British Journal of Nutrition (1987), **57**, 331–343

The effects of fruit juices and fruits on the absorption of iron from a rice meal

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(*Received 23 July 1986 – Accepted 8 December 1986*)

1. The effects of the chemical composition of fruit juices and fruit on the absorption of iron from a rice (*Oryza sativa*) meal were measured in 234 parous Indian women, using the erythrocyte utilization of radioactive Fe method.

2. The corrected geometric mean Fe absorptions with different juices varied between 0·040 and 0·129, with the variation correlating closely with the ascorbic acid contents of the juices (r_s 0·838, $P < 0·01$).

3. Ascorbic acid was not the only organic acid responsible for the promoting effects of citrus fruit juices on Fe absorption. Fe absorption from laboratory 'orange juice' (100 ml water, 33 mg ascorbic acid and 750 mg citric acid) was significantly better than that from 100 ml water and 33 mg ascorbic acid alone (0·097 and 0·059 respectively), while Fe absorption from 100 ml orange juice (28 mg ascorbic acid) was better than that from 100 ml water containing the same amount of ascorbic acid (0·139 and 0·098 respectively). Finally, Fe absorption from laboratory 'lemon juice' (100 ml orange juice and 4 g citric acid) was significantly better than that from 100 ml orange juice (0·226 and 0·166 respectively).

4. The corrected geometric mean Fe absorption from the rice meal was 0·025. Several fruits had little or no effect on Fe absorption from the meal (0·013–0·024). These included grape (*Vitis vinifera*), peach (*Prunus persica*), apple (*Malus sylvestris*) and avocado pear (*Persea americana*). Fruit with a mild to moderate enhancing effect on Fe absorption (0·031–0·088) included strawberry (*Fragaria sp.*) (uncorrected values), plum (*Prunus domestica*), rhubarb (*Rheum rhaponticum*), banana (*Musa cavendishii*), mango (*Mangifera indica*), pear (*Pyrus communis*), cantaloup (*Cucumis melo*) and pineapple (*Ananas comosus*) (uncorrected values). Guava (*Psidium guajava*) and pawpaw (*Carica papaya*) markedly increased Fe absorption (0·126–0·293).

5. There was a close correlation between Fe absorption and the ascorbic acid content of the fruits tested (r_s 0·738, $P < 0·0001$). There was also a weaker but significant correlation with the citric acid content (r_s 0·55, $P < 0·03$). Although this may have reflected a direct effect of citric acid on Fe absorption, it should be noted that fruits containing citric acid also contained ascorbic acid (r_s 0·70, $P < 0·002$). Similarly, the negative correlation (r_s −0·62, $P < 0·008$) between Fe absorption and the malic acid content of fruits may have been due to the fact that fruits with a high malic acid content tended to have low levels of ascorbic acid (r_s −0·45, $P < 0·06$).

6. These various results suggested that most fruits have only a limited effect on overall Fe nutrition. However, the presence of citrus fruit, guava or pawpaw would be expected to increase Fe absorption markedly from diets of low Fe availability.

The amounts of non-haem iron absorbed from a mixed diet are profoundly influenced by the relative proportions of promoters and inhibitors present in the individual constituents (Bothwell *et al.* 1979). Ascorbic acid is a major promoter of Fe absorption (Sayers *et al.* 1973, 1974*a*, *b*; Björn-Rasmussen & Hallberg, 1974; Rossander *et al.* 1979; Derman *et al.* 1980; Hallberg, 1981; Hallberg & Rossander, 1982*a*, *b*, 1984) and its effects are dose dependent (Sayers *et al.* 1973; Björn-Rasmussen & Hallberg, 1974; Derman *et al.* 1980). It has also been demonstrated that other organic acids, such as citric, malic and tartaric

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acids, have a similar though less-marked promoting effect on Fe absorption (Gillooly *et al.* 1983). In contrast, non-hydrolysable polyphenols (Gillooly *et al.* 1983) and phytates (Turnbull *et al.* 1962; Hallberg, 1981; Gillooly *et al.* 1983, 1984) inhibit Fe absorption. The present study was done in order to document the effects of fruit juices and fruit on Fe absorption from a rice meal, with particular reference to their organic acid, and polyphenol contents.

EXPERIMENTAL

Subjects

A group of 234 parous Indian housewives took part in the study. None was pregnant or lactating and all were unpaid volunteers. Their ages ranged between 21 and 74 (mean 37) years. They lived in municipal housing schemes in the Chatsworth and Phoenix areas near Durban. It has been established previously that Fe deficiency is a common problem among the women of this community (Mayet *et al.* 1972; MacPhail *et al.* 1981; Baynes *et al.* 1987).

Preparation and administration of the meals

The effect of a known amount of fruit and fruit juice on the absorption of Fe from a basic 200 g rice meal containing 0·4 mg Fe was measured in each of the studies. Two meals were consumed on consecutive days after an overnight fast. Only water was permitted during the meal and for 3 h afterwards. The rice meal was prepared by boiling parboiled polished rice (1 kg) for 20 min in 2000 ml water containing 20 g table salt. Since the Fe content in all the fruits tested was low, Fe as $FeSO_4 \cdot 7H_2O$ (3 mg Fe per subject) was added as a solution and thoroughly mixed in at the start of cooking. On one morning the meal was labelled with 2–3 μCi ^{59}Fe and on the other with 3 μCi ^{55}Fe (Amersham International plc, Amersham, Bucks). After boiling, 75 g yellow margarine and 150 g sucrose were added. Each subject received 200 g of the cooked rice meal. In 129 of the studies, Fe absorption from the basal rice meal was compared with that from the same meal supplemented with a fruit or fruit juice. In the remainder of the studies, a fruit or fruit juice was given with the rice meal on both days.

Fresh fruit was purchased within 24 h of administration. The fruit was peeled and chopped into small portions and served with the rice pudding. In all rice meals with fruit the mass of fruit eaten was 100 g/meal except in the case of pawpaw (*Carica papaya*), where both 100 g/meal and 50 g/meal were eaten, and banana (*Musa cavendishii*) where 100 g/meal and 200 g/meal were eaten. In one of the guava (*Psidium guajava*) studies, tinned guavas were used after the syrup had been drained and the fruit depipped. In the pineapple (*Ananas comosus*), strawberry (*Fragaria sp.*) and fresh guava studies, a fresh fruit purée was prepared in a food blender. With rhubarb (*Rheum rhaponticum*), plums (*Prunus domestica*), grapes (*Vitis vinifera*) and peaches (*Prunus persica*) a similar purée was prepared after gentle heating.

All fruit juices used in the fruit juice–rice meal studies were commercial preparations of pure juice. A 100 ml portion of each juice was consumed concurrently with a 200 g rice pudding meal.

Measurements of Fe absorption

At 2 weeks after the administration of the radiolabelled meals, blood was obtained by venepuncture for the measurement of ^{59}Fe, ^{55}Fe, haemoglobin concentration, serum Fe, total Fe-binding capacity and serum ferritin concentration. The blood was taken in the fasting state, stored at 4° and processed within 24 h. Immediately after venepuncture each subject drank 100 ml water containing 3 mg elemental Fe as $FeSO_4 \cdot 7H_2O$, 3 μCi ^{59}Fe and 30 mg ascorbic acid. Only water was permitted for the following 3 h. Further blood samples were taken 14 d later and the absorption of this reference dose of Fe was determined from the increment of ^{59}Fe in the blood. By expressing the absorption of Fe from the meals in relation to the reference absorption, a basis for comparison between subjects of differing Fe storage status was established (Rossander *et al.* 1979; Hallberg, 1981).

Radioisotopic, chemical and statistical methods

Duplicate 10 ml blood samples, duplicate rice samples and duplicate portions of standard radioactive Fe solutions were prepared for differential radioactive counting using the method of Eakins & Brown (1966). The activities of ^{55}Fe and ^{59}Fe in the processed samples were determined in Insta-Gel Scintillant (Packard Instrument Co., Illinois, USA) using a liquid-scintillation spectrometer (Packard-Tri-Carb AAA spectrometer, model no. 3375). The counting efficiency at optimal gain and window settings was 24% for ^{55}Fe and 42% for ^{59}Fe. The ^{59}Fe activity in 4-ml blood samples collected immediately before the reference Fe salt was administered and 2 weeks later was assessed against suitable standards using a Packard Autogamma Counter no. 5850 with a counting efficiency of 60%. The absorption values were calculated on the basis that 100% of the absorbed radioactivity was present in the haemoglobin of circulating erythrocytes (Bothwell *et al.* 1979), and that the blood volume of each subject was 65 ml/kg body-weight (Diem & Lentner, 1970). The calculated food Fe absorption was then corrected to an absorption of 0·40 for the reference Fe salt as follows:

$$\text{corrected food Fe absorption} = \frac{\text{calculated food Fe absorption} \times 0{\cdot}40}{\text{calculated reference Fe salt absorption}}$$

A value of 0·40 was selected as the reference point, since it represents approximately the amount absorbed by subjects who lack Fe stores but who are not yet anaemic (Hallberg, 1981). The corrected food Fe absorptions would therefore be expected to provide a fairly sensitive indicator of the relative availability of Fe in different meals.

Haemoglobin concentrations were measured by the cyanmethaemoglobin method. Serum Fe and total Fe-binding capacity were measured in accordance with the recommendations of the iron panel of the International Committee for Standardization in Haematology (1978*a*, *b*). The serum ferritin concentration was measured by the enzyme-linked immunosorbent assay described by Conradie & Mbhele (1980). The total and extractable polyphenol contents of fruits were measured by the method of Singleton & Rossi (1965). Concentrations of organic acids were either obtained from published values (Diem & Lentner, 1970; Lentner, 1981) or, if unavailable, measured locally using Boeringer–Mannheim food analysis kits (Mannheim, West Germany). While there is certainly variability in the organic acid content of fruits as a function of variety, maturity and post-harvest handling, the published values indicate the relative amounts present and the wide variation between fruit types. The phytate content of fruits was measured by the indirect method of Haugh & Lantzsch (1983). Crude fibre contents of the fruit tested were obtained from Lentner (1981). Since serum ferritin concentrations and Fe absorption values were positively skewed, they were expressed as geometric means and standard deviation ranges to normalize the distributions. Studies in which one meal was compared directly with another in the same group of subjects were evaluated by means of Student's paired *t* test. Spearman rank correlations were utilized to relate the geometric mean absorption of Fe from meals containing either fruit or fruit juices to their ascorbic acid contents.

Ethical considerations

Approval for these studies was obtained from the Committee for Research on Human Subjects of the University of the Witwatersrand, Johannesburg. Written, informed consent was obtained from each subject after the nature of the experiment had been explained to her by both an Indian assistant and the doctor performing the study. Each subject took part in one experiment only. It was calculated that if each test dose was completely absorbed, the total radiation dosage would be 143 mrems (Bothwell *et al.* 1979) which is 28% of the annual maximum permissable dose for members of the public (International Commission for Radiation Protection, 1960; South Africa Bureau of Standards, 1972). In practice, the percentage absorbed is much less, which makes the radiation exposure proportionately smaller.

RESULTS

Effect of the organic acid content of various fruit juices on Fe absorption from a 200 g rice meal

Haematological and Fe-related measurements on the groups of women studied are shown in Table 1. The groups were relatively homogeneous insofar as the haemoglobin and transferrin saturation values were concerned but there was some variation in the geometric mean serum ferritin concentrations, with a range from 7·3 to 25·4 μg/l. However, when the various study groups were compared using Student's unpaired *t* test with Bonferroni corrections, the ferritin concentrations were not statistically different in any group ($P > 0.05$). Fe absorption from the unsupplemented basal rice meal was low, with a corrected geometric mean value of 0·025 (0·007–0·086) (Table 2). An overall correlation between Fe absorption and the amounts of ascorbic acid present in the fruit juices was evident (r_s 0·838, $P < 0.01$). The range of absorptions was wide, from 0·035 (0·011–0·11) with grape juice to 0·150 (0·057–0·395) with pear juice. It was also noted that the amounts of ascorbic acid present in the drinks were not related to the relative contents of the fruits concerned but rather to the arbitrary amounts added by the manufacturers. Pineapple was the only fruit juice where Fe absorption seemed inappropriately high in relation to its ascorbic acid content (5·2 mg/100 ml). This may relate to the fact that pineapple contains appreciable amounts of citric acid (7·7 g/kg; Diem & Lentner, 1970).

Effect of citric acid content of citrus fruit on Fe absorption from a 200 mg rice meal

In the first experiment the geometric mean absorption of Fe from rice and laboratory 'orange juice' (100 ml water, 33 mg ascorbic acid and 750 mg citric acid) was 0·170 (0·074–0·389) (Table 3). The value was significantly higher (*t* 3·74, $P < 0.005$) than that obtained when the rice was fed with 100 ml water containing 33 mg ascorbic acid only (0·114 (0·053–0·245)). In a further experiment, the effects of 100 ml freshly-squeezed orange juice (28 mg ascorbic acid) were compared with those of the same amount of ascorbic acid in water at the same pH (3·0). Comparable values for Fe absorption from the rice meal were 0·139 (0·048–0·402) and 0·098 (0·041–0·232) respectively. These results were significantly different (*t* 2·56, $P < 0.025$). In a final experiment the effects of laboratory 'lemon juice' (100 ml orange juice plus 4 g citric acid) were compared with those of 100 ml orange juice. The orange juice used was obtained commercially and contained 30 mg ascorbic acid and 700 mg citric acid/100ml. Fe absorption from the rice meal was significantly greater (*t* 2·63, $P < 0.05$) with the laboratory 'lemon juice' than it was with the orange juice. Comparable values were 0·226 (0·089–0·576) and 0·166 (0·067–0·413) respectively.

Effects of various fruits on Fe availability from a 200 g rice meal

The effects of various fruits on Fe availability from a rice meal were measured in a number of studies. Haematological and Fe-related measurements on the groups of women who participated in these studies are shown in Table 4. The haemoglobin and transferrin saturations showed little variation between the groups. However, the geometric mean

Table 1. *Haemoglobin, transferrin saturation and serum ferritin values in fasting female subjects given 100 ml juice prepared from different fruits and served with a 200 g rice meal*

(Mean values, standard deviations and SD ranges)

Meal	No. of subjects	Haemoglobin (g/l)		Transferrin saturation (%)		Serum ferritin (μg/l)	
		Mean	SD	Mean	SD	Geometric mean	±1 SD
Rice meal alone	129	129	17	23·9	11·7	14·7	3·6–60·7
Rice meal plus:							
Apple juice (1·7 mg AA)*	14	134	11	28·9	5·6	25·4	15·2–42·4
Grape juice (1·4 mg AA)	10	124	18	21·1	8·8	5·3	0·5–51·9
Guava nectar (15 mg AA)	14	134	11	28·9	5·6	25·4	15·2–42·4
Apple juice (24 mg AA)	10	123	18	30·9	18·1	10·7	1·4–79·6
Pineapple juice (5·2 mg AA)	8	139	18	27·0	12·6	19·1	7·6–47·8
Orange juice (30 mg AA)	9	120	10	18·4	7·4	7·3	2·0–26·9
Pear juice (30 mg AA)	8	139	18	27·0	12·6	19·1	7·6–47·8

* Ascorbic acid (AA) content per 100 ml fruit juice given.

ferritin concentrations ranged from 6·7 to 50·0 μg/l, which suggested that there were some variations in the storage Fe status of the groups under study. However, using Student's unpaired *t* test with Bonferroni correction there was no statistical difference between groups ($P > 0{\cdot}05$). Several fruits had virtually no effect on the absorption of Fe from the basal rice meal (Table 5). The corrected geometric mean absorption from the meal was 0·025 (0·007–0·086) and values as low or lower were obtained with black and green grapes (*Vitis vinifera*), peaches (*Prunus persica*), apples (*Malus sylvestris*), avocado pear (*Persea americana*) and strawberry (*Fragaria sp*). With the exception of strawberry, ascorbic acid concentrations were very low in all these fruits and citric acid concentrations were low or moderate (peach) (Table 6). In contrast, several contained appreciable quantities of malic acid (> 200 mg/100 g). The reason for the apparently poor availability of Fe in the presence of strawberry was surprising in view of its relatively high content of both ascorbic and citric acid (60 and 1080 mg/100 g respectively). It contained only moderate amounts of condensed polyphenols (116 mg/100 g) and fibre (1·3 g/100 g) and in common with all the other fruits tested, negligible amounts of phytate. In fact, the effect of strawberry on Fe absorption from the rice meal was more positive than the corrected geometric mean values suggested. A direct comparison of Fe absorption results in the study in which rice plus strawberry were compared with rice alone gave uncorrected geometric mean values of 0·048 and 0·012 respectively (t 7·73, $P < 0{\cdot}0005$).

A second group of fruits appeared to have a mild to moderate promoting effect on the availability of Fe in a rice meal, with corrected geometric mean absorptions ranging between 0·031 and 0·064. The group included plum (*Prunus domestica*), rhubarb (*Rheum rhaponticum*), banana (*Musa cavendishii*), mango (*Mangifera indica*), pear (*Pyrus communis*) and cantaloup (*Cucumis melo*). A corrected geometric mean absorption value was not available for pineapple (*Ananas comosus*) but with an uncorrected value of 0·088, it was

Table 2. *Absorption of Fe (3 mg) as $FeSO_4 \cdot 7H_2O$ in fasting female subjects from 100 ml juice prepared from different fruits and served with a 200 g rice meal*

(Mean values and standard deviation ranges)

Reference salt*: Geometric mean	Reference salt*: ±1 SD		Fruit juice: Uncorrected geometric mean	Fruit juice: ±1 SD	Fruit juice: Corrected geometric mean†	Fruit juice: ±1 SD
0·412	0·195–0·868	Rice meal alone	0·019	0·005–0·070	0·025	0·007–0·086
		Rice meal plus:				
0·428	0·242–0·757	Apple juice (1·7 mg AA)‡	0·038	0·014–0·103	0·035	0·011–0·111
0·410	0·252–0·666	Grape juice (1·4 mg AA)	0·048	0·013–0·176	0·040	0·016–0·099
0·428	0·242–0·757	Guava nectar (15 mg AA)	0·099	0·044–0·222	0·092	0·035–0·241
0·489	0·341–0·702	Apple juice (24 mg AA)	0·129	0·056–0·303	0·111	0·038–0·331
0·366	0·254–0·526	Pineapple juice (5·2 mg AA)	0·097	0·043–0·221	0·121	0·061–0·237
0·510	0·224–1·117	Orange juice (30 mg AA)	0·166	0·067–0·413	0·123	0·078–0·193
0·366	0·254–0·526	Pear juice (30 mg AA)	0·138	0·057–0·331	0·150	0·057–0·395

* 3 mg Fe as ferrous ascorbate given in the fasting state.

† Individual results adjusted to a 40% reference absorption to give corrected geometric mean absorptions. Corrected values not available for seven of the seventy-three fruit-juice studies because of lack of reference absorption results.

‡ Ascorbic acid (AA) content per 100 ml fruit juice given.

https://doi.org/10.1079/BJN19870041 Published online by Cambridge University Press

Table 3. *The effect of citric acid and ascorbic acid on the absorption of Fe (3 mg) as $FeSO_4 \cdot 7H_2O$ in fasting female subjects given citrus fruit juice with a 200 g rice meal*

(Mean values, standard deviations and SD ranges)

No. of subjects	Haemoglobin (g/l)		Transferrin saturation (%)		Serum ferritin (μg/l)		Fe absorption		
	Mean	SD	Mean	SD	Geometric mean	±1 SD	'Fruit juice'	Geometric mean*	±1 SD
13	123	11	25·7	12·4	15·9	6·7–37·7	100 ml water with 33 mg ascorbic acid	0·114	0·053–0·245
							100 ml water with 33 mg ascorbic acid + 750 mg citric acid	0·170	0·074–0·389
13	124	18	21·4	6·6	15·8	4·9–50·5	100 ml water with 28 mg ascorbic acid	0·098	0·041–0·232
							100 ml fresh orange juice	0·139	0·048–0·402
9	120	10	18·4	7·4	7·3	2·0–26·9	100 ml commercial orange juice	0·166	0·067–0·413
							100 ml commercial orange juice with 4 g citric acid	0·226	0·089–0·576

* Uncorrected geometric mean absorptions. Reference absorptions not done in these experiments.

Table 4. *Haemoglobin, transferrin saturation and serum ferritin values in fasting female subjects given 100 g fruit served with a 200 g rice meal*

(Mean values, standard deviations and SD ranges)

Meal	No. of subjects	Haemoglobin (g/l)		Transferrin saturation (%)		Serum ferritin (μg/l)	
		Mean	SD	Mean	SD	Geometric mean	±1 SD
Rice meal alone	129	129	17	23·9	11·7	14·7	3·6–60·7
Rice meal plus:							
Peeled grape (black)	15	129	20	18·3	12·5	6·7	2·0–23·2
Unpeeled grape (green)	11	129	10	28·4	10·7	33·4	12·5–89·2
Peach	15	132	18	26·3	9·9	26·7	7·0–101·3
Apple	11	133	11	21·7	10·2	15·3	5·3–45·2
Unpeeled grape (black)	15	129	20	18·3	12·5	6·7	2·0–23·2
Avocado pear	14	130	28	18·7	9·9	7·5	1·2–45·9
Strawberry	13	135	8	28·5	7·4	19·8	9·3–41·9
Plum	11	129	10	28·4	10·7	33·4	12·5–89·2
Rhubarb	15	132	18	26·3	9·9	26·7	7·0–101·3
Banana	8	126	15	29·0	13·4	19·1	7·2–50·7
Mango	11	130	16	26·3	11·0	25·5	12·4–52·4
Pear	10	135	13	19·4	9·2	8·3	1·9–36·5
Banana (200 g)	4	123	20	21·2	14·9	16·3	6·7–40·7
Cantaloup	9	131	16	25·3	11·2	26·6	8·7–81·7
Pineapple	6	125	12	27·8	15·7	50·0	17·3–144·0
Guava	15	129	21	23·9	12·4	18·4	4·5–75·5
Pawpaw (50 g)	7	127	14	20·3	11·2	11·8	5·5–25·6
Pawpaw	7	127	14	20·3	11·2	11·8	5·5–25·6
Guava (tinned)	8	121	7	20·6	9·6	16·8	6·4–43·7

Table 5. *Absorption of Fe (3 mg) as $FeSO_4 \cdot 7H_2O$ in fasting female subjects given 100 g fresh fruit with a 200 g rice meal*

(Mean values and standard deviation ranges)

Fe absorption: Reference salt*: Geometric mean	Fe absorption: Reference salt*: ±1 SD	Meal	Fe absorption: Fruit: Uncorrected geometric mean	Fe absorption: Fruit: ±1 SD	Fe absorption: Fruit: Corrected geometric mean†	Fe absorption: Fruit: ±1 SD
0·412	0·195–0·868	Rice meal alone	0·019	0·005–0·070	0·025	0·007–0·086
		Rice meal plus:				
0·515	0·335–0·792	Peeled grape (black)	0·014	0·005–0·040	0·013	0·006–0·028
0·411	0·236–0·714	Unpeeled grape (green)	0·022	0·008–0·066	0·014	0·005–0·036
0·376	0·168–0·842	Peach	0·014	0·006–0·034	0·014	0·006–0·035
0·237	0·117–0·479	Apple	0·014	0·003–0·078	0·017	0·004–0·078
0·515	0·335–0·792	Unpeeled grape (black)	0·013	0·003–0·062	0·019	0·008–0·047
0·260	0·069–0·972	Avocado pear	0·016	0·003–0·074	0·021	0·010–0·042
0·662	0·509–0·861	Strawberry	0·048	0·015–0·152	0·024	0·006–0·083
0·411	0·236–0·714	Plum	0·045	0·019–0·109	0·031	0·014–0·073
0·376	0·168–0·842	Rhubarb	0·039	0·015–0·100	0·042	0·017–0·101
0·518	0·276–0·973	Banana	0·060	0·024–0·146	0·046	0·018–0·115
0·396	0·219–0·714	Mango	0·054	0·014–0·209	0·049	0·013–0·185
0·339	0·139–0·831	Pear	0·041	0·024–0·070	0·053	0·022–0·131
0·552	0·210–1·452	Banana (200 g)	0·081	0·067–0·098	0·059	0·023–0·154
0·380	0·194–0·747	Cantaloup	0·061	0·031–0·120	0·064	0·035–0·119
—	—	Pineapple	0·088	0·036–0·215	—	—
0·484	0·237–0·988	Guava	0·141	0·060–0·332	0·126	0·085–0·178
0·681	0·475–0·976	Pawpaw (50 g)	0·229	0·160–0·329	0·140	0·097–0·203
0·681	0·475–0·976	Pawpaw	0·295	0·181–0·481	0·173	0·109–0·274
0·259	0·099–0·681	Guava (tinned)	0·257	0·115–0·573	0·293	0·180–0·476

* 3 mg Fe as ferrous ascorbate given in fasting state.

† Individual results adjusted to a 40% reference absorption to give corrected geometric mean absorptions. Corrected values not available for fifty-one of 205 individual fruit studies because of lack of reference absorption results.

Table 6. *Organic acid, polyphenol and fibre contents of fruits*

	Organic acids (mg/100 g edible portion)				Polyphenols† (mg/100 g)		Fibre‡ (g/100 g)
	Ascorbic	Malic	Citric	Oxalic	Extractable	Condensed	
Peeled grape (black)	4	650	20*	7·9	23	9	0·5
Unpeeled grape (green)	4	650	20*	7·9	46	7	0·5
Peach	7	370	370*	0	90	42	0·6
Apple	5	270–1020	0–30	1·5	76	34	0·9
Unpeeled grape (black)	4	650	20*	7·9	53	46	0·5
Avocado pear	2*	203*	51*	—	100	32	1·5
Strawberry	60	160	1080	15·8	130	116	1·3
Plum	6	360–2390	30	11·9	142	45	0·7
Rhubarb	9	1770	410	537	23	24	0·7
Banana	10	500	150	0·7	130	52	0·6
Mango	35	—	—	—	91	36	0·9
Pear	4	120	240	6·2	60	0	1·5
Cantaloup	25	33*	—	2·7	40	0	0·3
Pineapple	17	120	770	1·5	44	39	0·5
Guava	180*	193*	462*	—	264	137	—
Pawpaw	154*	39*	329*	—	53	60	—
Guava (tinned)	262*	82*	393*	—	264	137	—

* Organic acid content measured locally. Other organic acid values from Lentner (1981) or Diem & Lentner (1970).
† Polyphenol content measured locally.
‡ Fibre values from Lentner (1981).

also included in the group. Insofar as organic acid, polyphenol and fibre contents were concerned, the findings were very similar to the previous group, although several had marginally higher ascorbic acid contents (Table 6).

The last group of fruit, which included pawpaw (*Carica papaya*) and guava (*Psidium guajava*), was associated with markedly increased availability of Fe from a rice meal, with corrected geometric mean absorption values varying between 0·140 and 0·293. The increased availability was directly related to the high ascorbic acid contents of these fruits.

DISCUSSION

The enhancing effects of certain fruit juices and fruit on food Fe absorption have previously been demonstrated in several studies. Moore & Dubach (1951) showed that Fe absorption from eggs was improved when eaten with 200 ml orange juice and attributed the effect to the ascorbic acid present in the juice. Similar findings were reported by Callender *et al.* (1970), while there are several studies demonstrating the enhancing effect of orange-juice drinks containing between 70 and 110 mg ascorbic acid on Fe absorption from different meals (Rossander *et al.* 1979; Hallberg, 1981). Insofar as fruits are concerned, Layrisse *et al.* (1974) showed that the addition of a portion of pawpaw containing 66 mg ascorbic acid increased Fe absorption from a maize meal from 0·014 to 0·088. In addition, Hallberg *et al.* (1974) found that a fruit mix of pawpaw, banana and orange (35 mg ascorbic acid per portion) improved absorption from a Thai meal threefold.

The present findings confirm and extend those of previous workers. In our studies, various fruit juices and fruits were tested for their ability to modify Fe absorption from a 200 g rice meal of low Fe availability. The overall pattern of results was uniform. The ability of various fruit juices to enhance Fe absorption from the rice meal was correlated with their ascorbic acid contents (r_s 0·85, $P < 0·02$) and the same was true of the fruits that were tested (r_s 0·78, $P < 0·0001$). On this basis, the only fruits that exerted an important enhancing effect on Fe absorption were those with high ascorbic acid contents. They included orange, pawpaw and guava. While other fruit, such as banana, cantaloup and pineapple, which contained lesser amounts of ascorbic acid, also promoted Fe absorption, the effects were modest. The dose-related effects of ascorbic acid were further suggested by two studies in which 100 g banana were compared with 200 g banana and 50 g pawpaw with 100 g pawpaw. Fe absorption was greater with the larger portion in each instance.

A second objective of the present study was to find out whether other organic acids present in fruit affect Fe absorption. This was done since we have previously shown that the geometric mean Fe absorption from a rice meal was increased significantly from 0·028 to 0·085 with 1 g citric acid, from 0·048 to 0·095 with 1 g L-malic acid and from 0·041 to 0·096 with tartaric acid (Gillooly *et al.* 1983). The only exception was oxalic acid; the addition of 1 g calcium oxalate to cabbage (*Brassica oleraceae*) was associated with some depression in Fe absorption from 0·320 to 0·195. There is still, however, controversy on the effect of individual organic acids. For example, citric acid has been reported to decrease by two-thirds Fe absorption from a simple Latin-American-type meal in human subjects (Hallberg & Rossander, 1984), while calcium oxalate has been found to have no effect on Fe absorption in rats (Van Campen & Welch, 1980). Special attention was paid to citric acid in the present study, since citrus fruit contains both ascorbic acid and citric acid in significant amounts. A direct comparison of a solution containing ascorbic acid (33 mg) with one containing the same amount of ascorbic acid and 1 g citric acid, indicated that the citric acid had an enhancing effect on the corrected geometric mean Fe absorption from the rice meal (0·114 and 0·170 respectively). In addition, orange juice was more effective than water containing the same amount of ascorbic acid (0·139 and 0·098 respectively).

Finally, when orange juice was supplemented with an amount of citric acid equivalent to that present in lemon juice, it had a greater promoting effect on Fe absorption (0·226 and 0·166 respectively). These three results suggest that the effect of citric acid is additive to that of ascorbic acid. Its action presumably occurs through its carboxylic and hydroxyl groups, which prevent polymerization of Fe hydroxides by forming unstable soluble complexes with Fe. However, its overall effects on Fe nutrition were difficult to assess. While there was a significant correlation between Fe absorption and the citric acid content of fruits (r_s 0·55, $P < 0·03$), those fruits with high citric acid contents also tended to have high ascorbic acid contents (r_s 0·70, $P < 0·02$) (Tables 5 and 6). It was also difficult to assign a definite role to malic acid. In fact, there was a significant negative correlation (r_s −0·62, $P < 0·008$) between the malic acid content of fruits and Fe absorption from the rice meal. It is doubtful whether this was due to a direct inhibitory effect, since we have previously shown that malic acid is itself a mild promoter of Fe absorption (Gillooly *et al.* 1983). It seems more likely that it was due to the fact that there was a suggestive inverse relation (r_s −0·45, $P < 0·06$) between the malic acid and ascorbic acid contents of fruits. Insofar as oxalic acid was concerned, only one fruit, rhubarb, had a high oxalate content (Table 6). It also had a high malic acid content and its overall effect was to cause a mild enhancement of the corrected geometric mean absorption of Fe from the rice meal (0·042 as compared with 0·025).

The question as to whether any of the fruit tested might have a major inhibitory effect on Fe absorption was not directly addressed, since the basal rice meal being tested was one of low Fe availability. However, from the composition of the fruit, it was apparent that none of them contained large amounts of known inhibitors of Fe absorption (Table 6). They contained negligible amounts of phytate, amounts of condensed polyphenols less than those that have been found to be inhibitory in previous vegetable studies (Gillooly *et al.* 1983) and only moderate amounts of fibre (Lentner, 1981).

One methodological point deserves mention. In the past, it was difficult to compare results obtained with different meals because of the major effects exerted on Fe absorption by the storage Fe status of the individuals tested. Because of this, it has become customary to find out the absorbing capacity of each individual by feeding a small 'reference' dose of ferrous ascorbate. Food Fe absorption results are then corrected to a reference absorption of 0·40, since this is the proportion absorbed by subjects with borderline deficiency (Hallberg, 1981). While the approach may have validity when the groups studied vary widely in terms of their storage Fe status, it appears to be of less value in a study such as the present one where the groups of Indian women were relatively homogeneous insofar as haemoglobin, transferrin saturation and ferritin values were concerned (Tables 1 and 4) (Baynes *et al.* 1987). Uncorrected and corrected Fe absorption values were very similar and the correlations between the uncorrected Fe absorption results and the ascorbic acid contents of the fruit juices and fruits were, in fact, higher than those obtained with the corrected results. For fruit juices the comparable values were r_s 0·95 ($P < 0·008$) and r_s 0·85 ($P < 0·02$), and for fruits r_s 0·86 ($P < 0·0001$) and r_s 0·78 ($P < 0·0001$).

In summary, the present findings indicate that the majority of fruit tested would be expected to exert a minimal effect on overall Fe nutrition when administered as part of a mixed meal. Several, however, with high ascorbic acid contents were shown to have a marked enhancing effect on Fe absorption from a rice meal. It is concluded that pawpaw, guava and citrus fruits could have a significant positive effect on Fe nutrition if they were regularly present in staple cereal diets of low Fe availability.

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Printed in Great Britain