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Impact of dietary iron intake on anaemia in Tanzanian schoolchildren

Department of Food Science and Nutrition, Tanzania Food and Nutrition Centre
Simon Tatala, MD
Godwin Ndossi, PhD
Department of Public Health and Nutrition, Harvard University, USA
Ulf Svanberg, PhD
Department of Food Science, Chalmers University of Technology, Sweden
Deborah Ash, PhD

Objective. To investigate the nutritional relationship between dietary intake and prevalence of anaemia among Tanzanian schoolchildren.

Methods. Dietary intakes of 101 schoolchildren aged 7 - 12 years were assessed using a pre-tested food frequency questionnaire. Haemoglobin (Hb), haematocrit, erythrocyte protoporphyrin (EP) and serum ferritin (SF) were used to determine their anaemia and iron status. Other socio-economic variables were collected using a profile questionnaire.

Results. Significantly lower intake of iron was seen in 48% of schoolchildren with Hb < 11.5 g/dl (anaemic) compared with those who were normal. Total iron intake was 22 ± 7 and 27 ± 13 mg/day respectively ($p < 0.05$). There was a general poor intake of iron from animal sources in all children. A higher iron intake was found in schoolchildren with normal iron status (by EP and SF levels) than in those who were not normal (26 ± 11 mg/day v. 22 ± 9 mg/day, $p < 0.05$). Iron deficiency was found in 45% of schoolchildren ($N = 80$) and 31% were categorised as having iron deficiency anaemia. The mean energy intake in boys was higher than in girls (2 150 ± 770 v. 1 830 ± 895 kcal/day respectively). Boys also had a higher intake of ascorbic acid (50 ± 32 v. 31 ± 23 mg/day, $p > 0.05$). In stepwise multiple regression analysis, daily iron intake remained the most significant nutrient predicting for Hb status. There was a significant correlation between iron intake and serum ferritin ($r = 0.233$, $p < 0.05$).

Conclusion. Iron intake in this Tanzanian community is inadequate for maintaining normal iron nutrition. The factors contributing to the inadequacy include consumption of foods with low iron bioavailability. Food-based intervention should be one of the important strategies for reducing the magnitude of the problem of anaemia in this community.

Low dietary iron intake has been an attributed cause of iron deficiency and anaemia in many parts of the developing world.[1,2] Children under the age of 5 years, and women during their reproductive years, are the most susceptible segments of the population.[3] In infants and children, iron deficiency is associated with impaired psychomotor development, decreased cognitive function, and negative behavioural changes.[4] In the long run these impairments have a serious adverse development and economic implication.[5] In developing countries dietary iron intake appears to be high, but most of it is of non-haem origin.[6,7] The absolute amount of dietary iron in these situations is therefore less important than its availability according to the type of meal in which it is found. When body iron stores are low, the absorption of non-haem iron increases, but this usually does not exceed 20% even when there is a concomitant ingestion of enhancers such as vitamin C and meat proteins.[7] Food absorption studies in humans have revealed that the absorption of haem iron is relatively unaffected by other dietary factors, while that of non-haem iron is influenced by them to a large extent. Haem iron from animal products is absorbed at 15 - 35% of intake, while non-haem iron absorption ranges from 2% to 20%.

Dependence on plant-based foods for iron nutrition may therefore result in a high prevalence of iron deficiency, particularly in populations at risk such as children and pregnant women, who have higher needs.[8-11] There is therefore a need to understand how dietary factors, including iron availability and intake, influence iron status.

Studies in Tanzania have indicated that there is a high amount of iron in cereals and vegetables consumed. However, this type of iron is usually of low bioavailability.[10,12] Our knowledge is limited regarding how the food consumption pattern in Tanzania is related to the prevalence of iron deficiency and anaemia. Hence, the purpose of this paper was to elucidate the relationship between food intake and iron status in a sample of anaemic schoolchildren in Tanzania.

Methods

Subjects

The study was conducted in five rural settlements of Mbori ward in Mpwapwa district, between July and August 1996. Schoolchildren aged 7 - 12 years were enrolled from 101 households. The children under study were a subsample of 840 children enrolled at baseline for anaemia intervention conducted during that time in the area.[11] These were grades I - IV Mbori primary school children, born and raised in the district and living in the area. The children under study completed baseline measurements before the dietary intake data were collected. Informed consent was obtained from parents and children to participate in the study. A structured profile questionnaire was used to collect nutrition particulars of schoolchildren before the dietary survey.

The food frequency questionnaire (FFQ)

A pre-tested food frequency questionnaire (FFQ) was used to interview householders on food intake and availability. The FFQ had a list of 35 food items identified from the community after market and household surveys. The FFQ included a list of food items (cereal staples) used for breakfast, lunch and dinner, and additional foods or snacks taken daily (Appendix A). The questions addressed were the number of days in a week the particular food was eaten in that household, and the portion size consumed by the index child per day. Interviews were conducted in Kiswahili. Nutritionists trained to estimate food portion sizes using utensils familiar to the community under study were used to collect food intake data. The estimated portion sizes were then measured to determine the translated weights or volumes to enable assessment of food intake. The FFQ was administered during a personal interview with the mother or guardian. Food items/meals consumed at school and away from home (snacks, seasonal fruits/cassava pieces) were also recorded. Information on seasonal foods was obtained to assist in explaining a possible variation in intake. Food samples commonly consumed in households were collected in sealed plastic bags and stored frozen at –20°C until analysed for total iron and iron solubility using an in vitro method.[10,12]

Nutrient intake data were analysed manually and using the Microsoft Excel computer software program. The Food and Agriculture Organization (FAQ) food composition table for use in Africa[13] was used to calculate nutrient intakes. Recommended dietary intakes (RDI) by age and sex were compared with the FAO/World Health Organization (WHO) RDIs[14,15] to assess the adequacy of diets and each individual's nutrient intake.

In vitro method to determine iron solubility

The collected staple foods and mixtures of commonly used foods were analysed using an *in vitro* method that estimates iron bioavailability. The *in vitro* method is a physiologically simulated peptic-pancreatin digestion[10,16] for soluble iron. Iron measurements were made on an atomic absorption spectrometer (PU 9100 X, Philips, Cambridge, UK). Total iron was determined after acid combustion in a microwave oven before it was analysed using high-performance liquid chromatography (HPLC) (Waters, 600 S Controller). All samples were analysed in duplicate. Percentage iron solubility was obtained by calculating the ratio of soluble iron after digestion to the total iron in the respective foods. In vitro solubility of iron was used as an estimation of iron bioavailability as it showed a high correlation with human studies of iron absorption.[17]

Biochemical analysis

Haemoglobin (Hb) concentration was determined using a HemoCue haemoglobinometer (HemoCue AB, Ängelholm, Sweden) and zinc protoporphyrin levels were measured on site using an AVIV haematofluorometer (AVIV Biomedical Inc., Lakewood, NJ, USA) and fingerprick blood samples. Hb measurement was done at an accuracy of ± 0.003 g/dl. Venous blood samples were collected and centrifuged after clotting at 1 000 × *g* for 20 minutes at room temperature. After separation, aliquots of sera were transferred to 2.0 ml cryogenic vials and frozen before transportation to the laboratory of Tanzania Food and Nutrition Centre (TFNC) in Dar es Salaam for analysis. Sera were transported frozen at –20°C in liquid nitrogen. Serum ferritin (SF) concentration was determined using the Elegance Amplified enzyme-linked immunosorbent assay (ELISA) system (Bioclone Australia Pty Ltd). Serum C-reactive protein (CRP) concentration was also determined using the ELISA system. The analyses for SF and CRP were performed at a precision with a coefficient of variation (CV) of < 10%. All analyses were performed within 1 month of collection.

Screening for parasitic infections

Stool and urine samples were screened microscopically for helminthic ova. Stool examination was done using the Kato-Katz method. Samples were examined on the day of collection. Two qualified laboratory technicians did the analysis and check on quality control. Interclass correlations between tests and quality control readings were 0.88 ± 0.01 for helminthic ova counts. Children with helminthic infections were treated with 400 mg albendazole. Children with schistosomiasis were treated with praziquantel (dose 40 mg/kg body weight). All children with splenomegaly and/or history suggestive of malaria, and severe anaemia were referred for diagnosis and treatment to the nearby health centre.

Anthropometry

Weight and height were measured, with schoolchildren in light clothing, to the nearest 0.1 unit. A Seca electronic scale (calibrated in kg) and a fixed-base portable stadiometer (in cm) were used for the measurements. Age was calculated from the birth date on school records, which were obtained from birth certificates. A medical doctor conducted clinical examinations.

Data analysis

Data were entered using Excel and were managed and analysed using the Systat statistical package (Systat Inc., 1997). Means and standard deviations (SDs) of all measured intakes for the total group of children with and without anaemia were compared using Student's *t*-test. Correlation between iron intake, iron status and the measured variables was considered significant when the *p*-value was ≤ 0.05. The cutoff level of iron intake used to categorise the different groups was 23 mg/day which is recommended for children between 6 and 12 years on a diet with an estimated low bioavailability.[13] Means of continuous variables were compared using the Student's *t*-test.

Ethical clearance

In Mpwapwa, communal consent was obtained in meetings with the district officials, village councils, schoolteachers and parents. The purpose and details of the study were explained to schoolchildren. The Research and Ethics Committee of the TFNC approved the study.

Results

Table I shows that the mean daily energy and nutrient intakes appear reasonable for the age range of these children. Mean iron intake was 27 ± 11 mg/day for boys and 24 ± 10 mg/day for girls. However, 52% of the schoolchildren had iron intakes below the WHO/UNICEF/United Nations University[15] RDI of 23 mg/day for a very low bioavailability (5%) diet. Energy intake was slightly higher in boys than girls ($p = 0.08$), and vitamin C intake was significantly ($p < 0.05$) higher in boys.[14]

Schoolchildren with anaemia had a significantly lower iron intake than those without anaemia (22 ± 7 v. 27 ± 12 mg/day) ($p < 0.05$) (Table II). A similar finding was noted for EP and SF, i.e. children with abnormal values had significantly lower iron intake. There was also a significantly ($p < 0.05$) higher energy intake in children with normal Hb concentrations compared with those who were anaemic (2 159 ± 956 v. 1 891 ± 675 kcal/day). Children who had iron deficiency (low SF and high EP values, respectively) also had significantly lower energy intake ($p < 0.05$).

In vitro iron solubility in foods consumed by these children ranged from 0.16 mg/100 g dry matter (dm) in cereals to 5.1 mg/100 g dm in vegetables, and the percentage solubility ranged from 1.2% in cereals to 28% in legumes (Table III). When composite diets of maize gruel and legumes were analysed according to the way they are consumed the highest in vitro iron solubility was about 5%.

Dietary sources of iron were similar for children with and without anaemia (Fig. 1). About 85% of the food sources of iron for both the anaemic and non-anaemic groups were plant-based, mostly cereals and green vegetables. Meat and meat products contributed only about 15% for both the non-anaemic and anaemic groups of children. In a stepwise multiple regression analysis, with haemoglobin as a dependent factor, daily iron intake remained the most significant factor ($p = 0.031$) predicting for Hb status in the measured schoolchildren (Table IV).

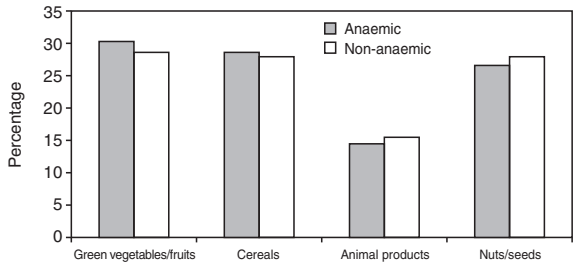

Fig. 1. Dietary sources contributing to iron intake (%) for schoolchildren in Mpwapwa district, Tanzania.

Table I. Daily nutrient intake of schoolchildren in Mpwapwa district grouped by sex*

Nutrients	Boys (*N* = 40)	Girls (*N* = 61)	All children (*N* = 101)
Iron (mg)	27 ± 11	24 ± 10	25 ± 11
% below cutoff†	(47.5)	(54.1)	(51.5)
Vitamin C (mg)	51 ± 31‡	32 ± 27	39 ± 36
Carbohydrates (g)	295 ± 92‡	249 ± 100	290 ± 100
Fat (g)	94 ± 50	77 ± 60	84 ± 60
Protein (g)	73 ± 33	62 ± 29	67 ± 30
% below cutoff†	(10.0)	(21.0)	(16.9)
Energy (kcal)	2 150 ± 770	1 830 ± 895	1 960 ± 860
% below cutoff†	(40.0)	(62.3)	(53.5)
Fibre (g)	23 ± 14‡	17 ± 9	20 ± 13

*Mean nutrient intake ± SD.
†Below FAO/WHO recommended daily intake.
‡Significantly different from girls ($p < 0.05$).

Table II. Daily nutrient intake of schoolchildren in Mpwapwa district grouped by iron status*

Nutrient intake	Serum ferritin (µg/l)		Erythrocyte protoporphyrin (µmol/mol haem)		Haemoglobin (g/dl)	
	Low† (*N* = 30)	Normal (*N* = 50)	High‡ (*N* = 20)	Normal (*N* = 60)	Anaemic§ (*N* = 38)	Normal (*N* = 42)
Iron (mg)	23 ± 8¶	26 ± 10	22 ± 8¶	26 ± 11	22 ± 7¶	27 ± 12
Vitamin C (mg)	29 ± 21	41 ± 29	30 ± 16	39 ± 16	40 ± 29	37 ± 27
Carbohydrate (g)	228 ± 72	282 ± 96	225 ± 65	279 ± 96	255 ± 91	290 ± 103
Fat (g)	77 ± 40	96 ± 62	64 ± 48	98 ± 59	78 ± 44	89 ± 67
Protein (g)	61 ± 23	69 ± 34	47 ± 18	74 ± 31	61 ± 27	73 ± 31
Energy (kcal)	1 764 ± 571¶	2 076 ± 832	1 612 ± 560¶	2 105 ± 850	1 891 ± 675¶	2 159 ± 956
Dietary fibre (g)	18 ± 12	19 ± 9	14 ± 8	21 ± 10	18 ± 10	19 ± 11

*Mean nutrient intake ± SD.
†SF < 20 µg/l.
‡EP > 125 µmol/mol haem.
§Hb < 11.5 g/dl.
¶Correlated significantly with iron status indicators ($p < 0.05$).

Table III. Food iron content and *in vitro* solubility of foods regularly consumed by schoolchildren in Mpwapwa district*

Food item	Total iron (mg/100 g dm)	Iron solubility*	
		mg/100 g dm	%
Cereals			
Finger millet	3.1	0.43 ± 0.03	12.6
Maize porridge	14.4	0.17 ± 0.05	1.2
Sorghum porridge	6.0	0.16 ± 0.06	2.6
Legumes			
Kidney beans	7.9	2.25 ± 0.05	27.9
Mung beans	5.7	1.17 ± 0.05	20.5
Cowpeas	5.9	1.64 ± 0.01	28.0
Vegetables			
Cowpea leaves	48.8	5.10 ± 0.02	13.0
Amaranth leaves	72.6	4.81 ± 0.05	6.6
Cassava leaves	6.2	0.37 ± 0.01	6.0
Meal mix (80:20)†			
Maize + amaranth	23.1	1.17 ± 0.09	5.1
Maize + kidney beans	13.1	0.37 ± 0.01	2.8
Maize + mung beans	12.6	0.31 ± 0.02	2.7
Maize + cowpeas	19.6	0.83 ± 0.01	4.2

*Mean of replicate samples analysed in duplicates.
†Dry weight ratio of cooked mixture.
dm = dry matter.

Of the 80 schoolchildren whose Hb concentration was measured, 47.5% were classified as anaemic (Hb < 11.5 g/dl). Forty-five per cent were iron deficient (SF < 20 µg/l and/or FEP > 125 µmol/mol haem) and 31% had iron deficiency anaemia (Hb < 11.5 g/dl and SF < 20 µg/l and/or FEP > 125 µmol/mol heam). Mean EP concentrations were significantly ($p < 0.05$) higher in the anaemic than in the non-anaemic children (Table V). CRP was measured in 42 of the schoolchildren. A larger proportion of children with increased CRP (CRP > 5 mg/l) were found in the anaemic group (17.6%) than in the non-anaemic group (8.0%). A screening for intestinal helminths showed positive findings in 2 of the children. Stunting was present in 47.5% of the schoolchildren (*N* = 0.80). Mean weight for age *z*-scores (WAZ), height for age *z*-scores (HAZ) and BMI were not significantly different between children in the anaemic and non-anaemic groups. Only 12% of the children were underweight.

Discussion

The present study shows that iron deficiency anaemia is a serious problem among schoolchildren in the Mpwapwa district in Tanzania. Similar findings have been reported in other studies.[10,18,19] Iron intake was significantly lower in children who had anaemia, implying that iron intake was marginal in this group. The stepwise multiple regression analysis (Table IV) also showed daily iron intake to be the most significant predictor of Hb status. This finding

supports the nutritional contribution of iron intake to anaemia in this community. This has also been reported in the Lindi rural study.[10]

Although the iron intake was high compared with the recommendation for a diet with low iron bioavailability (12 mg/d), the high prevalence of anaemia might therefore be a result of a diet with very low iron bioavailability. In fact, 50% of the schoolchildren had iron intakes below the RDI of 23 mg/d for children on a diet with very low iron bioavailability (WHO, 2001), i.e. 5%.[15] A very low bioavailability diet may be characterised as a simple, monotonous diet based on cereals, roots and tubers, with negligible quantities of iron enhancers such as meat, fish or ascorbic acid. By increasing the intake of these iron enhancers, such a diet may have a higher iron bioavailability (10%).

A lower iron and energy intake was also found in children with abnormal levels of SF and EP ($p < 0.05$). SF determines iron stores and EP is a measure of adequacy of iron nutrition in the functional compartment of the body where Hb is utilised. Although an elevated EP concentration could also be associated with infection, inflammation or lead poisoning,[20-22] lead poisoning is not prevalent in this area. Infections, however, can contribute to iron deficiency anaemia in this community. The finding of a higher percentage of children with raised CRP levels in the anaemic group (17.6% v. 8.0%) could be associated with the existence of chronic low-grade malaria, which is endemic in the area.[11] Malaria was not measured, but the questionnaire checked for any history of malaria fever. The current study shows that a few of the children with raised SF also had raised EP, indicating a possible false-negative finding for iron deficiency. This could explain the raised CRP among some anaemic children.[22] The other reason could be the use of a low cutoff level for CRP concentration in an area where

Table IV. Nutrients predicting for haemoglobin status in the diet of Tanzanian schoolchildren by stepwise multiple regression model*

Nutrients	Regression coefficient	Tolerance for entry into model†	F-value	*p*-value
Iron‡	0.035	1.000	4.833	0.031
Vitamin C	–0.077	0.847	0.492	0.485
Carbohydrates	–0.013	0.472	0.014	0.906
Energy	–0.026	0.495	0.054	0.817
Fat	–0.035	0.712	0.102	0.750
Fibre	–0.113	0.527	1.082	0.301
Proteins	0.050	0.363	0.210	0.648

*Regression coefficient (R) for model = 0.233, $R^2 = 0.054$.
†Minimum tolerance = 0.000.
‡Standard error of the mean = 0.016.

Table V. Iron and nutrition indicators (mean ± SD) in schoolchildren with and without anaemia, and percentage with nutritional problems

Nutritional indicator	Anaemic (*N* = 38)	Non-anaemic (*N* = 42)
Haemoglobin (g/dl)	9.9 ± 1.3	12.2± 0.7*
Haematocrit (%)	27 ± 5	33 ± 4*
Erythrocyte protoporphyrin (µmol/mol haem)	148 ± 105	58 ± 34*
Serum ferritin (µg/l)	28 ± 26	32 ± 18
C-reactive protein (µg/l, *N* = 42)	3.5 ± 4.5	2.3 ± 2.7
Weight for age *z*-scores (WAZ)	–1.2 ± 0.7	–1.5 ± 0.5
Height for age *z*-scores (HAZ)	–1.8 ± 1.1	–2.1 ± 1.0
Body mass index (BMI)	16.5 ± 1.5	16.5 ± 1.2
Prevalence of the factors (*N* = 80)	% of total	
Anaemia†	47.5	
Iron deficiency‡	45.0	
Iron deficiency anaemia§	31.3	
Stunted¶	47.5	
Underweight¶	11.9	
C-reactive protein (*N* = 42)II	11.9	

*Significantly different from the anaemia group ($p < 0.05$).
† Hb < 11.5 g or Hct < 34%.
‡ SF < 20 µg/l, or EP > 125 µmol/mol haem.
§ SF < 20 µg/l, or EP > 125 µmol/mol haem and Hb < 11.5 g/dl.
¶ Stunted or underweight HAZ or WAZ < –2.0.
II Inflammation sign is shown by CRP > 5 µg/l.

infections are common. Accordingly some researchers have been using a much higher cutoff,[23] i.e. > 10 mg/l.

Our study shows that plant-based foods, including cereals and vegetables, contributed 85% of dietary iron in the study children (Fig. 1.). The non-anaemic group seemed to consume a higher proportion of foods containing nuts and seeds as well as animal products, but the differences between the groups were not significant ($p > 0.05$). Meat, meat products and poultry contributed only 16% of dietary iron to the non-anaemic and 14.5% to the anaemic group of children. A high intake of vitamin C, as reported in this study, enhances non-haem iron absorption; however, these children tended to take foods containing vitamin C between the main meals, thus not providing the expected effect.[17,24] The reported high mean intake of ascorbic acid is explained by the high consumption of guavas and other locally grown vitamin C-rich fruits in season. These findings confirm the previously reported impact of a diet with very low iron availability on the prevalence of iron-deficiency anaemia.[10,16,25] Measurement of *in vitro* solubility in the diet of these children supports the assumption of a diet with very low iron availability (Table III).

Cereal staples commonly used by most Tanzanians have been shown to contain iron absorption inhibitors, particularly tannins and phytates, that can be reduced by several traditional methods of food processing.[15] These methods, when appropriately utilised, could improve the amount of available iron in staple foods. Dehulling can remove the polyphenols located mainly in the outer layers of the tannin-rich cereal grains. Absorption studies show that an increase in iron uptake from 2.4% to 6.3% occurs after dehulling brown sorghum and addition of ascorbic acid to the meals.[17] Soaking, germination and lactic acid fermentation are traditional food processing methods that may create optimal conditions for endogenous phytase activity in cereals. Phytases that hydrolyse phytate into lower inositol phosphates are present in most cereals and are activated during fermentation and germination. Phytate levels are reduced during fermentation. The fermentation and germination processes can improve the amount of soluble iron and increase food iron bioavailability from a low level (10%) to an intermediate level (12%),[7,8] and have proved to be of practical significance.[12,16] These findings, together with the observation that dietary iron availability is a problem, give this community a sustainable option to reduce the magnitude of the anaemia problem.

It is important that this community embark on a dietary approach to control anaemia since the availability of other iron-rich foods is limited. Traditional methods of food processing that reduce iron absorption inhibitors in foods and enhance iron availability should be encouraged. Increasing the intake of iron absorption enhancers such as ascorbic acid or meat at main meals will increase iron absorption and improve iron nutrition. As noted from the food intake interviews, meat consumption was low and ascorbic acid sources were taken between main meals. Studies elsewhere have shown that supplementation with a drink containing ascorbic acid and citric acid improves iron status indicators (EP and SF) in children.[11,26,27] This could be tried in this community using the available local fruits that are rich in vitamin C. Meat is known to promote uptake of non-haem iron from the diet.[8,28] It is not expected that poor rural people and especially the at-risk group, will increase intake of meat significantly to avoid iron deficiency in the near future. However, nutrition education on dietary diversification and modification should be emphasised.

Determining the accuracy of reported portion sizes and frequency of nutrient intake using food composition tables may be questionable, especially on an individual basis. However, these methods are adequate to describe intake in groups of children who are anaemic and those who are non-anaemic. The group intake data have helped to explain the association between dietary iron intake and iron status of the schoolchildren. FFQs allow assessment of long-term or usual food intake over a month or year. This reduces errors introduced by estimating usual intake from the day to day variability in 24-hour recalls.[29,30] The FFQ used in this study was designed based on food consumption in this Tanzanian community.[29] To avoid miscommunication the design took into consideration the cultural background of the community.

Conclusion

This study shows that schoolchildren with anaemia in this Tanzanian community have a lower iron intake than those who are not anaemic. There was also a significantly lower mean iron intake in children with abnormalities in iron nutrition indicators. Dietary sources of iron were mostly cereals and vegetables, which are known to contain phytates and tannins that inhibit absorption of non-haem iron. In vitro iron solubility tests of composite meals showed that iron in the local diet had a solubility of less than 6%. The diet consumed by these children can be categorised as being largely a 'very low bioavailability diet' due to low or no additional meat or vitamin C-containing foods as a meal component.

Recommendation

Increased intake of bioavailable iron should be one of the strategies for the prevention of iron deficiency anaemia in this community. To achieve this, the options are to improve household food processing methods, including germination and fermentation to enhance iron absorption from foods, to increase the consumption of ascorbic acid with main meals, and food fortification and deliberate addition of iron and vitamins to enrich cereal staple foods used in child feeding. People should be educated on how traditional methods of food processing can be used to minimise the effects of phytates and tannins that inhibit

iron absorption. Parasitic infections should be treated promptly and measures to prevent them should be instituted.

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1. World Health Organisation. Nutritional anemias. *World Health Organ Tech Rep Ser* 1968; No. 405.
2. DeMaeyer E, Adiels-Tegman M. The prevalence of anaemia in the world. *World Health Stat Q* 1985; **38:** 302-316.
3. World Health Organisation. *The Prevalence of Anaemia in Women, a Tabulation of Available Information*. Geneva: WHO, 1992.
4. Soewondo S, Husaini M, Pollitt E. Effects of iron deficiency on attention and learning processes in preschool children: Bandung, Indonesia. *Am J Clin Nutr* 1989; **50:** 667-674.
5. Bosta SS. Iron deficiency anaemia and the productivity of adult males in Indonesia. *Am J Clin Nutr* 1979; **32:** 916-925.
6. Salas J, Galan P, Arija V, Marti-Henneberg C, Hercberg S. Iron status and food intakes in a respresentative sample of children and adolescents living in a Mediterranean city of Spain. *Nutrition Research* 1990; **10:** 379-390.
7. Monsen ER. Iron nutrition and absorption: dietary factors that impact iron bioavailability. *J Am Diet Assoc* 1988; **88:** 786-790.
8. Cook JD, Monsen ER. Food iron absorption in human subjects. III. Comparison of the effect of animal proteins on non heme iron absorption. *Am J Clin Nutr* 1976; **29:** 859-867.
9. Yip R, Dallman PR. The roles of inflammation and iron deficiency as causes of anaemia. *Am J Clin Nutr* 1988; **48:** 1295-1300.
10. Tatala S, Svanberg U, Mduma B. Low dietary iron availability a major cause of anaemia. A nutrition survey in Lindi District of Tanzania. *Am J Clin Nutr* 1998; **68:** 171-178.
11. Latham MC, Ash D, Ndossi G, Mehansho H, Tatala S. Micronutrient dietary supplements — a new fourth approach. *Arch Latinoam Nutr* 2001; **51:** 37-41.
12. Lorri W, Svanberg U. An overview of the use of fermented foods for child feeding in Tanzania. *Ecology of Food and Nutrition* 1995; **34**: 57-63.
13. Food and Agriculture Organiszation. *Food Consumption Table For Use in Africa*. Rome: FAO, 1968.
14. FAO/WHO. Energy and protein requirements. Report of a joint FAO/WHO/UNU Expert Consultation. *World Health Organ Tech Rep Ser* 1986; No. 724: 145-156.
15. World Health Organization. Iron Deficiency Anaemia Assessment, Prevention and Control. A Guide for Programme Managers. UNICEF/UNU/WHO Report, 2001. WHO/NHD/01.3
16. Svanberg U, Lorri W, Sandberg AS. Lactic fermentation of non-tannin cereals: Effects on *in vitro* estimation of iron availability and phytate hydrolysis. *Journal of Food Science* 1993; **58:** 408-412.
17. Hallberg L, Brune M, Rossander L. Effect of ascorbic acid on iron absorption from different types of meals. *Hum Nutr Appl Nutr* 1986; **40A:** 97-113.
18. Stoltzfus RJ, Chwaya HM, Tielsch JM, Schulze KJ, Albonico M, Savioli L. Epidemiology of iron deficiency anaemia in Zanzibari schoolchildren: the importance of hookworms. *Am J Clin Nutri* 1997; **65:** 153-159.
19. Crompton DWT. Nutritional aspects of infection. *Trans R Soc Trop Med Hyg* 1986; **80:** 691-705.
20. Labbe RF, Finch CA. Erythrocyte protoporphyrin: application in the diagnosis of iron deficiency. In: Cook JD, ed. Methods in Haematology. Vol. 1. *Iron*. New York: Churchill Livingstone, 1980; 44-58.
21. Kuvibidila S, Yu L, Warrier RP, Ode D, Mbele V. Usefulness of serum ferritin in the assessment of iron status in non-pregnant Zairean women of child bearing age. *J Trop Med Hyg* 1994; **97:** 171-179.
22. Madanat F, El-Khateeb M, Tarawaneh M, Hijazi S. Serum ferritin in evaluation of iron status in children. *Acta Haematol* 1984; **1:** 111-115.
23. Wieringa FT, Dijkhuizen MA, West CE, Northrop-Clewes CA, Muhilal. Estimation of the effect of the acute phase response on indicators of micronutrient status in Indonesian infants. *J Nutr* 2002; **132:** 3060-3066.
24. Reddy MB, Hurrel RF, Cook JD. Estimation of non haem iron bioavailability from meal composition. *Am J Clin Nutr* 2000; **71:** 937-943.
25. Mamiro PRS, Van Camp J, Mwikya SM, Huyghebaert A. In vitro extractability of calcium, iron, zinc in finger millet and kidney beans during processing. *J Food Sci* 2001; **66:** 1271-1275.
26. Hunt JR, Mullen LM, Lykken GI, Gallagher SK, Nielsen FH. Ascorbic acid: effect on ongoing iron absorption and status in iron-depleted young women. *Am J Clin Nutr* 1990; **51:** 649-655.
27. Alexander D, Ball MJ, Mann J. Nutrient intake and hematological status of vegetarians and age-sex matched omnivores. *Eur J Clin Nutr* 1994; **48:** 538-546.
28. Bothwell TH, Baynes RD, MacFarlane BJ, MacPhail AP. Nutritional requirements and food iron absorption. *J Intern Med* 1989; **226:** 357-365.
29. Lukmanji Z, Ljugquvist B, Hedqvist F, Elisonguo C. Child feeding patterns in Tanzania with reference to feeding frequency and dietary bulk. Proceedings of the workshop 'Improving Young Child Feeding in Eastern and Southern Africa.' Nairobi, Kenya, 12 - 16 October 1987. Sponsored by IDRC, UNICEF, SIDA, 1988: 300-311.
30. Heitmann BL, Milman N, Hansen GL. Relationship between dietary iron intake, corrected for diet reporting error, and serum ferritin in Danish women aged 35 - 65 years. *Br J Nutr* 1996; **75:** 905-912.

Appendix A. **The pre-tested semi-quantitative food frequency questionnaire used to assess dietary intake in rural Tanzanian children (translated from a version in KiSwahili).**

Food items	Number of days on which food was eaten (per week)*	Portion eaten by index† child per day*
Main staple (maize, sorghum, rice, banana) _____ (name)		
Type (gruel/stiff porridge)		
Dark green leafy vegetables (spinach, amaranth, cassava, sweet potato, local green vegetables) _____ (name)		
Legumes (red beans, cowpeas, pigeon peas) _____ (name)		
Fruits (eggplant, oranges, lemon, guava, mangoes, watermelon, tomatoes, papaya, local fruits) _____ (name)		
Potatoes, cassava, bananas (cooked)		
Meat, liver		
Poultry		
Milk		
Wheat products (chapati, etc.)		
Oil seeds (groundnuts, sunflower) and extracted/oil/(groundnuts, sunflower) _____ (name)		
Margarine, ghee		
Pumpkin (and seeds)		
School meals _____ (name)		
Out of school and home meals/snacks _____ (name)		
Tea, coffee		
Eggs		

*Number of days or portions are recorded in spaces provided.
†Index = child in the age range who was included in the study.