Total iron (mg/100 g)	Ionisable iron %		Absolute available iron (mg/100 g)	Total iron (mg/100 g)	Ionisable iron %		Absolute available iron (mg/100 g)
		pH 1.35	pH 7.5			pH 1.35	pH 7.5	
Glass vessel	10.60 ± 0.004	41.04 ± 0.01	39.64 ± 0.02	4.20 ± 0.004	7.41 ± 0.003	38.54 ± 0.006	19.42 ± 0.01	1.44 ± 0.002
Aluminium vessel	10.10 ± 0.004	40.01 ± 0.01	37.31 ± 0.02	3.77 ± 0.003	7.10 ± 0.002	37.53 ± 0.005	18.10 ± 0.01	1.29 ± 0.001
Steel vessel	10.50 ± 0.004	41.00 ± 0.01	39.62 ± 0.02	4.16 ± 0.004	7.35 ± 0.001	38.52 ± 0.006	19.40 ± 0.01	1.43 ± 0.002
Iron vessel	10.91 ± 0.003	41.00 ± 0.01	37.87 ± 0.02	4.13 ± 0.004	7.48 ± 0.003	38.10 ± 0.005	19.01 ± 0.01	1.42 ± 0.002
Mud vessel	10.60 ± 0.004	41.03 ± 0.01	39.63 ± 0.02	4.20 ± 0.004	7.41 ± 0.002	38.53 ± 0.006	19.42 ± 0.01	1.44 ± 0.001
Tufflon coated vessel	10.61 ± 0.003	41.00 ± 0.01	39.65 ± 0.01	4.20 ± 0.004	7.40 ± 0.003	38.50 ± 0.006	19.42 ± 0.01	1.44 ± 0.002

mud vessel (39.63 per cent) and tufflon coated vessel (39.65 per cent) but slightly less in the case of aluminium vessel (37.31 per cent) and iron vessel (37.87 per cent).

The absolute available iron for bengal gram soaked and cooked in glass vessel, mud vessel and tufflon coated vessel (4.20 mg/100 g) was more compared to bengal gram soaked and boiled in steel vessel (4.16 mg/100 g), iron vessel (4.13 mg/100 g) or aluminium vessel (3.77 mg/100 g).

In case of green gram soaked and boiled in different vessels the total iron was maximum for green gram boiled in iron vessel (7.48 mg/100 g), followed by green gram boiled in mud vessel and glass vessel (7.41 mg/100 g), tufflon coated vessel (7.40 mg/100 g), steel (7.35 mg/100 g) and aluminium vessel (7.10 mg/ 100 g).

The ionsable iron at pH 1.3 was almost the same for green gram soaked and boiled in glass vessel (38.54 per cent), mud vessel (38.53 per cent), steel vessel (38.52 per cent), tufflon coated vessel (38.50 per cent), iron vessel (38.10 per cent) and less in the case of aluminium vessel (37.53 per cent).

At pH 7.5 the ionisable iron was more for green gram soaked and boiled in glass vessels, mud and tufflon coated vessels (19.42 per cent) followed by steel vessel (19.40 per cent) and iron vessel (19.01 per cent) and least in the case of aluminium vessel (18.10 per cent).

The absolute available iron was maximum for green gram soaked and boiled in glass, mud and tufflon coated vessels (1.44 mg/100 g) followed by steel vessel (1.43 mg/100 g) and minimum for green gram soaked and boiled in iron (1.42 mg/100 g) and aluminium vessel (1.29 mg/100 g).

3 Iron absorption enhancers and inhibitors in selected cereals and pulses and the effect of processing

Table 39 picturises the phytin phosphorus in whole and dehulled pulses.

Table 39. Phytin phosphorus in whole and dehulled pulses

Pulses	Whole	Dehulled
	Phytin P (mg/100 g)	Phytin P (mg/100 g)
Bengal gram	304.21 ± 0.044	133 ± 0.044
Green gram	206.45 ± 0.052	148 ± 0.067
Black gram	408.14 ± 0.087	169 ± 0.074
Soya bean	368.00 ± 0.043	151 ± 0.044

As seen in the table, on dehulling the phytin phosphorus in bengal gram reduces from 304.21 mg/100 g in whole to 133 mg/100 g.

In green gram the phytin phosphorus reduces from 206.45 mg/100 g in whole to 148 mg/100 g on dehulling and in Black gram a tremendous reduction is seen from 408.14 mg/100 g in whole to 169 mg/100 g on dehulling. In the case of soya bean, it reduced from 368 mg/100 g in whole to 151 mg/100 g on dehulling.

Table 40 displays the effect of germination of pulses and phytin phosphorus.

Table 40. Germination of pulses and phytin phosphorus

Pulses	Phytin P (mg/100 g)			
	Hours of germination			
	0	24	48	72
Bengal gram	304.21 ± 0.444	292.11 ± 0.021	227.00 ± 0.020	205.00 ± 0.041
Green gram	206.45 ± 0.052	159.13 ± 0.354	149.17 ± 0	149.27 ± 0
Horse gram	114.00 ± 0.55	101.74 ± 0.49	98.13 ± 0.76	93.12 ± 0.78
Cowpea	185.00 ± 1.43	173.00 ± 1.23	168.00 ± 1.44	133.00 ± 1.21
Soya bean	368.00 ± 0.043	278.00 ± 0.083	204.00 ± 0.073	162.00 ± 0.081

As seen in the table, the phytin phosphorus reduces in bengal gram from 304.21 mg/100 g to 292.11 mg.100 g on 24 hours of germination to 227 mg/100 g on 48 hours of germination to 205 mg/100 g on 72 hours of germination.

In green gram the phytin phosphorus levels reduces from 206.45 mg/100 g to 159.13 mg/100 g on 24 hours of germination. It further reduced to 149.17 on 48 hours of germination and a slight increase was seen on 72 hours of germination (149.27 mg/100 g).

In the case of horse gram the phytin phosphorus levels reduces from 114 mg/100 g to 101.74 mg/100 g on 24 hours of germination. It further reduces to 98.13 mg/100 g and 93.12 mg/100 g on 48 and 72 hours of germination.

For cowpea, the phytin phosphorus levels reduced from 185 to 173 on 24 hours of germination and this further reduced to 168 mg/100 g on 48 hours of germination to 133 mg/100 g on 72 hours of germination.

Table 41. Phytin phosphorus and ionisable iron in whole and dehulled pulses

Sample	Whole			Dehulled		
	Phytin P (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)	Phytin P (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)
Bengal gram	304.21 ± 0.044	10.32 ± 0.004	36.50 ± 0.03	133.0 ± 0.034	12.5 ± 0.012	78.00 ± 0.004
Green gram	206.45 ± 0.052	7.10 ± 0.004	8.20 ± 0.02	148.0 ± 0.015	7.32 ± 0.07	9.22 ± 0.1
Black gram	408.14 ± 0.053	9.2 ± 0.008	5.90 ± 0.004	169.0 ± 0.032	9.50 ± 0.004	15.40 ± 0.004
Soya bean	368.00 ± 0.043	11.6 ± 0.01	26.02 ± 0.05	151.0 ± 0.044	11.84 ± 0.32	26.88 ± 0.1

In the case of soya bean the phytin phosphorus reduced from 368 mg/100 g to 278 mg/100 g on 24 hours of germination to 204 mg/100 g and 162 mg/100 g on 48 and 72 hours of germination respectively.

Table 41 compares the phytin phosphorus and ionisable iron in whole and dehulled pulses.

In the case of bengal gram the phytin phosphorus reduced from 304.21 mg/100 g in whole to 133 mg/100 g on dehulling. While the total iron increased from 10.32 mg/100 g in whole to 12.4 mg/100 g on dehulling. The ionisable iron increased from 36.5 per cent in whole to 78 per cent on dehulling.

For green gram the phytin phosphorus reduced from 206.45 mg/100 g to 148 mg/100 g on dehulling while the total iron increased from 7.1 mg/100 g to 7.32 mg/100 g on dehulling. The ionisable iron increased from 8.2 per cent to 9.22 per cent on dehulling.

The phytin phosphorus for black gram reduced from 408.14 mg/100 g to 169 mg/100 g on dehulling. The total iron increased slightly from 9.2 mg/100 g to 9.5 mg/100 g on dehulling while the ionisable iron increased from 5.9 per cent in whole to 15.4 per cent on dehulling.

For soya bean the phytin phosphorus reduced from 368 mg/100 g to 151 mg/100 g on dehulling. The total iron increased slightly from 11.6 mg/100 g to 11.84 mg/100 g while the ionisable iron increased slightly from 26.02 mg/100 g to 26.88 mg/100 g on dehulling.

Table 42(a). Germination of bengal gran and green gram, phytin phosphorus and ionisable iron

Hours of germination	Bengal gram			Green gram		
	Phytin P (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)	Phytin P (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)
0	304.21 ± 0.044	10.32 ± 0.004	36.50 ± 0.03	206.45 ± 0.052	7.1 ± 0.004	8.20 ± 0.02
24	292.11 ± 0.21	11.40 ± 0.004	29.74 ± 0.02	159.13 ± 0.354	8.6 ± 0.004	14.42 ± 0.01
48	227.00 ± 0.020	11.40 ± 0.004	38.95 ± 0.03	149.17 ± 0	11.1 ± 0.003	42.89 ± 0.04
72	205.00 ± 0.041	12.70 ± 0.008	37.80 ± 0.03	149.27 ± 0	13.0 ± 0.004	40.08 ± 0.04

Table 42(a) shows the effects of germination of bengal gram and green gram on phytin phosphorus and ionisable iron.

In the case of bengal gram the phytin phosphorus reduced from 304.21 mg/100 g to 292.11 mg/100 g on 24 hours of germination to 227 mg/100 g and 205 mg/100 g on 48 and 72 hours of germination.

Regarding the total iron in bengal gram, it increased from 10.32 mg/100 g to 11.4 mg/100 g on 24 hours of germination. On 48 hours of germination it still remained 11.4 mg/100 g and then increased to 12.7 mg/100 g on 72 hours of germination.

The ionisable iron for bengal gram reduced from 36.5 per cent to 29.74 per cent on 24 hours of germination. On 48 hours of germination it increased to 38.95 per cent and then reduced to 37.8 per cent on 72 hours of germination.

On germinating green gram the phytin phosphorus reduced from 206.45 mg/100 g to 159.13 mg/100 g on 24 hours of germination. It further reduced to 149.17 mg/100 g and 149.27 mg/100 g on 48 hours and 72 hours of germination.

The total iron increased from 7.1 mg/100 g to 8.6 mg/100 g on 24 hours of germination of green gram. This further increased to 11.1 mg/100 g and 13.0 mg/100 g on 48 hours and 72 hours of germination.

On germination of green gram the ionisable iron percentage increased from 8.2 per cent to 14.42 per cent on 24 hours of germination. It further increased to 42.89 per cent on 48 hours of germination and reduced to 40.08 per cent on 72 hours of germination.

Table 42(b). Germination of horse gram and cowpea, phytin phosphorus and ionisable iron

Hours of germination	Bengal gram			Green gram		
	Phytin P (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)	Phytin P (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)
0	114.00 ± 0.55	8.9 ± 0.03	14.72 ± 0.05	185 ± 1.43	5.60 ± 0.008	30.36 ± 0.008
24	101.74 ± 0.49	8.6 ± 0.004	23.84 ± 0.05	173 ± 1.23	5.90 ± 0.004	31.53 ± 0.002
48	98.13 ± 0.76	10.2 ± 0.004	59.51 ± 0.02	168 ± 1.44	8.81 ± 0.004	33.14 ± 0.03
72	93.12 ± 0.78	11.8 ± 0.004	56.61 ± 0.001	133 ± 1.21	9.50 ± 0.02	32.53 ± 0.03

Table 42(b) depicts the effect of germination of horse gram and cowpea on phytin phosphorus and ionisable iron.

The phytin phosphorus reduced on germination of horse gram from 114 mg/100 g to 101.74 mg/100 g on 24 hours of germination. This further reduced to 98.13 mg/100 g and 93.13 mg/100 g on 48 hours and 72 hours of germination respectively.

The total iron in horse gram reduced from 8.9 mg/100 g to 8.6 mg/100 g on 24 hours of germination. On 48 hours of germination it increased to 10.2 mg/100 g and on 72 hours of germination it increased to 11.8 mg/100 g.

The ionisable iron of horse gram increase from 14.72 per cent to 23.84 per cent on 24 hours of germination. A further increase was seen to 59.51 per cent on 48 hours of germination but on 72 hours of germination it reduced to 56.61 per cent.

As seen in the table, on germination of cowpea the phytin phosphorus levels reduce from 185 mg/100 g to 173 mg/100 g, 168 mg/100 g and 133 mg/ 100 g on 24 hours, 48 hours and 72 hours of germination.

The total iron in cowpea increased slightly from 5.6 mg/100 g to 5.9 mg/100 g on 24 hours of germination. This further increased to 8.81 mg/100 g and 9.5 mg/100 g on 48 hours and 72 hours of germination.

The ionisable iron in cowpea increased from 30.36 per cent to 31.53 per cent and 33.14 per cent on 24 hours and 48 hours of germination respectively. A slight reduction to 32.53 per cent was seen on 72 hours of germination.

Table 42(c) depicts the effect of germination of soya bean on phytic acid and ionisable iron.

Table 42(c). Germination of soya beans, phytin phosphorus and ionisable iron

Hourse of germination	Phytin P (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)
0	368 ± 0.043	11.6 ± 0.01	25.86 ± 0.01
24	278 ± 0.083	13.3 ± 0.009	29.25 ± 0.02
48	204 ± 0.073	17.6 ± 0.004	30.17 ± 0.02
72	162 ± 0.081	17.6 ± 0.004	30.74 ± 0.01

In the case of soyabean, a reduction was observed in the phytin phosphorus levels from 368 mg/100 g to 278 mg/100 g, 204 mg/100 g and 162 mg/100 g on 24 hours, 48 hours and 72 hours of germination.

The total iron was found to increase from 11.6 mg/100 g to 13.3 mg/ 100 g and 17.6 mg/100 g on 24 hours and 48 hours of germination. On 72 hours of germination it still remained 17.6 mg/100 g.

The ionisable iron increased from 25.86 per cent to 29.25 per cent, 30.17 per cent and 30.74 per cent on 24 hours, 48 hours and 72 hours of germination.

Table 43 depicts the effect of germination of ragi on phytin phosphorus and ionisable iron.

Table 43. Germination of ragi, phytin phosphorus and ionisable iron

House of germination	Phytin P (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)
0	209 ± 1.12	6.79 ± 0.02	7.31 ± 0.02
24	187 ± 1.43	8.05 ± 0.048	18.17 ± 0.01
48	141 ± 1.87	12.08 ± 0.04	25.07 ± 0.01
72	140 ± 1.99	13.18 ± 0.06	20.17 ± 0.012

The phytin phosphorus reduced on germinating ragi from 209 mg/100 g to 187 mg/100 g, 141 mg/100 g and 140 mg/100 g on 24 hours, 48 hours and 72 hours of germination.

The total iron increased on germinating ragi from 6.79 mg/100 g to 8.05 mg/100 g, 12.08 mg/100 g and 13.18 mg/100 g on 24 hours, 48 hours and 72 hours of germination.

The ionisable iron increased from 7.31 per cent to 18.17 per cent and 25.07 per cent on 24 hours and 48 hours of germination. On 72 hours of germination it reduced to 20.17 per cent.

Table 44 compares the tannin content of whole and dehulled pulses.

Table 44. Tannin content of whole and dehulled pulses

Samples	Whole	Dehulled
	Tannin (mg/100 g)	Tannin (mg/100 g)
Bengal gram	298 ± 2.45	26 ± 1.78
Green gram	209 ± 3.28	30 ± 2.14
Black gram	419 ± 6.54	169 ± 7.12
Soya bean	50 ± 2.78	39 ± 1.11

As seen in the table the tannin content of whole bengal gram reduced from 298 mg/100 g to 26 mg/100 g on dehulling. In green gram the tannin content decreased from 209 mg/100 g in whole to 30 mg/100 g on dehulling. Similarly in black gram it reduced from 419 mg/100 g to 169 mg/100 g on dehulling and in soya been it decreased from 50 mg/100 g to 39 mg/100 g.

Table 45 depicts the effect of germination of pulses on tannin content.

Table 45. Germination of pulses and tannin content

Pulses	Tannin (mg/100 g)			
	Hours of germination			
	0	24	48	72
Bengal gram	298 ± 2.45	298 ± 2.45	202 ± 2.32	154 ± 1.78
Green gram	209 ± 3.28	196 ± 2.12	165 ± 2.11	133 ± 1.12
Horse gram	310 ± 3.54	288 ± 2.12	246 ± 3.12	201 ± 2.45
Cowpea	185 ± 2.12	168 ± 2.12	154 ± 2.14	148 ± 3.28
Soya bean	50 ± 2.78	43 ± 1.98	34 ± 1.11	22 ± 1.12

In bengal gram, the tannin content reduced from 298 mg/100 g to 202 mg/100 g and 154 mg/100 g on 48 hours and 72 hours of germination.

In the case of green gram the tannin content reduces from 209 mg/100 g to 196 mg/100 g, 165 mg/100 g and 133 mg/100 g on 24 hours, 48 hours and 72 hours of germination.

On germinating horse gram the tannin content reduced from 310 mg/100 g to 288 mg/100 g, 246 mg/100 g and 201 mg/100 g on 24 hours, 48 hours and 72 hours of germination.

The tannin content in cowpea reduced from 185 mg/100 g to 168 mg/100 g, 154 mg/100 g and 148 mg/100 g on 24 hours, 48 hours and 72 hours of germination.

Table 46. Tannin and ionisable iron in whole and dehulled pulses

Sample	Whole			Dehulled		
	Phytin P (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)	Phytin P (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)
Bengal gram	298 ± 0.03	10.32 ± 0.004	36.50 ± 0.03	26 ± 0.02	12.40 ± 0.012	78.00 ± 0.004
Green gram	209 ± 0.04	7.10 ± 0.004	8.20 ± 0.02	30 ± 0.04	7.32 ± 0.07	9.22 ± 0.1
Black gram	419 ± 0.004	9.20 ± 0.008	5.90 ± 0.004	169 ± 0.02	9.50 ± 0.004	15.40 ± 0.004
Soya bean	50 ± 0.05	11.60 ± 0.01	26.02 ± 0.05	39 ± 0.01	11.84 ± 0.32	26.88 ± 0.1

In case of soya bean, the tannin content reduced from 50 mg/100 g to 43 mg/100 g, 34 mg/100 g and 22 mg/100 g on 24 hours, 48 hours and 72 hours of germination.

Table 46 compares the tannins and ionisable iron in whole and dehulled pulses.

As seen from the table the tannin content of whole bengal gram reduced from 298 mg/100 g to 26 mg/100 g on dehulling. The total iron increased from 10.32 mg/100 g to 12.4 mg/100 g and the ionisable iron increased from 36.5 per cent to 78 per cent on dehulling.

In case of green gram the tannin content reduced from 209 mg/100 g in whole pulses to 30 mg/100 g on dehulling. The total iron increased slightly from 7.1 mg/100 g to 7.32 mg/100 g on dehulling and the ionisable iron increased from 8.2 per cent to 9.22 per cent.

The tannin content of whole black gram reduced from 419 mg/100 g to 169 mg/100 g on dehulling. The total iron increased from 9.2 mg/100 g to 9.5 mg/100 g on dehulling. While the ionisable iron increased from 5.9 per cent to 15.4 per cent.

In soya bean the tannin content reduced from 50 mg/100 g to 39 mg/ 100 g. The total iron increased from 11.6 mg/100 g to 11.84 mg/100 g while the ionisable iron increased from 26.02 per cent to 26.88 per cent.

Table 47(a) depits the effect of germination of bengal gram and green gram on tannin and ionisable iron.

Table 47(a). Germination of bengal gram and green gram, tannin and ionisable iron

Hours of germination	Bengal gram			Green gram		
	Tannin (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)	Tannin (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)
0	298 ± 0.51	10.32 ± 0.04	36.50 ± 0.03	209 ± 0.04	7.1 ± 0.004	8.20 ± 0.02
24	298 ± 0.42	11.40 ± 0.004	29.74 ± 0.04	196 ± 0.5	8.60 ± 0.004	14.42 ± 0.03
48	202 ± 0.52	11.40 ± 0.004	38.95 ± 0.05	165 ± 0.44	11.10 ± 0.003	42.89 ± 0.02
72	154 ± 0.34	12.70 ± 0.008	37.80 ± 0.04	133 ± 0.41	13.00 ± 0.004	40.08 ± 0.02

In case of bengal gram the tannin content reduced from 298 mg/100 g to 202 mg/100 g and 154 mg/100 g on 48 hours and 72 hours of germination. The total iron increased from 10.32 mg/100 g to 11.4 mg on 24 hours and 48 hours of germination. It further increased to 12.7 mg/100 g on 72 hours of germination. The ionisable iron reduced from 36.5 per cent to 29.74 per cent on 24 hour of germination. It increased to 38.95 per cent on 48 hours of germination and slightly reduced to 37.8 per cent on 72 hours of germination.

In case of green gram the tannin content decreased from 209 mg/100 g in whole green gram to 196 mg/100 g, 165 mg/100 g and 133 mg/100 g on 24 hours, 48 hours and 72 hours of germination.

The total iron in green gram increased from 7.1 mg/100 g to 8.6 mg/ 100 g, 11.1 mg/100 g and 13.0 mg/100 g on 24 hours, 48 hours and 72 hours of germination.

The ionisable iron in green gram increased from 8.2 per cent to 14.42 per cent and 42.89 per cent on 24 hours and 48 hours of germination. On 72 hours germination it reduced to 40.08 per cent.

Table 47(b) dipicts the effect of germination of horse gram and cowpea on tannin and ionisable iron.

In horse gram the tannin content reduce from 310 mg/100 g to 288 mg/100 g, 246 mg/100 g and 201 mg/100 g on 24 hours, 48 hours and 72 hours of germination. The total iron decreases from 8.9 mg/100 g to 8.6 mg/100 g on 24 hours of germination. On 48 hours of germination it increases to 10.2 mg/100 g and on 72 hours of germination it increases to 11.8 mg/100 g. The ionisable iron

Table 47(b). Germination of horse gram and cowpea, tannin and ionisable iron

Hours of germination	Bengal gram			Green gram		
	Tannin (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)	Tannin (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)
0	310 ± 0.02	8.9 ± 0.03	14.72 ± 0.003	185 ± 0.02	5.60 ± 0.008	30.36 ± 0.03
24	288 ± 0.01	8.6 ± 0.004	23.84 ± 0.004	168 ± 0.01	5.90 ± 0.004	31.53 ± 0.04
48	246 ± 0.01	10.2 ± 0.004	59.51 ± 0.03	154 ± 0.01	8.81 ± 0.004	33.14 ± 0.05
72	201 ± 0.02	11.8 ± 0.004	56.61 ± 0.04	148 ± 0.01	9.50 ± 0.02	32.53 ± 0.04

increases from 14.72 per cent to 23.84 per cent, 59.51 per cent and 56.61 per cent on 24 hours, 48 hours and 72 hours of germination.

In the case of cowpea the tannin content reduces from 185 mg/100 g to 168 mg/100 g, 154 mg/100 g and 148 mg/100 g on 24 hours, 48 hours and 72 hours of germination.

The total iron increase from 5.6 mg/100 g to 5.9 mg/100 g, 8.81 mg/100 g and 9.5 mg/100 g on 24 hours, 48 hours and 72 hours of germination respectively. The ionisable iron in cowpea increased from 30.36 per cent to 31.53 per cent, 33.14 per cent and 32.53 per cent on 24 hours, 48 hours and 72 hours of germination respectively.

Table 47(c) depicts the effect of germination of soyabean on tannins and ionisable iron.

Table 47(c). Germination of soya bean, tannin and ionisable iron

House of germination	Tannin (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)
0	50 ± 0.02	11.6 ± 0.01	26.02 ± 0.02
24	43 ± 0.01	13.3 ± 0.009	29.25 ± 0.02
48	34 ± 0.03	17.6 ± 0.004	30.17 ± 0.03
72	22 ± 0.02	17.6 ± 0.004	30.74 ± 0.03

As seen in the table the tannin content of soyabean reduced from 50 mg/100 g to 43 mg/100 g, 34 mg/100 g and 22 mg/100 g for 24 hours, 48 hours and 72 hours of germination respectively.

The total iron increased from 11.6 mg/100 g to 13.3 mg/100 g, 17.6 mg/100 g on 24 hours and 48 hours of germination. The total iron remained 17.6 mg/100 g even after 72 hours of germination. The ionisable iron of soya bean increased from 26.02 per cent to 29.25 per cent, 30.17 per cent and 30.74 per cent on 24 hours, 48 hours and 72 hours of germination.

Table 48 pictiures the effect of germination of ragi on tannin and ionisable iron.

Table 48. Germination of ragi, tannin and ionisable iron

House of germination	Tannin (mg/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)
0	673.87 ± 3.12	6.79 ± 0.02	7.31 ± 0.01
24	342.33 ± 2.23	8.05 ± 0.048	18.17 ± 0.02
48	208.44 ± 1.84	12.08 ± 0.04	25.07 ± 0.02
72	205.00 ± 1.63	13.18 ± 0.06	20.17 ± 0.012

The tannin content of ragi reduces from 673.87 mg/100 g to 342.33 mg/100 g, 208.44 mg/100 g and 205 mg/100 g on 24 hours, 48 hours and 72 hours of germination respectively.

The total iron of ragi increased from 6.79 mg/100 g to 8.05 mg/100 g, 12.08 mg/100 g and 13.18 mg/100 g on 24 hours, 48 hours and 72 hours of germination respectively. The ionisable iron increased from 7.31 per cent to 18.17 per cent, 25.07 per cent and 20.17 per cent on 24 hours, 48 hours and 72 hours of germination respectively.

Table 49 depicts the effect of fibre content of cereal/products on ionisable iron and absolute available iron.

Table 49. Fiber content of cereal/products, ionisable iron and absolute available iron

Sample	Crude fiber (g/100 g)	Total iron (mg/100 g)	Ionisable iron %		Absolute available iron
			pH 1.35	pH 7.5	
Rice parboiled (hand pounded)	0.223 ± 0.008	5.47 ± 0.13	30.61 ± 0.66	9.41 ± 0.28	0.51 ± 0.03
Rice parboiled (milled)	0.112 ± 0.009	3.35 ± 0.1	30.95 ± 0.1	18.16 ± 0.06	0.608 ± 0.02
Rice raw (hand pounded)	0.711 ± 0.062	4.18 ± 0.07	20.51 ± 0.33	6.26 ± 0.17	0.26 ± 0.003
Rice raw (milled)	0.118 ± 0.005	2.98 ± 1.3	10.25 ± 1.3	9.20 ± 0.03	0.274 ± 0.01
Wheat flour (whole)	2.140 ± 0.13	4.42 ± 0.28	40.64 ± 0.33	14.17 ± 0.06	0.63 ± 0.04
Wheat flour (refined)	0.414 ± 0.066	2.51 ± 0.25	39.12 ± 0.69	27.06 ± 0.42	0.68 ± 0.05

The crude fibre content of parboiled hand pounded rice was 0.223 g/100 g while the total iron was 5.47 mg/100 g and the absolute available iron was 0.51 mg/100 g. The ionisable iron at pH 1.35 was 30.61 per cent and at pH 7.5 was 9.41 per cent.

For parboiled milled rice the crude fibre content was 0.112 g/100 g while the total iron was 3.35 mg/100 g and the absolute available iron was 0.608 mg/100 g. The ionisable iron at pH 1.35 was 30.95 per cent and at pH 7.5 it was 18.16 per cent.

In the case of raw hand pounded rice the crude fibre content was 0.711 g/100 g. The total iron was 4.18 mg/100 g and the absolute available iron was 0.26 mg/100 g. At pH 1.35 the ionisable iron was 20.51 per cent and at pH 7.5 it was 6.25 per cent.

For milled raw rice the crude fibre was 0.118 g/100 g. The total iron was 2.98 mg/100 g and absolute available iron was 0.274 mg/100 g. The ionisable iron at pH 1.35 was 10.25 per cent and at pH 7.5 it was 9.2 per cent.

In whole wheat flour, crude fibre was 2.14 g/100 g while in refined wheat flour it was 0.414 g/100 g. The total iron was 2.51 mg/100 g in refined wheat flour when compared to 4.42 mg/100 g in whole wheat flour but the absolute available iron increased to 0.68 mg/100 g on refining when compared to 0.63 mg/100 g in whole wheat flour. The ionisable iron at pH 1.35 was 40.64 in whole wheat flour and 39.12 on refining and at pH 7.5 the ionisable iron was 14.17 per cent for whole wheat flour which increased to 27.06 per cent on refining.

Table 50. Fiber content of germinated ragi, ionisable iron and absolute available iron

Sample	Crude fiber (g/100 g)	Total iron (mg/100 g)	Ionisable iron %		Absolute available iron
			pH 1.35	pH 7.5	
Rai	4.08 ± 0.23	6.79 ± 0.02	10.78 ± 0.02	7.31 ± 0.04	0.49 ± 0.003
Ragi germinated (24 hours)	3.97 ± 0.05	8.05 ± 0.048	26.21 ± 0.16	18.17 ± 0.01	1.51 ± 0.006
Ragi germinated (48 hours)	3.85 ± 0.0047	12.08 ± 0.04	36.4 ± 0.01	25.07 ± 0.012	3.03 ± 0.01
Ragi germinated (72 hours)	3.90 ± 0.004	13.18 ± 0.06	61.57 ± 0.02	20.17 ± 0.012	2.65 ± 0.01

Table 50 depicts the effect of fibre content of germinated ragi on ionisable iron and absolute available iron.

The crude fibre reduced from 4.08 g/100 g to 3.97 g/100 g, 3.85 g/100 g and 3.90 g/100 g on 24 hours, 48 hours and 72 hours of germination respectively. The total iron increased from 6.79 mg/100 g to 8.05 mg/100 g, 12.08 mg/100 g and 13.18 mg/100 g on 24 hours, 48 hours and 72 hours of germination respectively. The ionisable iron at pH 1.35 increased from 10.78 per cent to 26.21 per cent, 36.4 per cent and 61.57 per cent on 24 hours, 48 hours and 72 hours of germination. At pH 7.5 the ionisable iron increased from 7.31 per cent to 18.17 per cent, 25.07 per cent and 20.17 per cent on 24 hours, 48 hours and 72 hours of germination. The absolute available iron increased from 0.49 mg/100 g to 1.51 mg/100 g, 3.03 mg/100 g and 2.65 mg/100 g on 24, 48 and 72 hours of germination.

Table 51 compares the fibre content of whole and dehulled pulses, total iron and ionisable iron.

In the case of bengal gram the fibre content reduced from 4.20 g/100 g to 1.35 g/100 g on dehulling while in black gram the fibre content reduced from 4.27 g/100 g to 0.883 g/100 g on dehulling and in greem gram the fibre content reduced from 4.64 g/100 g to 0.84 g/100 g on dehulling.

The total iron increased from 10.32 mg/100 g to 12.4 mg/100 g on dehulling bengal gram. In black gram the total iron increased from 9.2 mg/100 g to 9.5 mg/100 g on dehulling and in green gram the total iron increased from 7.1 mg/100 g to 7.32 mg/100 g on dehulling.

Table 51. Fibre content of whole and dehulled pulses, total iron and ionisable iron

Sample	Whole			Dehulled		
	Fibre (g/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)	Fiber (g/100 g)	Total iron (mg/100 g)	Ionisable iron (% of total)
Bengal gram	4.20 ± 0.08	10.32 ± 0.04	36.5 ± 0.03	1.35 ± 0.13	12.40 ± 0.12	78.00 ± 0.004
Green gram	4.27 ± 0.13	9.20 ± 0.008	5.9 ± 0.004	0.883 ± 0.04	9.50 ± 0.004	15.40 ± 0.004
Black gram	4.64 ± 0.11	7.10 ± 0.004	8.2 ± 0.02	0.84 ± 0.047	7.32 ± 0.07	9.22 ± 0.1

The ionisable iron increases from 36.5 per cent to 78 per cent in bengal gram while in black gram it increased from 5.9 per cent to 15.4 per cent and in green gram it increased from 8.2 per cent to 9.22 per cent.

Table 52 depicts the effect of fibre content of germinated pulses on total iron and ionisable iron.

In the case of bengal gram the fibre content reduced from 4.20 g/100 g to 3.85 g/100 g on 24 hours and 48 hours of germination. On 72 hours of germination it increased to 4.03 g/100 g. The total iron increased from 10.32 mg/100 g to 11.4 mg/100 g, 11.4 mg/100 g and 12.7 mg/100 g on 24 hours, 48 hours and 72 hours of germination. The ionisable iron reduced from 36.82 per cent to 29.74 per cent on 24 hours of germination. The ionisable iron then increased from 38.95 per cent and 37.77 per cent on 48 hours and 72 hours of germination.

In case of green gram, the fibre content reduced from 4.64 g/100 g to 3.82 g/100 g, 4.0 g/100 g and 4.03 g/100 g on 24, 48 and 72 hours of germination respectively. The total iron increased from 7.1 mg/100 g to 8.6 mg/100 g, 11.1 mg/100 g and 13.0 mg/100 g on 24, 48 and 72 hours of germination. The ionisable iron increases from 8.45 per cent to 14.42 per cent, 42.42 per cent and 40.08 per cent on 24, 48 and 72 hours of germination.

In the case of horse gram the fibre content reduced from 6.11 g/100 g to 4.97 g/100 g, 5.51 g/100 g and 5.75 g/100 g on 24, 48 and 72 hours of germination. The total iron reduced from 8.9 mg/100 g to 8.6 mg/100 g on 24 hours of germination. This increased to 10.2 mg/100 g and 11.8 mg/100 g on 48 hours and 72 hours of germination. The ionisable iron increased from 14.72 per cent to 23 per

Table 52. Fiber content of germinated pulses, total iron and ionisable iron

	Fibre (g/100 g)				Total iron (mg/100 g)				Ionisable iron pH 7.5%			
	Hours of germination				Hours of germination				Hours of germination			
	0	24	48	72	0	24	48	72	0	24	48	72
Bengal gram	4.20±0.08	3.85±0.1	3.84±0.1	4.03±0.04	10.32±0.004	11.4±0.004	11.40±0.004	12.7±0.008	36.82±0.005	29.74±0.02	38.95±0.03	37.77±0.03
Green gram	4.64±0.11	3.82±0.12	4.00±0.008	4.03±0.047	7.10±0.004	8.60±0.004	11.10±0.004	13.0±0.01	8.45±0.004	14.42±0.02	42.88±0.03	40.08±0.04
Horse gram	6.11±0.10	4.97±0.04	5.51±0.23	5.78±0.15	8.90±0.03	8.60±0.004	10.20±0.004	11.8±0.004	14.72±0.005	23.84±0.01	59.51±0.02	56.61±0.04
Cowpea	3.94±0.07	3.46±0.09	3.64±0.036	3.81±0.13	5.60±0.008	5.90±0.004	8.81±0.004	9.50±0.02	30.36±0.005	31.52±0.01	33.14±0.02	32.53±0.02

cent, 59.51 per cent and 56.61 per cent on 24 hours, 48 hours and 72 hours of germination.

In cowpea the fibre content reduced from 3.94 g/100 g on 24, 48 and 72 hours of germination. The total iron increased from 5.6 mg/100 g to 5.9 mg/100 g, 3.81 mg/100 g and 9.5 mg/100 g on 24, 48 and 72 hours of germination respectively. The ionisable iron increased from 30.36 per cent to 31.53 per cent, 33.14 per cent and 32.53 per cent on 24, 48 and 72 hours of germination respectively.

Table 53 depicts the effect of ascorbic acid in germinated pulses on total iron and ionisable iron.

In case of bengal gram the ascorbic acid increases from zero to 7 mg/100 g, 13 mg/100 g and 15 mg/100 g on 24, 48 and 72 hours of germination respectively. The total iron increased from 10.32 to 11.4 mg/100 g, on 24 hours and 48 hours of germination and 12.71 mg/100 g on 72 hours of germination. The ionisable iron reduced from 36.82 per cent to 29.74 per cent on 24 hours of germination. It increased to 38.95 per cent and 37.77 per cent on 48 and 72 hours of germination.

In the case of green gram, the ascorbic acid increased from zero to 7.0 mg/100 g, 13.0 mg/100 g and 14.0 mg/100 g on 24, 48 and 72 hours of germination. The total iron increased from 7.1 to 8.6 mg/100 g, 11.1 mg/100 g and 13 mg/100 g on 24, 48 and 72 hours of germination, respectively.

The ionisable iron increased from 8.45 per cent to 14.42 per cent, 42.88 per cent and 40 per cent on 24, 48 and 72 hours of germination.

Table 53. Ascorbic acid in germinated pulses, total iron and ionisable iron

	Ascorbic acid (mg/100 g)				Total iron (mg/100 g)				Ionisable iron pH 7.5%			
	Hours of germination				Hours of germination				Hours of germination			
	0	24	48	72	0	24	48	72	0	24	48	72
Bengal gram	-	9.0±0.47	13.0±0.47	15.0±0.47	10.32±0.004	11.4±0.004	11.40±0.004	12.7±0.008	36.82±0.005	29.74±0.02	38.95±0.04	37.77±0.003
Green gram	-	7.0±0.9	13.0±0.9	14.0±0.9	7.10±0.004	8.60±0.004	11.10±0.004	13.0±0.01	8.45±0.004	14.42±0.03	42.88±0.02	40.08±0.002
Horse gram	-	6.0±0.47	7.0±0.47	8.0±0.9	8.90±0.03	8.60±0.004	10.20±0.004	11.8±0.004	14.72±0.003	23.84±0.03	59.51±0.02	56.61±0.02
Cowpea	-	8.0±0.47	9.0±0.47	9.0±0.47	5.60±0.008	5.90±0.004	8.81±0.004	9.50±0.02	30.36±0.005	31.52±0.02	33.14±0.02	32.53±0.02

In case of horse gram the ascorbic acid increased from zero to 6 mg/ 100 g, 7.0 mg/100 g and 8.0 mg/100 g on 24, 48 and 72 hours of germination. The total iron at first reduced from 8.9 mg/100 g to 8.6 mg/100 g on 24 hours of germination, but increased to 10.2 mg/100 g and 11.8 mg/100 g on 48 and 72 hours of germination. The ionisable iron increased from 14.72 per cent to 23.84 per cent, 59.51 per cent and 56.61 per cent on 24, 48 and 72 hours of germination.

In the case of cowpea the ascorbic acid increased from zero to 8.0 mg/100 g, 9.0 mg/100 g and 9.0 mg/100 g on 24, 48 and 72 hours of germination. The total iron increased from 5.6 mg/100 g to 5.9 mg/100 g, 8.81 mg/100 g and 9.5 mg/100 g on 24, 48 and 72 hours of germination. The ionisable iron increased from 30.36 per cent to 31.52 per cent, 33.14 per cent and 32.53 per cent on 24, 48 and 72 hours of germination.

4 Total iron, ionisable iron and absolute available iron from local diets

Table 54 illustrates the total iron, ionisable iron and absolute available iron from three different types of diets identified as local diets for adult man.

Table 54. Total iron, ionisable iron and absolute available iron from diets

	RDA mg/day	Total iron from diet mg/day	Ionisable iron (%)		Absolute available iron mg/day
			pH 1.35	pH 7.5	
Diet I	28	31	6.82	0.92	0.284
Diet II	28	30	12.43	1.27	0.38
Diet III	28	34	21.65	6.71	2.28

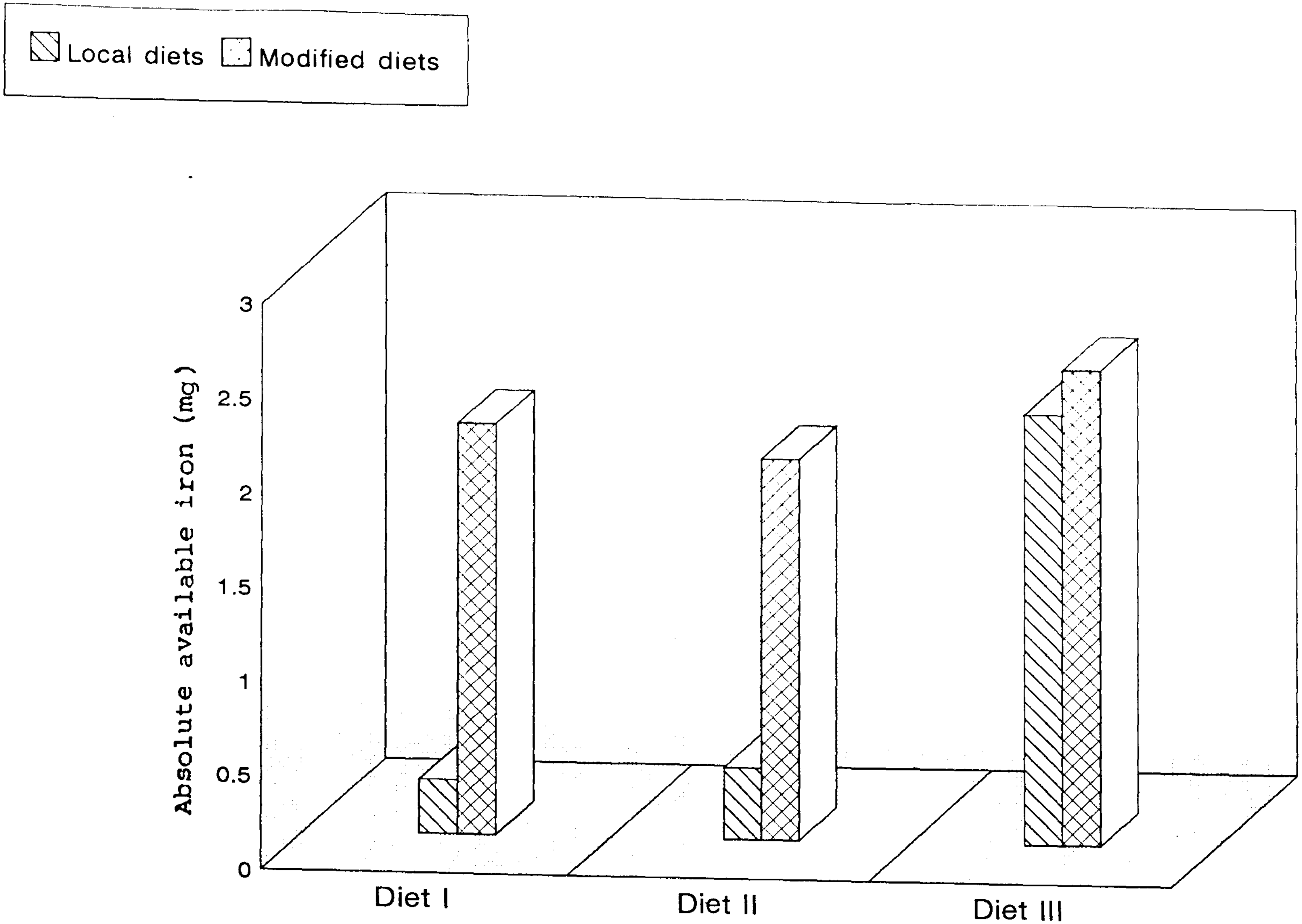


Fig.7. Comparison of absolute available iron of local and modified diets

As depicted in Table 54 maximum total iron was observed for Diet III (34 mg/day) followed by Diet I (31 mg/day). Lowest total iron value was observed for Diet II (30 mg/day). However all the total iron values were higher than the Recommended Dietary allowances for a man.

Ionisable iron at pH 7.5 was highest for Diet III (6.71 per cent) followed by Diet II (1.27 per cent). Ionisable iron was lowest for Diet I (0.92 per cent).

With regard to absolute available iron Diet III showed the maximum iron available (2.28 mg) followed by Diet II (0.38 mg). Lowest iron availability was found for Diet I (0.284 mg) (Fig.7).

5 Iron absorption enhancers and inhibitors in local diets

Table 55 presents the ascorbic acid content of the three different types of diets identified as local diets for adult man.

Table 55. Ascorbic acid content of local diets

	RDA mg/day	Ascorbic acid mg	Ionisable iron (pH 7.5) %
Diet I	40	26	0.92
Diet II	40	30	1.27
Diet III	40	28	6.71

Table 55 indicates that in all the diets ascorbic acid content was very low when compared to RDA. Maximum ascorbic acid was found in Diet II (30 mg) followed by Diet III (28 mg). Ascorbic acid was least for Diet I (26 mg).

Table 56 projects the phytin phosphorus content of the three different types of diets identified as local diets for adult man.

Table 56. Phytin phosphorus content of local diets

	Phytin phosphorus (%)	Ionisable iron (pH 7.5) (%)
Diet I	52	0.92
Diet II	47	1.27
Diet III	38	6.71

The percentage of phytin phosphorus was found to be high in Diet I (52 per cent). The lowest phytin phosphorus value was for Diet III (38 per cent). Diet II contained 47 per cent of phytin phosphorus.

Table 57 shows the tannin content of the three different types of diets identified as local diets for adult man.

Table 57. Tannin content of local diets

	Tannin (mg)	Ionisable iron (pH 7.5) (%)
Diet I	2420	0.92
Diet II	1740	1.27
Diet III	1473	6.71

As revealed in Table 57 tannin values was found highest in Diet I (2420 mg) followed by Diet II (1740 mg). Lowest tannin values were found to be in Diet III (1473 mg).

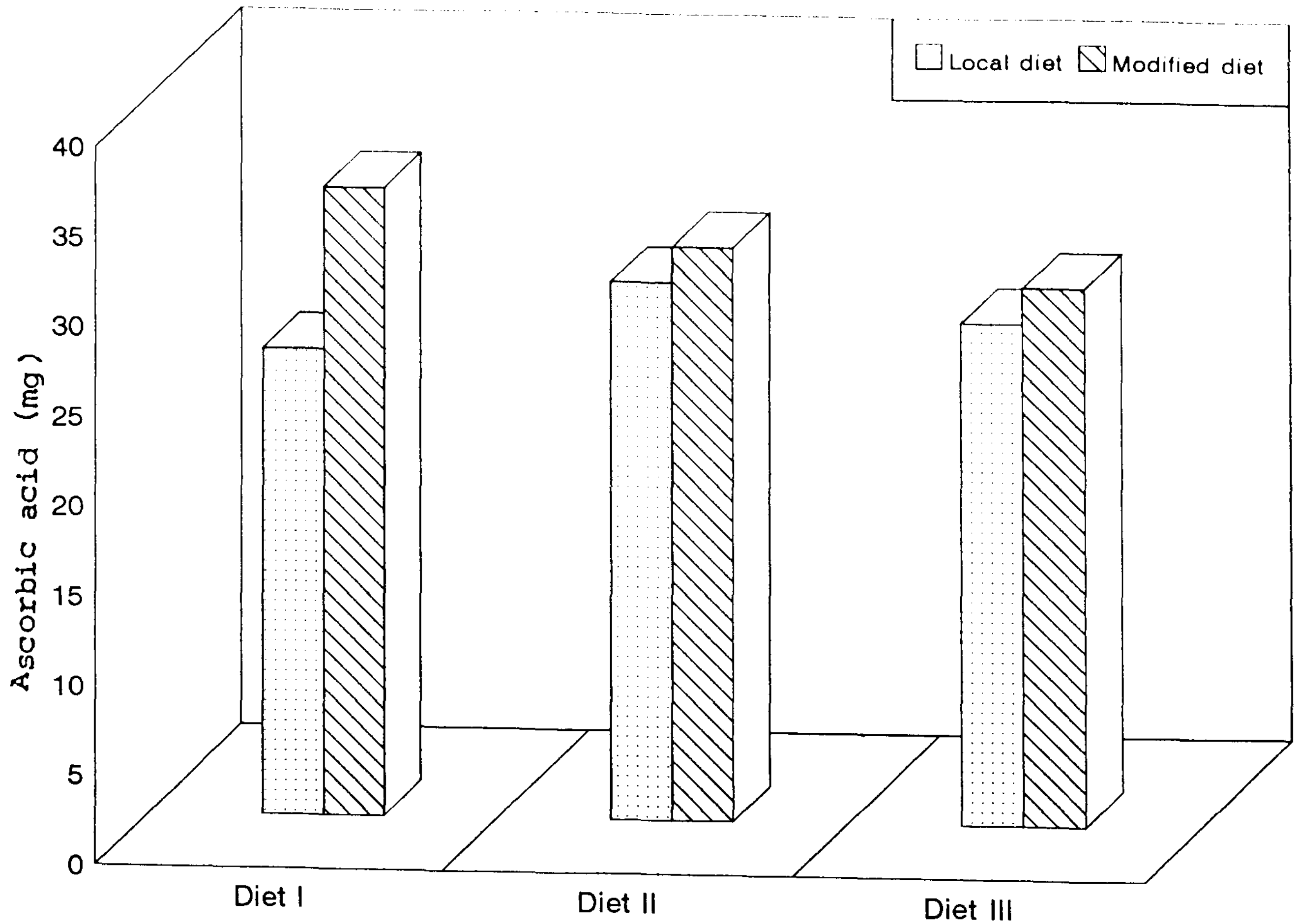


Fig.8. Comparison of ascorbic acid content of local and modified diets

Table 58 depicts the fiber content of three different types of diets identified as local diets of adult men.

Table 58. Crude fiber content of local diets

	Crude fiber (g)	Ionisable iron (pH 7.5) (%)
Diet I	0.88	0.92
Diet II	0.71	1.27
Diet III	0.84	6.71

As depicted in Table 58 crude fiber content was highest for Diet I (0.88 g) followed by Diet III (0.84 g). Diet II had the lowest crude fiber value (0.71 g).

6 Iron absorption enhancers and inhibitors in the modified diet

Ascorbic acid content of the modified local diets were estimated and the results are presented in Table 59.

Table 59. Ascorbic acid content of modified local diets

	Ascorbic acid (modified diet) mg	Ascorbic acid (local diet) mg
Diet I	35	26
Diet II	32	40
Diet III	30	28

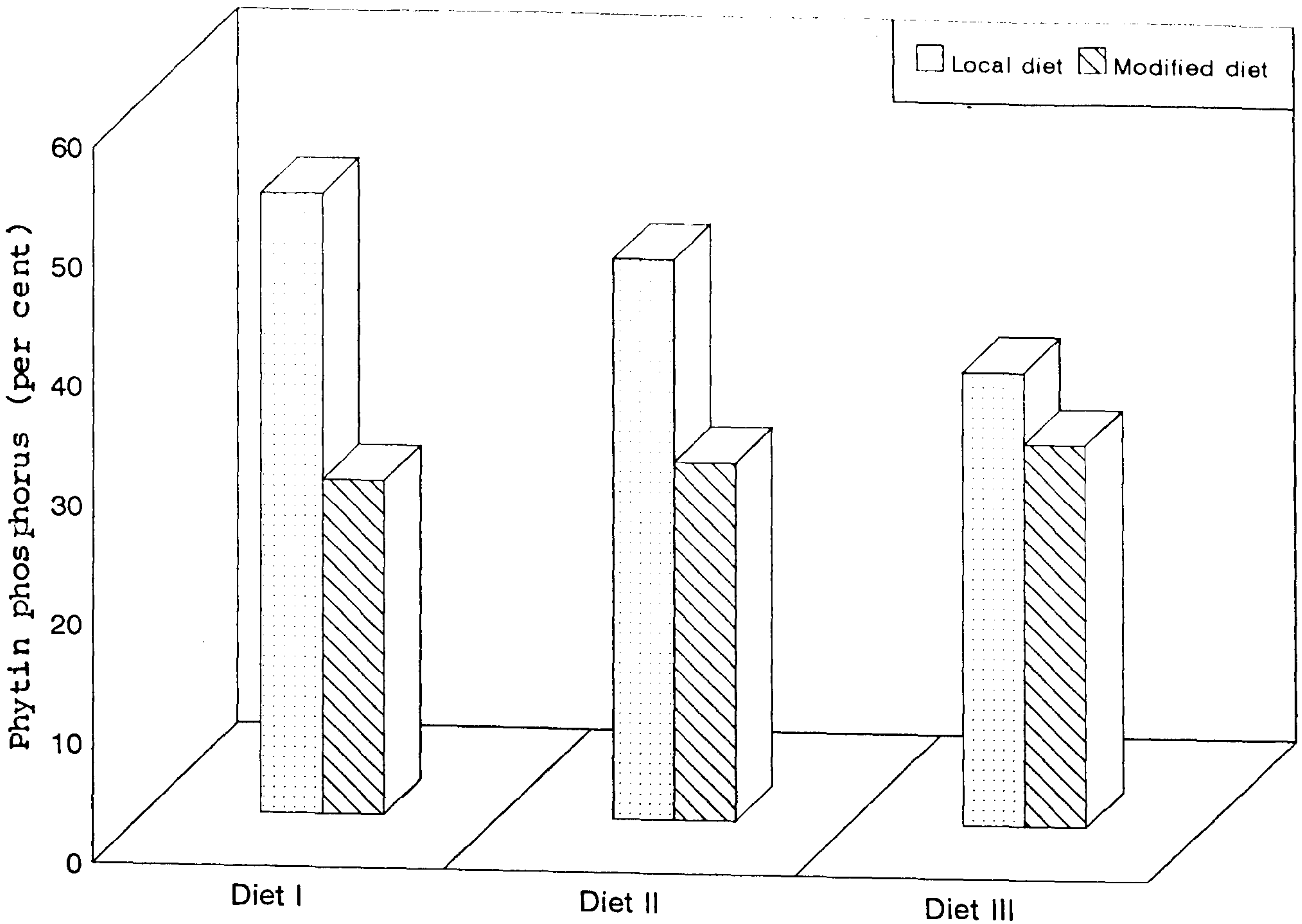


Fig.9. Phytin phosphorus content of local and modified diets

As revealed in Table 59 there was a significant increase in ascorbic acid content in modified diets. Maximum increase was observed for Diet I (35 mg) followed by Diet II (32 mg) (Fig.8).

Table 60 projects the percentage of phytin phosphorus in the modified diets.

Table 60. Phytin phosphorus content of modified diets

	Phytin phosphorus (%) (modified diet)	Phytin phosphorus (%) (local diet)
Diet I	28	52
Diet II	30	47
Diet III	33	38

As shown in Table 60, the percentage of phytin phosphorus was found to be decreasing in the modified diets. Maximum decrease was observed in Diet I (24 per cent) followed by Diet II (17 per cent). There was only a 5 per cent decrease in phytin phosphorus in Diet III. The percentage of phytin phosphorus of local and modified diets is compared in Fig.9.

Tannin content of the modified diets were estimated and is presented in Table 61.

Table 61. Tannin content of modified diets

	Tannin (mg) (modified diet)	Tannin (mg) (local diet)
Diet I	1048	2420
Diet II	1433	1740
Diet III	1470	1473

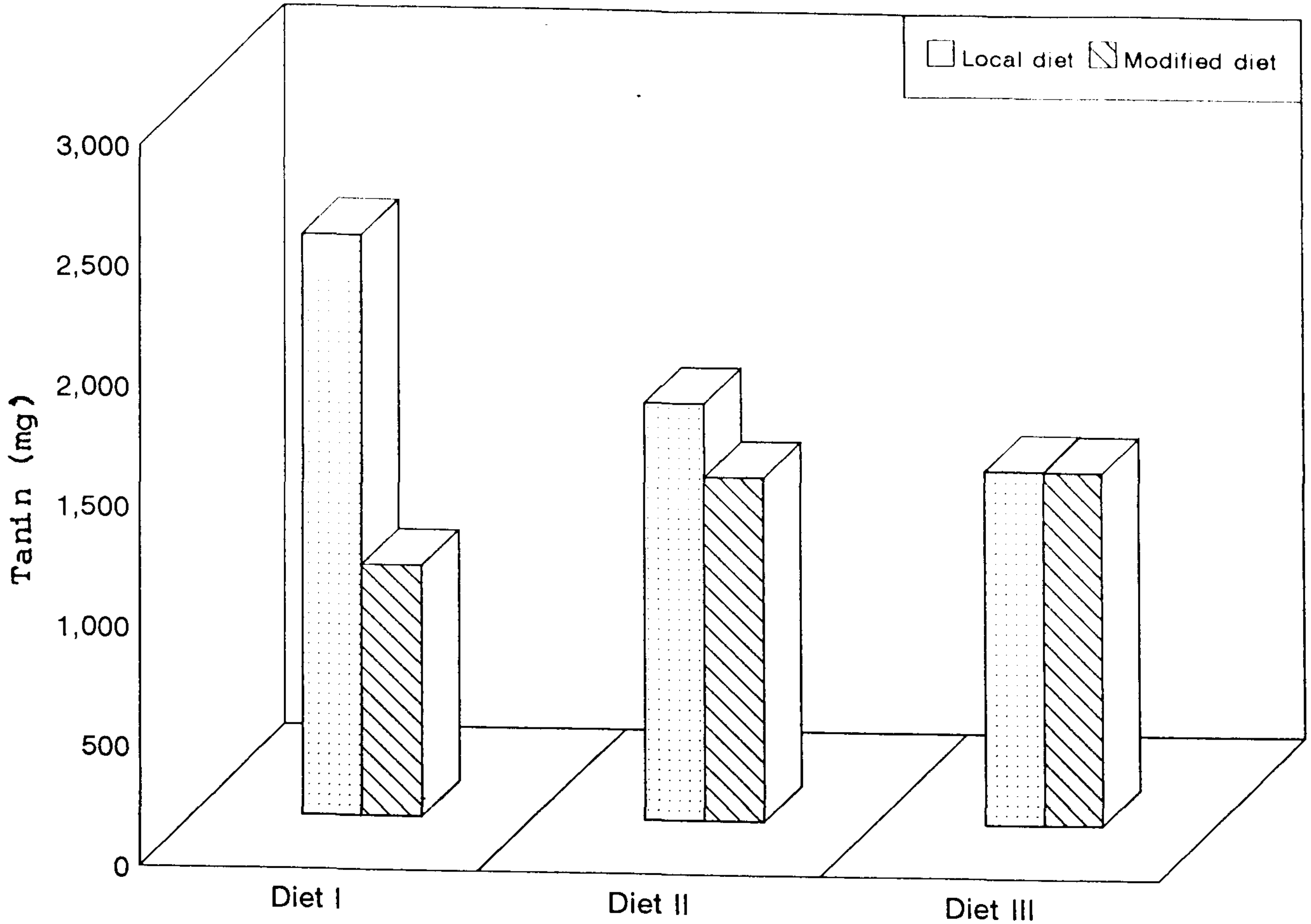


Fig.10. Comparison of Tannin content of local and modified diets

As presented in Table 61, there was also a decrease in tannin content in modified diets. Maximum decrease was observed for Diet I (1048 mg) followed by Diet II (1433 mg). There was only a slight decrease in tannin content in Diet III (1470 mg). The comparison of tannin content of local and modified diet is shown in Fig.10.

Crude fiber content of the modified diets are presented in Table 62.

Table 62. Crude fiber content of modified diets

	Crude fiber (g) (modified diet)	Crude fiber (g) (local diet)
Diet I	0.64	0.88
Diet II	0.71	0.71
Diet III	0.80	0.84

As depicted in Table 62, crude fiber was lies in Diet II (0.64 g). There was not much difference in the case of Diet II (0.71 g) and Diet III (0.80 g).

7 Total iron, ionisable iron and absolute available iron in modified diets

Total iron, ionisable iron and absolute available iron in the modified diets were estimated and is presented in Table 63.

Table 63. Total iron, ionisable iron and absolute available iron in modified diets

Modified diets	Total iron from diet mg/day	Ionisable iron (%)		Absolute available iron mg/day
		pH 1.35	pH 7.5	
Diet I	33	7.43	6.41	2.12
Diet II	32	14.08	6.33	2.02
Diet III	37	23.44	6.80	2.52

As revealed in Table 63, there was an increase in total iron in modified diets (Diet I - 33 mg, Diet II - 32 mg and Diet III - 37 mg).

With regard to ionisable iron at pH 7.5, there was a tremendous increase from 0.92 to 6.41 per cent in the case of Diet I and from 1.27 to 6.33 per cent in the case of Diet II. There was not much increase in the case of Diet III (6.80 mg).

Maximum absolute available iron was found to be in Diet III (2.52 mg) followed by Diet I (2.12 mg). Absolute available iron for Diet II was found to be 2.02 mg.

Absolute available iron iron in local diets and modified diets are presented in Table 64.

Table 64. Absolute available iron in local and modified local diets

	Absolute available iron (mg)	
	Local diet	Modified diet
Diet I	0.284	2.12
Diet II	0.38	2.02
Diet III	2.28	2.52

As presented in Table 64, the absolute available iron increased from 0.284 to 2.12 mg in Diet I and from 0.38 to 2.02 in Diet II. In Diet III the increase was only from 2.28 to 2.52 mg. The comparison of the absolute available iron from both local and modified diets is graphically represented in Fig.7.

Discussion

DISCUSSION

The discussion pertaining to the study is explained under the following headings.

Total and ionisable iron content of selected cereals and pulses

The above study indicated that among cereals the total iron was found to be maximum in ragi (6.79 mg/100 g) but the absolute available iron was found to be more in wheat flour (0.63 mg/100 g). The lowest absolute available iron was observed in raw rice (0.24 mg/100 g). The low availability of iron inspite of its high iron content in ragi may be attributed to its high fibre and tannin content. Tannin are considered responsible for the reduced availability of iron because of the formation of insoluble complexes.

Out of the six pulses analysed in the above study the total iron was found to be maximum in soya bean (11.6 mg/100 g) closely followed by bengal gram (10.23 mg/100 g) and black gram (9.2 mg/100 g). But the absolute available iron was maximum for bengal gram (3.8 mg/100 g) followed by soya bean (3.0 mg/100 g) while it was least for black gram (0.5 mg/100 g), black gram was found to be high in phytin phosphorus, and tannin levels. Soya bean was found to have a high phytin phosphorus content and also high iron availability next to bengal gram among pulses. Although it is well documented that phytate may interfere greatly with divalent metals, the effect on iron availability is still a matter of controversy.

Effect of different methods of processing, cooking and cooking utensils on the total and ionisable iron content of cereals and pulses

On analysing the iron content of processed rice it was observed that the total iron was maximum for parboiled and hand pounded rice (5.47 mg/100 g) while the absolute available iron was maximum for parboiled and milled rice (0.608 mg/100 g). This may be due to a reduction in fibre content due to milling. Reinhold (1981) had also observed that fibre rather than phytate is responsible for the low availability of iron from cereal products. The absolute available iron was least in the case of raw hand pounded rice (0.26 mg/100 g).

On processing wheat flour it was observed that the absolute available iron increased in refined wheat flour (0.68 mg/100 g) where as the total iron was more for whole wheat flour (4.42 mg/100 g). This may be because the fibre and phytic acid content reduces on refining the wheat flour making the iron more available to the body. Absolute available iron was least for ragi when compared to rice and wheat.

According to Rao and Prabhavathi (1982) legume seeds contain significant amounts of tannin which are mainly present in the seed coat. Decortication of seeds reduced tannin to a low level with a significant increase in ionisable iron. Thus, the proportion of ionisable iron increases significantly on dehulling. The present study also revealed that there was on increase in the total iron and absolute available iron of the dehulled pulses when compared to whole pulses except in the case of soya beans. The absolute available iron in whole soya bean was more (3.0 mg/100 g) when compared to dehulled soya bean (2.59 mg/ 100 g).

According to Reddy (1985) ragi had a low iron bioavailability but when ragi was germinated for 48 hours the bioavailability improved slightly. In the present study also the total iron of ragi showed a two fold increase from 6.79 mg/100 g to 13.18 mg/100 g on germinating for 72 hours. The absolute available iron increased from 0.49 mg/100 g in ragi to 3.03 mg/100 g on 48 hours of germination. However, it was observed that with increased germination time

(72 hours) the absolute available iron reduced to 2.65 mg/100 g showing that only 48 hours of germination will be enough in the case of ragi to get the maximum increase of absolute available iron. The increase in availability of iron during germination may be attributed mainly to the fact that the phytic acid present as a constituent in many cereals reduce iron absorption by forming insolute complex of ferric phytate which was made soluble during germination.

In all the selected pulses total iron and absolute available iron (mg/100 g) increased with the increase of germination time. Iron was maximum for soya bean (11.6 mg/100 g) which increased to 17.6 mg/100 g after germination for 72 hours. A two fold increase in the total iron was observed in green gram from 7.1 mg/100 g to 13.0 mg/100 g after 72 hours of germination where as only a slight increase was observed from 10.32 mg/100 g to 12.7 mg/100 g for bengal gram after 72 hours of germination.

In the present study the absolute available iron in green gram increased 8-9 fold from 0.6 mg/100 g to 5.21 mg/100 g on germination. The percentage increase was least in the case of bengal gram from 3.8 mg/100 g to 4.8 mg/100 g on germination. Antinutritional factors in legumes such as phytates and tannins which adversely affect the bioavailability of bivalent ions are broken down on germination and this may be the reason for the high absolute available iron content of pulses after germination.

According to Mc Farlane *et al.* (1990) iron absorption was found to be significantly improved on fermentation and this was adequately explained with reference to a change in the protein composition of the product. In the present study there was not much difference between the total iron of unfermented batter (4.79 mg/100 g), fermented batter (4.77 mg/100 g) and prepared idli (4.77 mg/100 g). However, the absolute available iron increased from 2.45 mg/100 g in unfermented batter to 2.49 mg/100 g in fermented batter and 2.56 mg/100 g in the prepared idli. Thus iron became more available on fermentation and cooking by steaming.

Food processing such as heat treatment may contribute to either enhanced or reduced availability. New compounds may be formed, the food environment may be altered and new external factors may be introduced. This means that the bioavailability of iron in cooked food may not reflect the bioavailability of the original food iron.

In the present study, on roasting cereals, the total iron and the absolute available iron was seen to increase. Unprocessed wheat flour had the maximum value for total iron which increased from 4.42 mg/100 g to 4.67 mg/100 g on roasting and the absolute available iron increased from 0.63 mg/100 g to 0.71 mg/100 g on roasting. Similarly roasting of milled raw rice increased the ionisable iron from 9.2 to 9.36 per cent. In Kerala, roasted milled raw rice and wheat are used in the preparation of many traditional breakfast and snack items.

Though ragi has a low iron bioavailability on germinating and roasting there was on increase in total iron as well as absolute available iron. The total iron increased from 6.79 mg/100 g to 6.9 mg/100 g on roasting. Germinated and roasted ragi showed a further increase in total iron from 8.08 mg > 12.41 mg > 13.90 mg/100 g with the period of germination when compared to roasted samples.Germinated and roasted ragi had better iron availability and the maximum value for absolute available iron was observed for ragi germinated for 48 hours and then roasted. The results are in accordance with the study conducted by Lee and Chydesdale (1975) that processing such as germination, roasting and milling showed two to four fold increase in the biologically available iron.

On roasting pulses it was observed that the total iron in bengal gram reduced from 10.32 mg/100 g to 9.6 mg/100 g while the absolute available iron almost doubled from 3.8 mg/100 g to 7.44 mg/100 g. In green gram and black gram there was a ten to fifteen fold increase in the absolute available iron. This may be due to the substantial increase in the ionisable iron due to roasting of pulse.

On dehulling and roasting of pulses, the total iron was found to be maximum for dehulling and roasting when compared to only dehulling or only roasting in all the pulses analysed. This was mainly because dehulling reduces the tannin in pulses while roasting makes the non-heme iron more available to the body. The absolute available iron increased 10-15 fold for bengal gram, green gram and black gram while only a slight increase was observed for soya bean from 3.0 mg/100 g to 3.36 mg/100 g on dehulling and roasting. One potential drawback to the use of soyabean is that it has on inhibitory effect on iron absorption in humans. Several studies had indicated that full fat soya flour, textured soya flour and isolated soya protein all markedly reduced non heme iron absorption. The nature of substance in soyabean that inhibit iron absorption is not clear. However, soy protein products are known to contain appreciable quantities of phytate, which is on important inhibitor of iron absorption in wheat bron.

On frying rice and wheat it was observed that there was a slight increase in both total iron and absolute available iron in raw rice, whole wheat and refined wheat flour. A similar result was observed on frying pulses which only in black gram the absolute available iron doubled from 3.8 mg/100 g to 7.23 mg/100 g on frying.

When pulses were dehulled and fried both the total iron and absolute available iron were maximum for dehulled and fried pulses when compared to whole, fried or dehulled pulses. Bengal gram being an exception where the absolute available iron was more for dehulled bengal gram (9.7 mg/100 g) when compared to dehulled and fried bengal gram (8.77 mg/100 g). Dehulling reduced the tannin, phytin phosphorus and fibre levels and frying after dehulling further improves the iron availability.

Effect of boiling of rice (excess water method) showed that both the total iron and absolute available iron increased on boiling when rice was subjected to pressure cooking it was found that total iron and the absolute available iron was more for pressure cooked rice. This may be due to the loss of inhibitory fact on during cooking under pressure.

The total iron and the absolute available iron of pulses was found to increase on soaking and boiling pulses when compared to raw pulses. By just soaking in water appreciable quantities of tannin will be leached out which will enhance the availability of iron after cooking. A further increase was observed in both the total iron and absolute available iron on pressure cooking of the soaked pulses.

The effect of steaming of idli batter showed that there was no change in the total iron of idli batles and steamed idli. While a slight increase in the absolute available iron was observed from 2.49 mg/100 g to 2.56 mg/100 g after steaming. Earlier studies on bioavailability of iron indicated that fermentation of rice and pulse mix used for idli preparation did not alter the ionisable iron content when compared with unfermented mix.

The effect of roasting of the selected cereals and pulses with different cooking vessels (glass vessel, aluminium vessel, steel vessel, iron vessel, mud vessel and tufflon coated vessel) on total and absolute available iron were studied. It was found that the total iron was maximum for both cereals and pulses roasted in iron vessels. It may be due to the contamination of iron from the iron cook ware. But there was no corresponding increase in the bioavailable iron roasted in iron vessels. The absolute available iron was found to be maximum in the case of cereals and pulses roasted in glass vessles, mud vessels and tufflon coated vessels. This may be attributed to the fact that these vessels are inert and hence do not react with food constituents upon heating. It was also found that both the total iron and the absolute available iron was least in the case of cereals and pulses roasted in aluminimum vessels indicating that aluminimum vessels react with food constituents forming complex compounds which make the iron unavailable.

When the pulses were roasted after dehulling in different vessels, a similar trend was observed as in the case of roasting, except for further increase in the values of both total and absolute available iron. This may be attributed to a decrease in phytin phosphorus, tannin and fibre content due to dehulling of pulses.

A similar trend was also observed in the case of other cooking methods like frying, dehulling and frying and soaking and boiling of pulses.

It was also found that the total iron was maximum in parboiled and raw rice boiled in iron vessels the values being 3.48 mg/100 g and 3.27 mg/100 g for parboiled and raw rice respectively. The absolute available iron was found to be maximum in the case of rice cooked in glass vessel, steel vessel and mud vessel.

From the above findings it can be concluded that the total iron was maximum for cereals and pulses cooked in iron vessels while the absolute available iron of the same was less when compared to other cooking vessels. This indicates the non availability of the contaminent iron in foods.

Iron absorption enhancers and inhibitors in selected cereal and pulses and the effect of processing

In cereals and pulses, phytates, tannins and fibre are considered to be potent iron inhibitors. In the present study when phytin phosphorus in whole and dehulled pulses were analysed a considerable reduction of phytin phosphorus was observed in dehulled pulses with a simultaneous increase in the percentage of ionisable iron. This may be due to the reduction of phytin phosphorus on dehulling.

When these pulses were germinated it was observed that the phytin phosphorus levels in bengal gram reduced from 304.21 mg/100 g to 205 mg/100 g on 72 hours of germination. But maximum ionisable iron was observed for 48 hours of germination (38.95%). A similar trend was observed in the case of other pulses also indicating that 48 hours of germination of pulses is sufficient for maximum iron absorption. During germination when the effect of phytin phosphorus on ionisable iron was compared it was observed that with increasing hours of germination the phytin phosphorus levels reduced while the total and ionisable iron increased. But after 48 hours of germination the percentage of ionisable iron decreased. In the case of soya bean phytin phosphorus reduced to 162 mg/100 g from 366 mg/100 g after 72 hours of germination and maximum ionisable iron was also observed during this germination period (30.74%).

When ragi was germinated and phytin phosphorus and ionisable iron levels were analysed a similar result as in the case of pulses was observed. During germination of ragi the phytin phosphorus reduced from 209 mg/100 g to 140 mg/100 g during 72 hours of germination and the availability of iron increased up to 2.07 per cent during 48 hours of germination beyond which there observed a reduction in the form of bioavailable iron ie. 20.17 per cent for 72 hours of germination. Ragi is a common infant food in South India and is rich in iron also.

Germination of ragi is a traditional method of processing of ragi which had its beneficial effects with regard to iron availability.

In the present study the comparison of the tannin content of whole and dehulled pulses revealed that on dehulling there was a tremendous reduction in the tannin levels and a proportionate increase in the ionisable iron levels thus increasing the total and absolute iron of pulses on dehulling. This may be because, seed coat that are rich in tannins are removed on dehulling. Thus reducing the tannin levels in pulses. Among pulses black gram has the maximum value for tannins while soyabean had the minimum value (50 mg/100 g). After dehulling tannin content was least for bengal gram (26 mg/100 g) followed by green gram (30 mg/100 g).

On germinating pulses it was found that with increasing hours of germination a reduction of tannin content was observed. The least tannin content was observed for soyabeans germinated for 72 hours ie. 22 mg/100 g. A similar trend was observed with other pulses also. Previous studies had indicated significant amounts of tannins in beans and legume grains but not in soyabean since most of the tannin in legume seeds resides with the seed coat, decorticating may be a practical way to reduce the tannin content. It was also observed that the tannin content of legumes can be reduced by germination with a consequent increase in iron availability.

On germinating ragi, it was observed that the tannin reduced from 673.87 mg/100 g to 205 mg/100 g on 72 hours of germination while the total iron increased from 6.79 mg/100 g to 13.18 mg/100 g and ionisable iron increased from 7.31 per cent to 25.07 per cent in 48 hours of germination and beyond this the ionisable iron was found to be decreasing (20.17%). Among the commonly consumed cereals in Kerala, only ragi is rich in tannins and by germinating the ragi, its tannin content can be reduced appreciably.

Reinhold *et al.* (1985) suggested that fibre was responsible for the low iron bioavailability observed from cereals. Under in vitro conditions iron was reportedly bound by acid detergent fibres and neutral detergent fibres from wheat and maize. In this study the effect of fibre content of cereals/products on absolute available iron revealed that whole wheat flour contained the maximum amount of crude fibre (2.14 mg/100 g) while parboiled milled rice contained the least amount of crude fibre (0.112 g/100 g). This may be because fibre is lost during milling process. However, the absolute available iron was more for refined wheat flour (0.68 mg/100 g) when compared to other cereals.

On germinating ragi it was observed that the fibre content reduced from 4.08 g/100 g to 3.85 g/100 g on 48 hours of germination and then slightly increased on 72 hours of generation. A simultaneous increase in the absolute available iron was observed from 0.49 mg/100 g to 3.03 mg/100 g on 48 hours of germination which reduced to 2.65 mg/100 g on 72 hours of germination.

A similar trend was observed on germinating pulses also.

The fibre content of whole and dehulled pulses revealed that on dehulling the fibre reduced substantially when compared to whole pulses.

Ascorbic acid is a powerful promoter of non heme iron absorption. According to Cook and Monsen (1977) about 75 mg of ascorbic acid increased non heme iron absorption three to four fold. Pulses do not contain ascorbic acid except when germinated.

In this study the ascorbic acid increased as the germination time increased and an increase in the total iron and ionisable iron was also observed. The maximum ascorbic acid was observed in germinated bengal gram. Ascorbic acid may reduce ferric iron to its ferrous oxidation state which is in an absorbable form.

Further ferric iron may form a ferric ascorbate complex at the low pH prevailing in the stomach. This Fe-Chelate remains stable and soluble at the higher pH in the duodenum. Thus making iron available for absorption.

Total iron, ionisable iron and absolute available iron from local diets

Studies conducted by NIN (1989) had indicated that iron absorption from Indian diets varied from 1-5 per cent depending on the principal cereal in the diet. In the present study also iron absorption from the 3 local diets identified as typical Kerala diets revealed that total iron content of the diet was more than the recommended dietary allowances (28 mg/day). With regard to the percentage of ionisable iron at pH 7.5. Diet III had the maximum ionisable iron (6.71%). This high ionisable iron when compared to the other two diets may be due to the presence of heme iron in this diet. Previous studies has also indicated non heme iron even when present in small quantities was found to increase the ionisable iron content of the diet.

Ionisable iron for Diet I (0.92 per cent) may be due to the presence of whole gram rich in tannins.

Absolute available iron was found to be maximum in Diet III (2.28 mg) which is due to the presence of non-heme iron.

Iron absorption enhancers and inhibitors in local diets

Ascorbic acid is the best enhances of non heme iron absorption. Ascorbic acid was found to be very low in local diets. Maximum ascorbic acid was found in Diet II (30 mg). This ascorbic acid content may be the reason for the increased ionisable iron in Diet II (1.27%) compared to Diet I (0.92%) both diet being non heme iron deits. Even though Diet III contained less ascorbic acid (28 mg) the high ionisable iron may be due to the heme iron in that diet.

Iron absorption inhibitors like phytin phosphorus was found to be maximum in Diet I (52%) which had the lowest ionisable iron (0.92%). When phytin phosphorus content was reduced as in Diet II (47%) ionisable iron was found to be increasing (1.27%) which proves that phytin interfears with iron absorption.

Analysis of the diets consumed in different regions in India (NIN, 1989) indicated that the daily intake of tannin may vary from 1500-2500 mg. In the present study also the tannin content of the local Diet was found to be 2420 mg in Diet I, 1740 mg in Diet II and 1473 mg in Diet III. Besides whole grams, some of the commonly used condiments and spices like tamarind, chillies, turmeric powder and coriander contain a fairly high concentration of tannins and although used in small quantities, they may contribute significant amount of tannins to the diet.

Dietary fiber is also claimed as an inhibitor of mineral absorption. In the present study, maximum crude fiber was observed for Diet I (0.88 g) followed by Diet III (0.84 g) and Diet I (0.71 g).

Iron absorption enhancers and inhibitors in modified diets

Local diets were modified by substituting foods suitably processed, which reduced the iron absorption inhibitors or by adding foods rich in iron absorption enhancers. In the modified diet, ascorbic acid was found to be maximum in Diet I (35 mg) where the green gram used was germinated. Germination of legumes had shown to increase the ascorbic acid content. Improvement of ascorbic acid content in Diet II (32 mg) was mainly due to the addition of lime juice and by grinding curry leaves along with the preparation.

There observed a reduction in phytin phosphorus content in modified diets, the least value being in Diet I (28%) followed by Diet II (30%).

With regard to Tannin content in modified Diets, maximum reduction in tannin content was observed in Diet I (1048 mg) followed by Diet II (1433 mg). Reduction in tannin content may be attributed to decortication and germination of pulses.

In modified diets fiber content was low in Diet I (0.64 g). This may be also due to the decortication and germination of legumes used in the diet.

Total iron, ionisable iron and absolute available iron in modified diets

Total iron content was maximum for modified Diet III (37 mg) followed by Diet I (33 mg). In all the 3 diets modified, total iron was found to be increasing.

Even without modification the local Diet III contained high absolute available iron (2.28 mg) when compared to Diet I and II. The inclusion of heme iron is the main reason for this which enhanced the iron absorption. This absolute available iron increased to 2.52 mg in modified diet. But Diet I and Diet II being non heme iron diets, absolute available iron increased from 0.284 to 2.12 mg and 0.38 to 2.02 mg respectively. This may be due to the processing methods employed which decreased the iron absorption inhibitors like tannins and phytates by the addition of foods rich in iron absorption enhances like ascorbic acid.

The absorption of dietary iron is highly variable and depends on what other foods are eaten with the meal, especially on the balance between foods that promote and those that inhibit iron availability.

An increase in iron intake is not always possible but `manipulation' of iron bioavailability ultimately may result in better iron utilization. Various factors are known to affect iron bioavailability. Of the diet related factors heme iron, and ascorbic acid have a strong positive effect on iron availability for absorption, whereas oxalates and polyphenols seem to be strong inhibitors of iron availability. Because of the many interactions that may occur simultaneously, the net effect of the various combined factors in a meal is not equal to the sum of the individual factors.

Summary

SUMMARY

The present study entitled 'Nutritional studies on the bio-availability of iron from cereals and pulses' was designed to determine the bio iron availability by an in vitro technique in cereals and pulses commonly consumed in Kerala and also in typical Kerala diets.

Raw, dehulled and milled samples of the above foods were also studied in this regard. Changes in the availability of iron due to common household cooking methods such as germination, roasting, frying and boiling were also evaluated.

Total iron in any food did not reflect the amount of ingested iron available to the body. So the food sources of iron are rated on the basis of per cent iron availability. This rating can also be criticised because it does not account for the absolute available iron derived from 100 g of food. Actual amount of available iron present in 100 g of the food depend on the per cent iron availability and total iron content. Evaluating an iron source according to the absolute available iron content, would minimise the above criticisms. Therefore the absolute available iron content of the each food tested were also calculated.

The observations from the present study indicated that among the three cereals selected (Rice, Wheat and Ragi) the total iron was maximum for ragi while the absolute available iron was maximum for wheat flour and minimum for raw rice. The low bioavailability of iron in ragi in spite of its high iron content may be attributed to its high fibre and tannin content.

Among the six pulses analysed (Bengal gram, Horse gram, Cow pea, Black gram, Green Gram and Soya bean) the total iron and the absolute available iron was maximum for bengal gram and soya bean while the total iron was least for

cowpea and the absolute available iron was least for black gram. Black gram was found to be high in phytin phosphorus and tannins which are known inhibition of iron absorption.

On processing rice the total iron was found to be maximum in the case of porboiled and hand pounded rice while the absolute available iron was more for porboiled milled rice due to the reduction in the fibre content as a result of milling. The absolute available iron was least in the case of raw milled rice.

On processing wheat flour, the total iron was maximum for whole wheat flour while the absolute available iron was maximum for refined wheat flour owing to the reduction of fibre and phytic acid content on refining wheat flour. Absolute available iron was least for ragi when compared to rice and wheat.

On dehulling pulses both total and absolute available iron was found to increase except in the case of soya bean. This can be attributed to the fact that decortication of seeds reduced tannin to a low level with a significant increase in the ionisable iron.

The low iron bioavailability of ragi was considerably improved on 48 hours of germination but seemed to reduce on 72 hours. Showing that only 48 hours of germination will be enough in the case of ragi to get the maximum increase absolute available iron.

When pulses were germinated, the total and absolute available iron increased with increase in time of germination. The percentage increase of absolute available iron was highest in green gram and least for bengal gram. This may be due to the break down of antinutritional factors such as tannin and phytates during germination.

There was a slight increase in the absolute available iron of fermented and unfermented idli batter which further increased in the case of prepared idli. Thus iron became more available on fermentation and cooking by steaming.

When the effect of different cooking methods were analysed, the total and the absolute available iron seem to increase on roasting. On germinating and roasting ragi; almost a two fold increase was observed in total iron and four to six fold increase in the absolute available iron was observed.

On roasting bengal gram the total iron reduced which the absolute available iron almost doubled. On roasting black gram and bengal gram the absolute available iron increased ten to fifteen fold. A further increase was observed in both total and absolute available iron when pulses were roasted after dehulling except in soya bean oweing to the appreciable quantities of phytates which are important inhibitors of iron absorption.

When cereals and pulses were fried only a slight increase in the total and absolute available iron was observed except for bengal gram where the absolute available iron almost doubled. The total and absolute available iron was found to be more for pulses which were fried after dehulling when compared to dehulling or frying except in the case of bengal gram, where the absolute available iron was maximum for dehulling. This reinforces the fact that dehulling reduces the inhibitory factors and frying after dehulling further improves the iron availability.

The total iron and the absolute available iron was maximum for pressure cooked rice rather than rice boiled by excess water method. This increase in the total and absolute available iron may be due to the loss of inhibitory factors during cooking under pressure.

When pulses were boiled after soaking the total and absolute available iron increased due to the leaching out of appreciable quantities of tannin thus enhancing the availability of iron after cooking. A further increase in both total and absolute available iron was observed on pressure cooking the soaked pulses.

While the absolute available iron increased slightly on steaming idlis, no change was observed in the total iron of idli batter and steamed idli. The effect of different cooking vessels on the total iron and absolute available iron were studied by different cooking and processing methods like roasting, germinating and roasting, dehulling and roasting, frying, dehulled and frying of pulses, boiling of parboiled rice and soaking and boiling of pulses. It was observed that the total iron was maximum for cereals and pulses cooked in iron vessels. This may be due to the contamination of iron from iron cookware. The absolute available iron was maximum for cereals and pulses cooked in glass vessels closely followed by tufflon coated and mud vessels due to the inert character of these vessels. The total iron and absolute available iron was least in the case of cereals and pulses cooked in aluminium vessels indicating that aluminium vessels react with food constituents forming complex compounds which makes the iron unavailable. Hence it is advisable to use glass, mud or tufflon coated vessels as they are inert when compared to iron or aluminium vessels.

In cereals and pulses, phytates, tannins and fibre are considered to be potent iron inhibitors. The phytin phosphorus in whole and dehulled pulses were analysed. Whole black gram contained maximum amount of phytin phosphorus and green gram contained the least amount. On dehulling, the phytin phosphorus was found to reduce in all the pulses. The percentage ionisable iron was also found to increase on dehulling thus increasing the absolute available iron.

Germination greatly reduced the phytin phosphorus levels in pulses. Thus increasing the total iron and a proportionate increase of ionisable iron and absolute available iron was also observed.

Similar observation was noted in case of ragi where the phytin phosphorus reduced on germination thus increasing the total iron. The ionisable iron was first found to increase up to 48 hours of germination but reduced slightly on 72 hours of germination indicating that 48 hours of germination was sufficient for maximum iron absorption. Since ragi is a commonly consumed infant food in South India and is rich in iron, germination of ragi has beneficial effects with regard to iron absorption.

The tannin content of whole and dehulled pulses revealed that whole black gram had the maximum amount of tannins. Since most of the tannins in legumes are in the seed coat, dehulling reduces the tannin content of pulses and it was found to be least for dehulled bengal gram. On germination the tannin content of pulses reduced with consequent increase in the iron availability.

The effect of germination of ragi on tannin and ionisable iron revealed that the tannins reduced with increasing hours of germination while the total iron and ionisable iron increased with germination. Ragi is a commonly consumed cereal in Kerala which is high in tannin and by germinating ragi the tannin content can be reduced appreciably.

On analysing the fibre content of cereals it was found that whole wheat flour contained the maximum amount of crude fibre while parboiled milled rice contained the least amount of crude fibre. The absolute available iron was more for refined wheat flour when compared to other cereals. On germinating ragi the total and absolute available iron were found to increase with a simultaneous reduction in the fibre content up to 48 hours of germination.

Dehulling of pulses substantially reduced the fibre simultaneously increasing the total iron content. The fibre content reduced on germinating pulses for 48 hours and then slightly increased on 72 hours of germination indicating that 48 hours of germination is adequate for maximum reduction in fibre content. Among pulses hors gram had the highest fibre content.

Pulses do not contain ascorbic acid other than when they are germinated. Ascorbic acid reduces the ferric iron to it ferrous oxidation state which is the available form to the body. Thus, with increase in germination time the ascorbic acid, total and absolute available iron were seen to increase. Among the pulses analysed bengal gram was found to have the highest ascorbic acid content on germination.

Iron absorption studies from three local diets identified as typical Kerala diets revealed that Diet-III which had heme iron had the highest ionisable iron. In diets with no hem iron the absolute available iron was found to be low.

Iron absorption inhibitors like phytin phosphorus, tannins and crude fibre was also found to be higher in local diets.

Local diets when modified by substituting or supplementing with foods which contain iron absorption enhancers or by processing methods which reduced iron absorption inhibitors, it was found that there was an increase in the ascorbic acid content and a decrease in tannin, phytin phosphorus and crude fiber in modified diets and an increase in the absolute available iron.

Enhanced production and consumption of animal foods would be a solution to the problem of poor availability of dietary iron as heme iron are readily absorbed and they also enhance non heme iron availability. However, the present limitations in the production and availability of foods of animal origin, the low purchasing power of the majority of the people and cultural constraints on intake of animal foods are formidable barriers. It is probable therefore that for a long time to over come the need for iron will be met only through non heme iron sources.

From the results of the study it was concluded that substitution or supplementation of locally available, low cost foods high in bioavailable iron to rice based diets would enhance the absolute available iron of our diets and such combinations require to be encouraged.

Thus this study emphasises the prevention of iron deficiency anemia among different segments of the population pattern by suggesting modifications for combinations of local foods in existing diets.

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NUTRITIONAL STUDIES ON THE BIOAVAILABILITY OF IRON FROM CEREALS AND PULSES

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ABSTRACT OF THE THESIS

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ABSTRACT

Nutritional studies to evaluate the bioavailability of iron was conducted among three selected cereals i.e., rice, wheat and ragi and six pulses i.e., Bengal gram, green gram, black gram, horse gram, cowpea and soya bean.

The results of the study indicated that among cereals though the total iron was maximum for ragi but the absolute available iron was less mainly due to its high fibre and tannin content. Its availability was considerably improved by germinating ragi for 48 hours when cereals were processed, refined wheat flour had the maximum iron availability owing to the reduction of fibre and phytic acid content on refining, while ragi had the least iron availability.

Among pulses the total and absolute available iron was maximum for bengal gram and soya bean and least for black gram which was found to be high in phytin phosphorus and tannin content. The total and absolute available iron increased on dehulling pulses except in the case of soyabean. This increase in iron was mainly due to the fact that most of the tannins reside in the seed coat of pulses which are removed on dehulling. A further increase in the iron content was observed on germinating the pulses due to the break down of antinutritional factors during germination.

A slight increase in the absolute available iron of fermented and unfermented idli batter was observed which became more available on cooking by steaming.

On germinating and roasting ragi almost a four to six fold increase in the absolute available iron was observed while in pulse the absolute available iron almost doubled on roasting bengal gram while a ten to fifteen fold increase was

observed in black gram. A further increase in iron was observed on roasting the pulses after dehulling. Similarly, on frying cereals and pulses only a slight increase in total and absolute available iron was observed which considerably increased when pulses were fried after dehulling.

The total iron and absolute available iron was maximum for pressure cooked rice rather than rice boiled by excess water method. Similar results were observed when pulses were boiled after soaking due to the leaching of appreciable quantities of tannins. A further increase in iron content was observed on pressure cooking the soaked pulses.

The effect of different cooking vessels on the total and absolute available iron, observed by different cooking and processing methods revealed that the total iron was maximum for cereals and pulses cooked in iron vessels mainly due to the contamination of iron from the iron cook ware. The absolute available iron was maximum for cereals and pulses cooked in inert vessels like glass, mud and tufflon coated vessels and it was least in the case of aluminium vessels which react with food constituents forming complex compounds which makes the iron unavailable.

Phytin phosphorus, an inhibitor of iron absorption was noted to reduce on dehulling and germinating of cereals and pulses thus increasing the absolute available iron. Among pulses, whole black gram contained the maximum amount of phytin phosphorus and tannins while green gram contained the least amount of phytin phosphorus. It was observed that the tannin content in pulses greatly reduced on dehulling pulses as the tannins are in the seed coat, consequently increasing the iron availability. When ragi was germinated the tannin content reduced increasing the total, ionisable and absolute available iron.

On analysing the fibre content of cereals it was observed that whole wheat flour had the maximum amount of crude fibre which reduced to a minimum on refining thus increasing the absolute available iron. Similar results were observed when ragi was germinated where the fibre content reduced with increasing hours of germination up to 48 hours.

When pulses were dehulled, fibre was seen to reduce greatly simultaneously increasing the iron availability. On germinating pulses, similar results were observed up to 48 hours of germination indicating that 48 hours of germination is adequate for maximum reduction in fibre content.

Pulses do not contain ascorbic acid other than when they are germinated. Thus with increase in germination time the ascorbic acid is seen to increase simultaneously increasing the total and absolute available iron. Among the pulses analysed bengal gram was found to have the highest ascorbic acid content on germination.

Iron absorption studies from typical Kerala diets revealed that diet III containing heme iron had the highest ionisable iron while all the diets were high in iron absorption inhibitors. Modification of the local diets by supplementing or substituting foods containing iron absorption enhancers or by processing methods increased the absolute available iron from the diets. Thus by substituting or supplementing locally available, low cost foods, high in bioavailable iron to rice based diets would enhance the absolute available iron of our diets.

Appendices

APPENDIX-I
Composition of Local Diets

DIET-I

Early morning		Tea
Break fast	9 AM	Puttu Bengal gram curry Tea
Mid morning	11 AM	Tea
Lunch	1 PM	Rice, sambar, mango pickle, tapioca kootu, butter milk
Evening	4 PM	Tea
Supper	8 PM	Rice, green gram curry, papad, mango pickle

Quantity consumed / day - Diet I

Foodstuffs (g)	*RDA (g/day)	Consumed (g/day)
Cereals	520	410
Pulses	50	40
Green leafy vegetables	40	0
Roots and tubers	60	55
Other vegetables	70	15
Fruits	30	0
Milk	200	30
Sugar and Jaggery	35	20
Oils and fats	45	35
Flesh foods and fish	30	-
Egg	30	-
Coconut	-	48

*(ICMR, 1984) for moderate activity

DIET-II

Early morning		Tea
Break fast	9 AM	Idli, coconut chutney, tea
Mid morning	11 AM	Tea
Lunch	1 PM	Rice, sambar, tender jackfruit thoran, papad, butter milk
Evening	4 PM	Tea
Supper	8 PM	Rice, tapioca curry, coconut chutney, butter milk

Quantity consumed / day - Diet II

Foodstuffs (g)	*RDA (g/day)	Consumed (g/day)
Cereals	520	410
Pulses	50	40
Green leafy vegetables	40	0
Roots and tubers	60	50
Other vegetables	70	20
Fruits	30	0
Milk	200	30
Sugar and Jaggery	35	20
Oils and fats	45	30
Flesh foods and fish	30	-
Egg	30	-
Coconut	-	40

*(ICMR, 1984) for moderate activity

DIET-III

Early morning		Tea
Breakfast	9 AM	Vellayappam Egg curry Tea
Mid morning	11 AM	Tea, dhal vada
Lunch	1 PM	Rice, sambar, fish fry, pickle
Evening	4 PM	Tea
Supper	8 PM	Rice, potato curry, papad, pickle

Quantity consumed / day - Diet III

Foodstuffs (g)	*RDA (g/day)	Consumed (g/day)
Cereals	520	400
Pulses	50	38
Green leafy vegetables	40	0
Roots and tubers	60	45
Other vegetables	70	15
Fruits	30	0
Milk	200	30
Sugar and Jaggery	35	20
Oils and fats	45	35
Flesh foods and fish	30	20
Egg	30	15
Coconut	-	35

*(ICMR, 1984) for moderate activity

APPENDIX-II
Composition of Modified diets

DIET-I

Early morning		Tea
Break fast	8 AM	Puttu, bengal gram, dhal curry, tea, plantain
Mid morning	11 AM	Tea
Lunch	1 PM	Rice, sambar (with more vegetables), green mango pickle, tapioca thoran, butter milk
Tea	4 PM	Tea
Supper	8 PM	Rice, green gram (germinated) curry, papad, mango pickle

Quantity of foodstuffs in modified Diet I

Foodstuffs (g)	Quantity (g/day)
Cereals	410
Pulses	40
Green leafy vegetables	0
Roots and tubers	55
Other vegetables	50
Fruits	30
Milk	30
Sugar and Jaggery	20
Oils and fats	35
Flesh foods and fish	0
Egg	0
Coconut	48

DIET-II

Early morning		Tea
Breakfast	9 AM	Idli, coconut chutney (by grinding curry leaves and adding lime juice), tea
Lunch	1 PM	Rice, sambar (with more vegetables), tender jackfruit thoran, papad, buttermilk
Evening	4 PM	Tea
Supper	8 PM	Rice, tapioca curry, coconut chutney (by grinding curry leaves), butter milk

Quantity of foodstuffs in modified Diet II

Foodstuffs (g)	Quantity (g/day)
Cereals	420
Pulses	10
Green leafy vegetables	10 (curry leaves)
Roots and tubers	50
Other vegetables	50
Fruits	6 (lime juice)
Milk	30
Sugar and Jaggery	20
Oils and fats	30
Flesh foods and fish	0
Egg	0
Coconut	60

DIET-III

Early morning		Tea
Breakfast	9 AM	Vellayappam, egg curry, tea, plantain
Midmorning	11 AM	Tea, dhal vada
Lunch	1 PM	Rice, sambar (with more vegetables), fish fry, pickle
Evening	4 PM	Tea
Supper	8 PM	Rice, potato curry, papad, pickle

Quantity of foodstuffs in modified Diet III

Foodstuffs (g)	Quantity (g/day)
Cereals	400
Pulses	38
Green leafy vegetables	0
Roots and tubers	45
Other vegetables	50
Fruits	0
Milk	30
Sugar and Jaggery	20
Oils and fats	35
Flesh foods and fish	20
Egg	15
Coconut	35