Choice of foods and ingredients for moderately malnourished children 6 months to 5 years of age

Kim F. Michaelsen, Camilla Hoppe, Nanna Roos, Pernille Kaestel, Maria Stougaard, Lotte Lauritzen, Christian Mølgaard, Tsinuel Girma, and Henrik Friis

Abstract

There is consensus on how to treat severe malnutrition, but there is no agreement on the most cost-effective way to treat infants and young children with moderate malnutrition who consume cereal-dominated diets. The aim of this review is to give an overview of the nutritional qualities of relevant foods and ingredients in relation to the nutritional needs of children with moderate malnutrition and to identify research needs. The following general aspects are covered: energy density, macronutrient content and quality, minerals and vitamins, bioactive substances, antinutritional factors, and food processing. The nutritional values of the main food groups—cereals, legumes, pulses, roots, vegetables, fruits, and animal foods—are discussed. The special beneficial qualities of animal-source foods, which contain high levels of minerals important for growth, high-quality protein, and no antinutrients or fibers, are emphasized. In cereal-dominated diets, the plant foods should be processed to reduce the contents of antinutrients and fibers. Provision of a high fat content to increase energy density is emphasized; however, the content of micronutrients should also be increased to maintain nutrient density. The source of fat should be selected to supply optimal amounts of polyunsaturated fatty acids (PUFAs), especially n-3 fatty acids. Among multiple research needs, the following are highlighted: to identify the minimum quantity of animal foods needed to support acceptable child growth and development, to examine the nutritional gains of reducing contents of antinutrients and fibers in cereal- and legume-based diets, and to examine the role of fat quality, especially PUFA content and ratios, in children with moderate malnutrition.

Kim F. Michaelsen, Camilla Hoppe, Nanna Roos, Pernille Kaestel, Maria Stougaard, Lotte Lauritzen, Christian Mølgaard, and Henrik Friis are affiliated with the University of Copenhagen, Copenhagen, Denmark. Tsinuel Girma is affiliated with Jimma University, Jimma, Ethiopia.

Please address inquiries to the corresponding author: Kim F. Michaelsen, Department of Human Nutrition, University of Copenhagen, Rolighedsvej 30, DK-1958 Frederiksberg C, Denmark; e-mail: kfm@life.ku.dk.

Introduction

Child malnutrition is a major global health problem, leading to morbidity and mortality, impaired intellectual development and working capacity, and increased risk of adult disease. This review will deal with the needs of children between the ages of 6 months and 5 years with moderate malnutrition. Infants below 6 months of age should (ideally) be exclusively breastfed, and if malnourished, will have special needs, which will not be covered here. Moderate malnutrition includes all children with moderate wasting, defined as a weight-for-height between −3 and −2 z-scores of the median of the new World Health Organization (WHO) child growth standards and all those with moderate stunting, defined as a height-for-age between −3 and −2 z-scores. There are no specific recommendations on the optimal treatment of children with severe stunting, but it is assumed that children with severe stunting would benefit from a diet adapted for moderately stunted children, as pointed out in the proceedings of this meeting on the treatment of moderate malnutrition [1]. Throughout this review, we have therefore not distinguished between children with moderate stunting and those with severe stunting.

A recent (2005) analysis by the Maternal and Child Malnutrition Study Group (MCUSG) of data from 388 national surveys from 139 countries [2] has provided new estimates of the global prevalence of underweight, stunting, and wasting among children below 5 years of age, based on the new WHO Child Growth Standards. Of the 556 million children under 5 years of age in low-income countries, 20% (112 million) were underweight, 32% (178 million) were stunted, and 10% (55 million) were wasted, including 3.5% (19 million) who were severely wasted. Thus, about 36 million children are suffering from moderate wasting. Underweight, stunting, and wasting each contributes to child mortality and disease burden. Of the almost 10 million deaths annually among children below 5 years of age, it was estimated that the attributable fractions of underweight, stunting, and wasting were 19%, 15%, and 15%, respectively, whereas intrauterine growth restriction and low birthweight accounted for only 3.3%. Altogether, these anthropometric indicators of malnutrition, using −2 z-scores as cutoffs, accounted for 21.4% of child mortality and 21.1% of child disease burden [2]. Of the 14.6% of deaths attributable to wasting, only 4.4% were due to severe wasting, and hence 10.2% of the deaths, or about 1 million, were due to moderate wasting.

The typical diet in populations with a high prevalence of malnutrition consists predominantly of a starch-rich staple, such as a cereal (maize, rice) or tuber (cassava), with limited amounts of fruits, vegetables, legumes, and pulses, and little or no animal-source food. Such a diet is bulky, has a low density of energy and nutrients and a low bioavailability of minerals, and will result in impaired growth, development, and host defense to infections. In addition, introduction of such a diet too early or contamination of the diet will lead to frequent infections, which will further impair nutritional status and, hence, increase the risk of infectious diseases. Young children are also likely to be more sensitive to the effect of antinutrients, e.g., high levels of phytate, which impairs the absorption of several growth-limiting minerals, such as zinc. Infants and young children are especially vulnerable to malnutrition because they have a high growth velocity and also high energy and nutrient needs. Growth velocity up to the age of about 2 years is especially high, and it is also during this period that the brain reaches almost 90% of adult size. Global figures on nutritional status have also shown that malnutrition among children below 5 years of age develops mainly during the period from 6 to 18 months [3]. This period, which is the complementary feeding period, is therefore of special importance and will be given special attention in this review. Breastmilk is not included among the foods discussed in this review, as the importance of breastfeeding, especially for malnourished infants and young children, has been emphasized in many other reviews. In the treatment of moderate malnutrition, it is very important that breastfeeding be continued whenever possible and that the dietary treatment given does not replace breastmilk.

As pointed out in the review by Golden on the nutritional requirements of moderately malnourished children [4], the nutritional needs of a wasted and a stunted child differ. In particular, the time needed to reverse the condition will differ considerably between wasting and stunting. It will often be possible to reverse moderate wasting within 2 to 4 weeks, whereas reversing moderate stunting may take months or years, if it is possible at all. Reversing stunting is easier the earlier treatment is started, and the first 2 years especially seem to be a "window of opportunity." Thus, the requirements of stunted children may be different for different age groups. The main difference between the requirements of wasted and stunted children will be that wasted children have a higher energy requirement and therefore will also benefit from a higher energy density and a higher fat content of the diet, provided the need for other nutrients is covered. If stunted children, with no wasting, are given a diet with high energy density and high fat content over longer periods, there is a risk that they will develop obesity. However, in populations with a high rate of malnutrition, it is likely that those in the age group from 6 to 24 months would benefit from a relatively high energy density, even if they have not yet developed moderate wasting or are "only" moderately stunted. Thus, a diet with a high energy density could have an important role in preventing moderate malnutrition in such populations. When the need for other nutrients is expressed in relation to energy content, it is likely that the requirements will not differ much between children with moderate wasting and stunting [4, 5]. Other factors might also influence the requirements of a moderately malnourished child. The needs are likely to be different if the child is malnourished because of gastrointestinal problems, with impaired absorption of nutrients, or is malnourished mainly due to recurrent infectious diseases, as compared with a child with malnutrition due mainly to an insufficient diet.

The aim of this review is to identify *foods and ingredients* appropriate to treat moderately malnourished children. These foods should be used to create a *diet* that can fulfill the requirements of moderately malnourished children. Some foods and ingredients of limited availability may only be appropriate as part of home-based diets in specific settings, whereas others could be used in food supplements distributed by international organizations, nongovernmental organizations (NGOs), and governments. In **table 1**, the desirable characteristics of such a diet are outlined, and these characteristics will be discussed in detail in this review. Individual foods and ingredients may fulfill only some of these characteristics. For instance, green leafy vegetables may provide a high content of micronutrients and be a valuable food, although they have low fat and low energy contents.

Nutritional qualities of foods and ingredients

Energy density

The energy density is one of the most important qualities of foods for wasted children. If the energy density is too low, the food becomes too bulky, and the child will not be able to eat adequate amounts. Infants and

TABLE 1. Important characteristics of diets appropriate for children with moderate malnutrition

High content of micronutrients, especially growth (type II) nutrients
High energy density
Adequate protein content
High protein quality and availability
Adequate fat content
Appropriate fat quality, especially n-3/n-6 PUFA content
Content of some animal-source foods
Low content of antinutrients
Low risk of contamination
Acceptable taste and texture
Culturally acceptable
Easy to prepare
Affordable and available

PUFA, polyunsaturated fatty acid

young children have a limited gastric capacity and an energy requirement per unit body weight about three times as high as adults. If a diet has a very low energy density, even nonmalnourished children may not be able to eat adequate amounts because of the bulkiness of the diet. The energy density is most important for children with wasting, as they have an increased energy need for catch-up growth.

The most important factor influencing energy density is the fat content, as the energy density of fat (9 kcal/g) according to the Atwater factors is more than double that of protein and carbohydrate (4 kcal/g). Another important factor is the water content. A biscuit will typically have an energy density of 4 kcal/g, whereas the energy density is much lower in gruels and porridges given to infants. These will typically have densities between 0.6 and 0.8 kcal/g, but the density may be as low as 0.25 kcal/g if the food is based on only cereal and water [6]. The energy density of gruel and porridge is influenced by the type of flour, the fiber content, the method of processing the flour, how the porridge is cooked, and which ingredients are added. The energy density of a meal is calculated as the crude energy content of the ingredients, without taking into account the fact that some of the energy is not available, such as that of fibers. It is likely that this unavailable fraction is higher in malnourished infants and young children than in healthy adults.

Brown et al. have described in detail how different levels of energy density can influence energy intake and how energy intake is also affected by the number of meals given [7]. The effect of meal frequency and energy density on energy intake was examined in 6- to 18-month-old Peruvian children recovering from malnutrition [8]. The energy densities of the diets were 0.4, 0.7, 1.0, and 1.5 kcal/g. When the number of meals per day (from three to five) was controlled for, the energy intake increased with higher energy densities. However, there were some adjustments, as the children were eating smaller amounts. Although the amount eaten was less with the higher energy densities, the children did not compensate fully. Interestingly, when the energy density increased from 1.0 kcal/g, which is usually considered an adequate energy density, to 1.5 kcal/g, the energy intake per kilogram of body weight increased by approximately 20% to 25%.

In a review of complementary feeding, nine studies comparing energy intake in malnourished children receiving diets with different energy densities were identified [7]. In six of the studies, energy intake was considerably higher when the children were given an energy-dense diet. In most of the studies, the level of the energy density in the low-energy-density diet was about 0.5 kcal/g or lower. However, a study of 5- to 18-month-old malnourished children in Bangladesh compared a diet with an energy density of 0.92 kcal/g with a diet of 1.47 kcal/g and also found an increase (about 50%) in energy intake in the group on the energy-dense diet [9]. Thus, increasing energy densities to above 1.0 kcal/g also resulted in increased energy intake among malnourished children. Several studies have shown that ready-to-use therapeutic foods (RUTFs) are very effective in treating severely wasted children [10–12]. A key characteristic of RUTFs is the very high energy density, about 5 kcal/g. However, in populations with a high rate of malnutrition, it is likely that those in the age group from 6 to 24 months would benefit from a relatively high energy density, even if they have not yet developed moderate wasting or stunting. Thus, an energy-dense diet could have an important role in preventing moderate malnutrition in such populations. In addition to the high energy density, other characteristics, such as the supply of milk protein, the fact that they are nutritionally complete in micronutrients, and the fact that they can be eaten without preparation and that most children like them, are likely to contribute to the effectiveness of RUTFs.

In nonbreastfed 6- to 18-month-old children, the minimum energy density of the diet, assuming three daily meals and a functional gastric capacity of 30 g/kg body weight, has been calculated as between 1.00 and 1.08 kcal/g [13]. If the child receives five meals per day, the minimum values are from 0.60 to 0.65 kcal/g. In the 1980s, Cameron and Hofvander suggested that the energy density of diets given to nonmalnourished children in low-income countries should be considerably higher, between 1.5 and 2.0 kcal/g, to provide enough energy [14]. However, these estimates were based on the energy requirements from 1985 [15], which at that time were about 20% higher than current estimates [16].

Diets with a considerably higher energy density than 1 kcal/g and even 2 kcal/g may be beneficial in treating moderately wasted children. These children have an increased energy need for catch-up, and some will have a poor appetite with an inability to eat large amounts. One of the reasons that RUTFs have been so successful in the treatment of severe wasting is likely to be their high energy density of about 5 kcal/g. However, there is a need for intervention studies examining the potential effects of a high-energy diet given to children with moderate malnutrition. A potential adverse effect of a diet with a high energy density in breastfed infants could be a reduction in breastmilk intake, as shown in two studies [17, 18]. However, other studies could not find such an effect [19, 20].

A high energy density can be achieved by reducing the water content of the food and by adding oils or sugar. It is usually considered to be difficult to produce gruels and porridges with energy densities above 1.5 to 2.0 kcal/g. Reducing the water content will result in foods that are not easy for infants and young children to eat because of inappropriate texture and viscosity, and if sugar and other water-soluble ingredients are added in high amounts, the osmolarity will easily become too high. Preferably, the osmolarity should not be much above 300 mOsm/kg [4]. Adding more oil to the diet will not have these negative effects, but the acceptability of adding considerably higher amounts of oil to the foods given to children with moderate malnutrition should be examined further (see Fat Content, below). However, when high amounts of oils (or other ingredients with "empty calories," such as sugar) are added to the diet, it is very important that the nutrient density in the total diet be adequate. In populations with a high rate of malnutrition, it is likely that those in the age group from 6 to 24 months would benefit from a relatively high energy density, even if they have not yet developed moderate wasting or moderate stunting. Thus, an energy-dense diet could also have an important role in preventing moderate malnutrition in such populations.

Conclusions and recommendations on energy density

» Children with stunting have smaller energy requirements than children with moderate wasting and therefore do not have the same need for foods with a high energy density. The energy density of their food probably should not be much higher than that of food for children without malnutrition.
» Energy densities between 1 and 1.5 kcal/g are recommended for infants and young children with stunting.
» Giving a diet with a high energy density for a long period to stunted children could potentially lead to obesity.
» For children with moderate wasting, foods with energy densities between 1.5 and 2.0 kcal/g should be preferred.
» High energy densities can be obtained by adding fats or oils to the food, which will not increase the osmolarity.

Research recommendations

» Research is needed to further define the optimal energy density among both stunted and moderately wasted children.
» It should be investigated whether energy densities higher than 2.0 kcal/g given to children with moderate wasting have advantages and can increase gain in lean body mass.

Water content

The water content of foods differs considerably, from a very high content in liquid foods to a very low content in dry foods such as biscuits. Semiliquid foods or foods fed with a spoon, such as porridges and mashes, are important in the diet of infants and young children, and here the water content is an important determinant of important characteristics such as energy density and viscosity. High water content in a food reduces the energy density and increases the bulk of the food, and if the water content is too high, it will negatively influence energy intake. On the other hand, low water content will increase the viscosity of the food and may make it difficult for young children to eat.

Foods with very low water content, such as RUTFs or biscuits, have a long shelf-life, since the low water content impairs microbial growth if the food becomes contaminated. The minimum water requirement (the water content not bound to food molecules, expressed as the water activity level) for the growth of microorganisms has been determined [21]. For bacteria it is typically 0.85, and for yeast and molds it is as low as 0.61. The water activity level is 0.99 in fresh meat, 0.95 in bread, 0.3 in biscuits, and 0.2 in milk powder. RUTFs have a water activity level of about 0.4 and a shelf-life up to 2 years.

If foods with low water content are given, such as biscuits, there is a need to cover the water requirements in another way, through drinks. If the child drinks unboiled water, the risk of infections from contaminated water is increased, when compared with a situation where the child will receive water in foods that have been boiled or heated, provided the food is given just after preparation and is not contaminated before consumption. As pointed out in the review by Golden, it is especially important that the water requirement be covered in malnourished children, as they have reduced ability to concentrate urine [4].

Macronutrients

Protein

Dietary protein content and quality are of major importance in the treatment of malnourished children. If the content, quality, or availability is too low, it will limit growth and thereby recovery. If the intake is above the requirement, the surplus protein will be metabolized into energy, which is not an energy-efficient process. A surplus will also produce urea, adding to the renal solute load, which is a problem in malnourished children [4]. Furthermore, too much protein might have a negative impact on appetite [22], which is especially harmful in malnourished children undergoing treatment. In severe malnutrition, a high protein intake might compromise liver function [4], but to what degree this is the case for moderate malnutrition is not known. Finally, protein, especially if it comes from animal sources, is typically an expensive ingredient in a diet, which is another reason for not supplying a surplus of protein.

In deciding the optimal protein content of a diet for moderately malnourished children, both the amount and the quality of protein should be taken into account. In the review by Golden [4], it is suggested that the protein requirement of children with moderate malnutrition should be at least 24 of g protein/1,000 kcal (equivalent to about 9.6 protein energy percent [E%]) and preferably 26 g/1,000 kcal (10.4 E%) and that the protein digestibility-corrected amino acid score (PDCAAS) should be at least 70%. These amounts take into account both the extra needs of moderately malnourished children for growth and the extra allowances needed while they are suffering from infectious diseases. This is considerably higher than that in the recent World Health Organization/Food and Agriculture Organization (WHO/FAO) report on protein requirements [5], which recommended a minimum of 6.9 protein E% on the assumption of a catch-up growth of 5 g/kg per day and 8.9 PE% if 10 g/kg per day is assumed. In a review of the composition of fortified blended foods, we suggested aiming for a protein E% of about 12, taking into account that the food supplement would not cover the whole diet [23]. As suggested in the conclusions of this meeting, it is recommended that the protein E% in diets for children with moderate malnutrition should not be above 15 [1].

Protein quality

High-quality protein is defined as protein that supports maximal growth. The various protein quality indexes include one or more factors related to amino acid profile, digestibility, and the presence of inhibiting or enhancing components in the food ingested.

Previously, the protein efficiency ratio (PER) was the most widely used index for evaluating protein quality. It is defined as body weight gain divided by the amount of test protein consumed by a young growing rat. An important disadvantage of the PER is the differences in growth patterns between rats and humans and the different amino acid requirements [24].

The protein digestibility-corrected amino acid score (PDCAAS) is a more recent method to evaluate protein quality and has been introduced because of the weakness of other indexes such as PER. PDCAAS has been adopted by FAO/WHO as the method of choice for evaluating protein quality in human nutrition [5]. PDCAAS represents the amino acids available after protein digestion, that is, the content of the first limiting essential amino acid in a test protein divided by the content of the same amino acid in a reference pattern of essential amino acids [25]. The index also includes the digestibility of the protein, defined as the true digestibility of the test protein measured in a rat assay [24]:

$$PDCAAS = AAS \times TD,$$

where AAS is the amino acid score and TD is the true digestibility.

The highest PDCAAS value that any protein can achieve is by definition 1.0 or 100%, which means that 100% or more of the requirement of essential amino acids is achieved. A score above 100% should by definition be truncated to 100%, because any amino acids in excess of what is required for building and repairing tissues are catabolized. However, when calculating PDCAAS values of diets or foods with several ingredients, the exact PDCAAS value of these ingredients is important, also when PDCAAS is above 100%. Truncation limits the information provided about the potency of a specific protein source to counteract and balance inferior proteins in mixed diets [25]. Therefore, PDCAAS values above 100% are used in this review without truncating.

There are several limitations that must be considered when using PDCAAS: the validity of using the protein requirement of children in a reference amino acid pattern, and the validity of using true digestibility and the truncation of values above 100%. The reference scoring pattern is based on the amino acid requirements of children older than 1 year [26]. Because the basic data were obtained from children who were recovering from malnutrition, the relevance of these amino acid requirements for healthy children can be questioned. In this review, the fact that the data were obtained from children who were recovering from malnutrition should be seen as an advantage, since the focus is on malnourished children. The reference pattern does not, however, include amino acids that may be important under specific physiological and pathological conditions, such as in children and adults suffering from HIV/AIDS [25]. Another limitation is that the list of the amino acid requirements used to identify the limiting amino acid has only one value for total sulfur amino acids, a group that also includes methionine, which is one of the limiting amino acids in soy [25]. PDCAAS is based on protein input and output and may overestimate the protein quality, as it does not take into consideration amino acids that are left unabsorbed in the ileum and are used by bacteria in the colon instead. Similarly, amino acids that are bound to antinutritional factors and thereby are unavailable for absorption are assumed to be digested when the PDCAAS value is calculated [26]. Different PDCAAS values can be obtained for the same food item because of varying values of amino acids in various food tables. Thus, PDCAAS values for the same food might vary, as seen in **table 2**, in which examples of PDCAAS values of different foods from the literature are given together with values we have calculated.

Calculating the PDCAAS value for a food with two or more ingredients is complicated. It is not enough to know the PDCAAS value for each ingredient if the limiting amino acid is not the same. If that is the case. it is necessary to know the amino acid composition of each of the ingredients, to identify the limiting amino acid in the combined food.

There is strong evidence that adding animal-source foods to diets for moderately malnourished children will improve growth and recovery. This could be due to the higher micronutrient intake or the lower intake of antinutrients, as described in Animal-Source Foods, below. However, it is likely that the improved protein quality also plays an important role. We have therefore calculated how different amounts of milk (skimmed-milk powder) and meat (beef) added to different vegetable-source foods influence PDCAAS values. In **table 3** we have calculated how PDCAAS is influenced by replacing 10%, 25%, or 50% of the *weight* of the vegetable-source food by milk or meat. In **table 4** we have performed the same exercise, but with the *protein content* of the vegetable-source food being replaced by protein from animal-source foods.

When the amount of animal food added is based on protein weight (**table 4**), there is not much difference between the effects of milk and meat on PDCAAS. For the vegetable-source foods with the lowest PDCAAS (wheat, maize, black beans, and cassava), it is only when 50% of the protein is replaced by an animal-source food that the increases are up to a level of 80% or above. If only 25% of the protein is replaced, the PDCAAS values are around 60% or lower. When the calculations are based on the weight of foods (**table 3**), milk has a more pronounced effect on the PDCAAS than meat, because meat contains only 20% protein, as compared with 36% in dry skimmed-milk powder. Adding 25% milk powder brings PDCAAS values to a reasonable level (above 70%), whereas the PDCAAS level when meat is added is only 60% or slightly above for wheat, maize, or black beans.

If the aim is to increase the PDCAAS of a combined vegetable and animal meal or diet to a level of 70%

TABLE 2. PDCAAS values of different foods

Food	PDCAAS (%)—from literature[a]	PDCAAS (%)—our calculations[b]
Animal-source foods		
Beef	92 [25]	94
Egg	118 [25]	
Cow's milk	121 [25]	112
Whey protein concentrate	114–161 [23, 24]	
Skimmed-milk powder	124 [24]	
Vegetable-source foods		
Oats	45–51 [29]	60
Rapeseed meal	46 [30]	
Maize	52 [31]	35
Wheat	54 [31], 42 [25]	37
Cassava	57 [31]	44
Rice	65 [31]	54
Black beans	72 [26]	45
Yam	73 [31]	55
Potato	82 [31]	71
Soybeans	90 [31], 91 [25]	93

a. Sources of protein digestibility-corrected amino acid score (PDCAAS) values are given in square brackets.
b. PDCAAS values were calculated on the basis of data from USDA Nutrient Database [27] and the National Danish Nutrient Database [28] with reference to 2- to 5- year-old children recovering from malnutrition [25].

TABLE 3. PDCAAS values (%) with limiting amino acid in parentheses if various proportions of the *weight* of a cereal, legume, or root are replaced by animal protein

Food item	0%	Milk (dry skimmed milk) 10%	Milk 25%	Milk 50%	Meat (beef) 10%	Meat 25%	Meat 50%
Wheat	37 (Lys)	55 (Lys)	75 (Lys)	98 (Lys)	49 (Lys)	66 (Lys)	92 (Lys)
Rice	54 (Lys)	75 (Lys)	93 (Lys)	110 (Lys)	70 (Lys)	88 (Lys)	98 (Trp)
Maize	35 (Lys)	56 (Lys)	78 (Trp)	95 (Trp)	50 (Lys)	62 (Trp)	76 (Trp)
Oats	60 (Lys)	73 (Lys)	88 (Lys)	105 (Lys)	69 (Lys)	82 (Lys)	96 (Trp)
Soybeans	93 (Lys)	96 (Lys)	99 (Lys)	106 (Lys/Trp)	95 (Lys)	98 (Lys)	100 (Trp)
Black beans	45 (SAA)	56 (SAA)	71 (SAA)	93 (SAA)	50 (SAA)	60 (SAA)	77 (SAA)
Potato	71 (SAA)	106 (SAA/Thr)	113 (Trp)	112 (Trp)	94 (SAA)	99 (Trp)[a]	96 (Trp)[a]
Cassava	44 (Lys)	85 (Lys)	103 (Thr)	111 (Trp)	74 (Thr)	92 (Thr)	95 (Trp)
Yam	55 (Lys)	96 (Trp)	105 (Trp)	110 (Trp)	78 (Trp)	87 (Trp)	91 (Trp)

PDCAAS, protein digestibility-corrected amino acid score; SAA, sulfur amino acids
a. Values decrease, as trypsin is lower in beef than in soybeans.

TABLE 4. PDCAAS values (%) with limiting amino acid in parentheses if various proportions of the *protein content* of a cereal, legume, or root are replaced by animal protein

		Milk (dry skimmed milk)			Meat (beef)		
Food item	0%	10%	25%	50%	10%	25%	50%
Wheat	37 (Lys)	45 (Lys)	57 (Lys)	79 (Lys)	46 (Lys)	60 (Lys)	84 (Lys)
Rice	54 (Lys)	61 (Lys)	71 (Lys)	88 (Lys)	62 (Lys)	73 (Lys)	93 (Lys)
Maize	35 (Lys)	42 (Lys)	54 (Lys)	75 (Lys+Trp)	43 (Lys)	55 (Trp)	67 (Trp)
Oats	60 (Lys)	65 (Lys)	74 (Lys)	90 (Lys)	66 (Lys)	77 (Lys)	95 (Lys)
Soybeans	93 (Lys)	96 (Lys)	101 (Lys)	107 (Trp)	97 (Lys)	100 (Trp)[a]	98 (Trp)[a]
Black beans	45 (SAA)	51 (SAA)	62 (SAA)	81 (SAA)	50 (SAA)	60 (SAA)	88 (SAA)
Potato	71 (SAA)	76 (SAA)	84 (SAA)	97 (SAA)	75 (SAA)	82 (SAA)	93 (SAA)
Cassava	44 (Lys)	51 (Lys)	62 (Lys)	81 (Lys)	52 (Lys)	64 (Lys+Thr)	80 (Thr)
Yam	55 (Lys)	61 (Lys)	70 (Trp)	84 (Trp)	61 (Trp)	66 (Trp)	75 (Trp)

PDCAAS, protein digestibility-corrected amino acid score; SAA, sulfur amino acids
a. Values decrease, as trypsin is lower in beef than in soybeans.

to 80%, as suggested in the review by Golden [4], then adding about 33% to 40% of the protein content as animal food to vegetable foods with the lowest PDCAAS values would be sufficient. To make a significant impact on growth, a prudent recommendation would be that at least one-third of the protein intake should come from animal products if the staple food has a low PDCAAS.

The calculations made here, combining only two foods, are simple as compared with calculations for the total diet, which typically will contain several other ingredients. These other ingredients could have a lower PDCAAS value, reducing the PDCAAS of the whole diet. But they could also have an amino acid pattern that would complement the pattern of the remaining foods, resulting in a higher PDCAAS of the total diet.

Conclusions and recommendations on protein

» Protein intake and quality are important determinants of growth in the treatment of moderately malnourished children.
» A surplus of protein in the diet may reduce appetite and is an ineffective and costly source of energy
» A high protein quality, i.e., PDCAAS > 70% to 80%, should be aimed for.
» Children receiving a diet with a low PDCAAS would benefit from addition of animal-source foods to the diet. It is suggested that about one-third of the protein intake should come from animal-source foods to make a significant impact on growth.

Fat

Fat content

Fat is an important source of energy for infants and young children. The fat content of human milk is high, with about 50% of the energy coming from fat, underlining that fat requirements are high in early life. After introduction of complementary foods, the fat content of the diet decreases, but there is at present no general agreement about the optimal level of fat in complementary foods and in diets for young children. Several recommendations from high-income countries have stated that there should be no restrictions on fat intake during the first years of life, without giving a minimum level [32]. For complementary feeding of children who are not malnourished, a level of 30 to 45 fat E% has been recommended, including the fat from breastmilk [33]. For foods used in emergencies, a fat content of 30 to 40 E% has been recommended for complementary feeding [34]. In the WHO guidelines for nonbreastfed infants and young children, the amount of fat to be added to a diet, aiming at 30 fat E% in the total diet, has been calculated [13]. If the diet contains no animal-source foods, it is recommended that 10 to 20 g of fat or oil should be added to the diet, while it is recommended that children eating animal-source foods, including whole milk, should only be given an additional 5 g of fat or oil daily, equal to one teaspoon per day.

Two reviews have evaluated the evidence for a negative effect of a low fat energy percentage in the diet of children in low-income countries. Prentice and Paul [35] concluded that many children in low-income countries would benefit from an increased fat intake, and they suggested a minimum level of 20 to 25 fat E%. They were cautious about recommending a much higher intake of fat because of the potential risk of obesity and comorbidities seen in many countries, but this is not likely to be a concern in the treatment of children with moderate malnutrition, where the period of treatment is limited. In an analysis of national data from 19 countries from Latin America, Uauy and coworkers [36] compared food-balance sheets with prevalence rates of underweight, stunting, and wasting in the countries. They found that a diet with less than 22% of energy from fat was likely to restrict growth and also that a low intake of animal fats was likely to have a negative effect on growth.

Fortified blended foods such as corn–soy blend and UNIMIX are given to children with moderate malnutrition. These blends have a low fat content, about 14% to 16% of the energy. They are meant to be distributed with separate provision of oil, but to what extent the oil is added to these fortified blended foods when they are given to infants and young children is not known. In some programs, corn–soy blend is mixed with oil before it is handed out. The reason for not adding oil to the fortified blended foods at production is that they would rapidly become rancid and have a shelf-life of only some weeks. However, if oils with added oxidants are used, the shelf-life is longer.

Children with moderate malnutrition, especially those with moderate wasting, have an increased need for energy for catch-up growth and thus require a diet with a high energy density. A diet with high fat content is therefore likely to be beneficial for these children. It is interesting that foods used for treatment of children with severe malnutrition have a very high fat content. In F100 about 50% of the energy comes from fat, and in RUTFs the percentage of energy from fat is between 50% and 60%.

Given the high energy needs of wasted children and the positive results obtained with foods with a high fat content in the treatment of severe malnutrition, it seems prudent to aim at a fat intake close to the upper limit of the range suggested in the review by Golden [4], which is 45 E% for treatment of moderately wasted children. For children with moderate stunting, who need treatment for longer periods, a fat energy percentage close to the lower limit, which is 35 E%, is probably sufficient.

Conclusions and recommendations on fat content

» A low content of fat in the diet reduces the energy density and total energy intake.

» Diets for moderately malnourished children should aim at a fat energy percentage between 35 and 45, and not go below a minimum level of 30 fat E%.

» When the fat content is increased, there may be a need to also increase the content of other nutrients to avoid a decline in the nutrient density.

Research recommendations

» It is plausible that children with moderate wasting would benefit from a diet with a fat content closer to the upper limit (45 E%), whereas a fat content closer to the lower limit (35 E%) will be sufficient for children with stunting. However, there is a need to perform studies to explore optimal fat content further and to examine how different fat contents influence gain in lean body mass.

Fatty acid composition and content of essential fatty acids

Apart from supplying energy, dietary fat plays an important role in allowing adequate absorption of fat-soluble vitamins and an adequate supply of essential fatty acids. The differences between fat sources with respect to absorption of the fat-soluble vitamins vitamin A, D, and E appear to be small. About 5 g of fat has been found to be needed per meal to provide good bioavailability of vitamin A. The absorption seems to be improved somewhat by fat rich in oleic acid (C18:1), but other oils are probably almost as good [37]. Therefore, we assume the essential fatty acid issue to be the most relevant with respect to moderately malnourished children.

There are two types of essential fatty acids, the n-6 and the n-3 polyunsaturated fatty acids (PUFAs), which in most diets are provided by vegetable oils in the form of linoleic acid (C18:2n-6) and α-linolenic acid (C18:3n-3), respectively. Essential fatty acids may also be supplied from meat and fish in their long-chained forms, arachidonic acid (C20:4n-6), eicosapentaenoic acid (C20:5n-3), and docosahexaenoic acid (C22:6n-3).

According to the Nordic Nutrition Recommendations [38], the fat intake of young children (1 to 2 years) should have a quality that provides 5 to 10 E% as essential fatty acids, including at least 1 E% of n-3 PUFA and have a ratio of n-6 to n-3 PUFA between 3 and 9. The need for essential fatty acids is expected to follow the need for energy, and thus the requirements, expressed in weight of essential fatty acids, are expected to increase during a refeeding phase. The FAO/WHO recommendations from 1994 include a general statement that the ratio of linoleic acid to α-linolenic acid in the diet should be between 5 and 10 [39]. Furthermore, it is stated that during the complementary feeding period and until at least 2 years of age, a child's diet should provide similar levels of essential fatty acids as are found in breastmilk. According to the Codex Alimentarius Standard for Infant Formula [40], the ratio of linoleic acid to α-linolenic acid should be between 5 and 15. These recommendations are based on the range of ratios found in breastmilk. However, the ratio in breastmilk tends to be high (up to 15) in populations where mothers have very low intakes of n-3 fatty acids: below the recommended levels [41]. Thus, it is likely that a range between 5 and 9 is more optimal. It makes most sense to use the ratio between n-6 and n-3 PUFA for fatty acids on the same metabolic level (linoleic acid and α-linolenic acid or arachidonic acid vs. n-3 long-chain PUFA [LCPUFA]). However, most foods except fish have only a limited amount of LCPUFA. For these foods, the linoleic acid/α-linolenic acid ratio is almost identical to the n-6/n-3 PUFA ratio.

Golden in his review suggests that the requirement for n-6 PUFA in moderately malnourished individuals is 4.5 E% (equivalent to 5 g/1,000 kcal) and the n-3 PUFA requirement is 0.5 E% (equivalent to 0.55 g/1,000 kcal) [4]. Thus, these recommendations imply an n-6/n-3 PUFA ratio of 9.

A conditional requirement for n-3 LCPUFA is presently established in premature infants, but more mature infants and older children may also benefit from an intake of preformed n-3 LCPUFA. The n-3 LCPUFAs (eicosapentaenoic acid and docosahexaenoic acid) are more efficiently used for tissue incorporation and specific body functions. In primates, it has been shown that n-3 LCPUFAs supplied to the diet of the pregnant or lactating mother are around 10 times more efficiently incorporated into the fetal or infant brain [41]. Inclusion of a small amount of fish, containing eicosapentaenoic acid and docosahexaenoic acid, in the diet will make a great contribution relative to α-linolenic acid with respect to fulfillment of the n-3 PUFA-requirements of all young children.

Infants and young children in low-income countries who are born with low birthweights and thus poor fetal stores, such as premature infants, may be expected to be especially vulnerable and dependent on a postnatal dietary supply of n-3 LCPUFA. Children in low-income countries may have additional requirements due to environmental stress, such as infections. Therefore, we would suggest that more emphasis be given to secure an optimal intake of n-3 PUFAs for children with moderate malnutrition.

Fat composition of the diet

The diets in most low-income countries consist mainly of basic stable foods—cereals, legumes, and roots. Generally, the content of PUFA in these stable foods is low (except for peanuts and soybeans) (**table 15**). The cereal staples and peanuts have a relative high content of n-6 PUFAs and only very small amounts of n-3 PUFAs. It is thus plausible that the general trend in low-income countries is that the dietary intake of many malnourished children is closer to meeting the recommendations for n-6 PUFAs than those for n-3 PUFAs, and that these diets do not meet the recommended n-6/n-3 ratio. An exception could be populations where, for example, the intake of fish or soy oil is high. Only a few studies have examined the dietary intake of children in low-income countries to an extent that allows adequate assessment of the intake of essential fatty acids. The most important fat sources in 24- to 36-month-old Gambian children have been found to be peanuts and peanut oil, cereals, and palm oil. These sources were found to supply 4.6 E% linoleic acid, sufficient according to recommendations, but only 0.13 E% α-linolenic acid, giving a n-6/n-3 PUFA ratio of almost 30 [35]; this ratio is much higher than 15, which is the upper limit seen in human milk in Western countries and therefore is also the upper limit in the current recommendations for infants [35, 41]. However, in 1- to 5-year-old Chinese children with a high prevalence of stunting, the daily intake of essential fatty acids was found to be low (3.3 E%) but was balanced with respect to the n-6/n-3 PUFA ratio [42]. Other studies have looked at the dietary PUFA supply from breastmilk [43]. These studies show that the n-6/n-3 PUFA ratio in human milk varies considerably between low-income countries, but in some low-income countries it has been found to greatly exceed 15, possibly due to a high and unbalanced intake of n-6 PUFAs in the mothers' diet. Thus, in a population with a low n-3 intake, breastfed infants will also have a low supply of n-3 PUFAs and consequently an increased need when they start complementary foods. Supplementing the diet of the lactating mother with foods containing n-3 PUFAs is therefore a way to improve the n-3 PUFA status of the young child.

Symptoms and effects of insufficient fat intake

The signs of severe n-6 PUFA deficiency are scaly skin, impaired water balance, dehydration, and poor growth [44]; whereas] n-3 PUFA deficiency has less obvious signs, manifesting in neurological symptoms, slow visual maturation, delayed motor skill development, and impaired learning [41]. Furthermore, other studies suggest that essential fatty acid deficiency may result in increased susceptibility to infectious disease, shortened erythrocyte survival, and some changes in the structure and function of the heart, liver, gastrointestinal tract, and other organs.

n-3 LCPUFAs are specifically up-concentrated in the central nervous system. Several studies have shown that the intake of n-3 LCPUFAs may affect the function of the central nervous system during early infancy [41], and that they may also affect cognitive development, attention, and behavior [45, 46]. An effect of docosahexaenoic acid supplementation on cognitive function has been shown in preterm infants, most likely because they are born with small stores of LCPUFAs [47]. As many infants in low-income countries are born with low birthweight to mothers who also have low n-3 PUFA intakes, they are likely to be deficient at birth and would probably benefit from a high n-3 PUFA intake and preferably an intake of eicosapentaenoic acid and docosahexaenoic acid from animal sources.

Only a few well-performed studies have examined the PUFA status of young children in low-income countries [48]. Some of these studies have shown high levels of the essential fatty acid deficiency indicators, and most studies show low levels of docosahexaenoic acid and n-6 PUFAs in plasma or blood cell membranes, when compared with children from high-income countries [48]. In a study comparing 18-month-old children from Cambodia and Italy, the Cambodian children had lower levels of linoleic acid than the Italian children, but their α-linolenic acid levels were comparable to those of the Italian children and their LCPUFA levels were higher [49]. The Cambodian children's higher LCPUFA levels could, however, be because they were still breastfed. Among the Cambodian children, 27% were stunted and 5% were wasted. An intervention with micronutrients resulted in a significant increase in linoleic acid and α-linolenic acid, but not of LCPUFAs, suggesting that their PUFA metabolism was influenced by their poor micronutrient status.

Some of the signs of malnutrition may in part be explained by a lack of PUFAs, e.g., the high infection rate [50] and skin changes [51]. Dry, flaky skin is common in cases of moderate malnutrition, and mothers of children treated with fat-based spreads often comment on the improvement of the skin during treatment [4]. Observational studies from China and Africa have suggested that a high n-6 fatty acid intake combined with a low n-3 fatty acid intake also has a negative effect on both weight gain and linear growth [42, 52]. It is also plausible that low n-3 PUFA intake could cause delayed cognitive development. Verbal learning and memory were improved in an intervention study in South Africa among schoolchildren receiving a bread spread with fish flour from a marine source [53].

Thus, essential fatty acid deficiency could be involved in several of the signs that are seen in malnourished children. However, there is a lack of intervention studies proving that insufficient PUFA intake causes some of the signs seen in children with moderate malnutrition, and that the children in fact would benefit from an extra supply.

Conclusions and recommendations on fat quality

- The intake of PUFAs is likely to be low in children with moderate malnutrition.
- The intake of n-3 PUFAs seems to be especially low, resulting in a high n-6/n-3 PUFA ratio.
- Several of the manifestations in children with moderate malnutrition could be caused by PUFA deficiency, but evidence is lacking.
- It is recommended that diets for moderately malnourished children contain at least 4.5 E% of n-6 PUFA and 0.5 E% of n-3 PUFA.
- The n-6/n-3 ratio in the diet should be below 15 and preferably between 5 and 9.
- Foods with a high n-3 PUFA content, such as soybean oil, rapeseed oil, and fish, should be promoted.

Research recommendations

- Research is needed to define the optimal content of PUFA in diets for children with moderate malnutrition

Carbohydrates

Simple sugars

The most important dietary mono- and disaccharides are glucose, fructose, lactose, and sucrose (sugar). These sugars are good sources of energy and will typically increase the energy density of a diet. Sucrose can be added to foods given to children with moderate malnutrition. The advantages and disadvantages of using sugar are described in a separate section on Sugar under Relevant Foods and Ingredients, below.

Lactose comes mainly from milk and milk products. Lactose maldigestion and intolerance are prevalent in many populations in low-income countries, but symptoms are not common before the age of 3 to 5 years, and lactose maldigestion does not seem to be a major problem in the treatment of malnutrition [54, 55]. Even if malnutrition has a negative effect on the intestinal lactase content, the positive results of treating severely malnourished children with F100, which contains about 21 g of lactose per 100 g of dry F100, suggest that the lactose content of foods given to children with moderate malnutrition is not likely to be a problem. RUTFs also contain a considerable amount of lactose (about 12 g/100 g), which does not seem to cause problems when given to malnourished children. Studies of pigs have suggested that lactose may have a positive effect on growth; it enhances calcium absorption and is likely to have a beneficial luminal effect in the intestine [56]. Breastmilk also has a high lactose content, and it has been suggested that this has a prebiotic effect, i.e., stimulating the growth of a beneficial intestinal flora, as some of the lactose will enter the large intestine and act as indigestible fiber [57]. Lactose enhances the absorption of calcium, magnesium, and perhaps phosphorus in infants [58]. However, there is no evidence that lactose improves calcium absorption in adults [59].

Starch

Starch is the most widespread polysaccharide in the human diet. The main sources are staple foods such as cereals, roots, and tubers. The staple food with the largest amount of starch is maize, but wheat, rice, and potatoes also have high contents of starch. Starch is stored as amylose and amylopectin in granules in plant tubers and seeds [60]. Starch is a polysaccharide carbohydrate consisting of α-1-4 linked glucose monomers. Around 20% to 30% is amylose, a linear glucose polymer, and the remaining 70% to 80% is amylopectin, a branched polymer. The ratio of amylose to amylopectin varies between foods; e.g., some varieties of maize contain over 50% amylose, whereas other varieties have almost none [61].

α-Amylase is a digestive enzyme that breaks down starch to maltose and dextrins. Dextrins are mixtures of linear glucose polymers. Amylose starch is less digestible than amylopectin. Maltodextrin is absorbed as rapidly as glucose but does not have the same sweet taste [62].

A considerable fraction of starch is so-called resistant starch, which is inaccessible to enzymatic digestion. Resistant starch may serve as a substrate for the microflora in the colon, where it is microbially degraded to short-chain fatty acids; therefore, physiologically, resistant starch may be considered a soluble dietary fiber [63]. Some short-chain fatty acids may have anti-inflammatory properties [64, 65] .

Dietary fiber

No universally accepted definition of dietary fiber exists. A useful and generally accepted definition is that dietary fiber consists of nonstarch polysaccharides such as cellulose, hemicellulose, pectin, β-glucans, plant gums, and mucilages. In some definitions of dietary fiber, resistant starch components such as oligosaccharides and inulin and noncarbohydrate components such as lignin, waxes, and chitins are also included. Dietary fibers are also called "nondigestible carbohydrates," especially in relation to the physiological effects of these substances in infants and young children [57].

The most fiber-rich plant foods are unrefined cereals and legumes, including soybeans, beans, lentils, and peas. All plant foods contain both insoluble and water-soluble dietary fibers, although in varying quantities. Insoluble fibers, e.g., celluloses, some hemicelluloses, and lignin, are indigestible or only partially fermented in the large intestine. Insoluble fiber in the diet causes soft stools and shortens intestinal transit time, which may reduce the digestibility and availability of nutrients. Food processing, such as extrusion cooking, can to some degree solubilize insoluble fibers, especially in wheat flour [66]. Soluble fibers, e.g., pectins, gums, and mucilages, are found in all plant foods, especially fruits and vegetables, but in varying amounts. Soluble fibers possesses water-binding properties and are relatively rapidly fermented in the colon. Some soluble dietary fibers, such as inulin, can improve absorption of calcium [67–69].

Diets with a high content of soluble dietary fibers may lead to flatulence due to their relatively rapid fermentation in the large intestine [70]. In particular, a group of oligosaccharides, α-galactosides, typically found in legumes, are digested in the colon by bacteria, resulting in the production of short-chain fatty acids and gases that cause flatulence.

High intake of soluble dietary fibers has been shown to lead to negative effects on energy intake in the short term [71] as well as in longer-term studies [72] in healthy subjects and in malnourished children [73].

There are several studies and reviews dealing with the potential negative effect of dietary fibers on energy intake and growth in infants and children. Dietary fibers may reduce energy intake through a suppressing effect on appetite, and they may increase fecal losses of energy due to reduced absorption of fat and carbohydrate [57]. In a study from the Netherlands of infants and young children receiving a "macrobiotic" diet with a high content of dietary fiber (13 g/day), weight gain and linear growth were reduced considerably as compared with a control group [74]. The diet of these children was high in dietary fiber and low in fat, contained no animal-source foods, and had an overall low energy density; thus, the reason for this lower rate of weight gain in children receiving a macrobiotic diet cannot be attributed only to the high content of dietary fiber.

In an intervention study, 7- to 17-week-old infants were given weaning cereals containing wheat and soybeans or wheat and milk and with different fiber contents [75]. The intake of cereal was significantly lower (34 g/day) in a group with a high content of dietary fibers (8.0%) than the intake (42 g/day) in a group with a low intake of dietary fibers (1.8 g/day). There was no difference in apparent absorption of energy or nitrogen between the groups. More children were withdrawn from the wheat and soybeans group than from the wheat and milk group because the infants refused the cereal or got sick. One-third of the infants with high fiber intake were reported to have gritty stools. The infants in the study were very young and had no major problems from the high-fiber diet, but they had only a limited intake of cereal, with most of their energy coming from infant formula. The significant decrease in energy intake from the cereal and the higher withdrawal among those receiving the high-fiber cereal are worrying in relation to vulnerable malnourished children.

The US reference intake of total dietary fiber for children 1 to 3 years of age is 19 g/day, equivalent to 11 g/1,000 kcal [76]. This is a very high intake and is most likely too high for malnourished children, especially if they have gastrointestinal problems. A previous recommendation from the American Academy of Pediatrics was 0.5 g/kg body weight, which is much less than the US reference intake and only about one-quarter of the Institute of Medicine (IOM) recommendation for children 1 year of age [77]. Another recommendation suggested that from the age of 3 years the dietary fiber intake should be 5 g plus 1 g for each year of age [78].

In a population with a high risk of obesity and diabetes, a high intake of dietary fibers is recommended because of their effects on satiety, improved glucose tolerance, and decreased serum cholesterol and triglycerides [57]. Another reason to recommend a diet with relatively high dietary fiber content to young children in the same societies is to accustom them to a high-fiber diet. However, these arguments are not relevant for children with moderate malnutrition. The total intake of dietary fiber for children with moderate malnutrition should be as low as possible. Children under treatment for severe acute malnutrition with F100 receive a diet with no dietary fiber. Furthermore, breastfed infants receive no fiber. Children with moderate malnutrition typically receive home-made diets based mainly on cereals and legumes, as alternatives are costly. Such home-made foods are relatively high in insoluble dietary fiber.

If the dietary fiber content is very low, it may result in constipation, but that is generally not an issue in children treated for malnutrition. It is recommended that insoluble fibers should be present in low amounts in the diet, because they increase bulk and reduce gastrointestinal transit time. The diet should contain a relatively high proportion of soluble fibers, because of their prebiotic properties, leading to an increased fermentation and support of the growth of a beneficial colonic microflora. It is probable that resistant starch and/or oligosaccharides—or other substrates resistant to digestion in the small intestine of the child with moderate malnutrition—may have prebiotic properties in the child with moderate malnutrition.

Until more evidence is available, it is not possible to give recommendations for an upper level of intake of fibers that will not result in problems for children with moderate malnutrition. In dietary products used for children with moderate malnutrition, the content of fibers, and especially of insoluble fibers, should be kept as low as possible. This is especially important during the first 2 years of life and in children with gastrointestinal problems.

With a cereal-based diet, it is difficult to follow the lowest of the recommendations for fiber intake, which is the American Academy of Pediatrics recommendation of less than 0.5 g/kg body weight per day. Assuming that the energy intake is 100 kcal/kg body weight and that two-thirds of energy intake comes from cereals and legumes, this will be equal to about 20 g of dry cereals and legumes per kilogram of body weight. To fulfill the recommendation of not more than 0.5 g of total fiber per kilogram of body weight, the content of total fibers in the cereals and legumes should be below 2.5%. Thus, this recommendation can only be reached if the stable food is rice (**table 12**) or if the amount of cereals and legumes is reduced.

Conclusions and recommendations on carbohydrates

» Lactose maldigestion and intolerance is generally not a problem in the treatment of children with moderate malnutrition.
» Lactose may improve mineral absorption and have prebiotic effects.
» Starch is an important and cheap source of energy for children with moderate malnutrition.
» Dietary fibers increase bulk and satiety and reduce nutrient and energy digestibility, which may be harmful to children with malnutrition.
» It is unknown to what degree fibers are available as energy in infants and children with moderate malnutrition, especially if they have gastrointestinal problems.
» In infants and children up to 2 years of age, the fiber intake, and especially the intake of insoluble fibers, should be kept as low as possible until further evidence is available.
» There are inadequate data to determine an upper limit for intake of insoluble dietary fibers.
» The content of total dietary fibers and of insoluble fibers should be declared on foods produced to treat children with moderate malnutrition.

Research recommendations

» There is a need to perform studies examining the effects of different levels of fiber intake in children with moderate malnutrition, including measurements of the amount of energy in the stools.
» There is a need for further studies to determine the physiological effects of resistant starch, oligosaccharides, especially α-galactosides, and soluble and insoluble dietary fibers in children with moderate malnutrition.
» Effective methods to lower the fiber content of foods for children with moderate malnutrition should be identified and developed.

Minerals and vitamins

All micronutrients are essential to normal functions of biological processes and human health. However, in this article, emphasis is on those nutrients that are important for growth and whose availability is affected by the food matrix or food processing and that are therefore considered to be of particular importance in children with moderate malnutrition.

Minerals

Iron

Iron is involved in many vital functions in the human body. First, iron is important for oxygen transport. Further, iron is essential to brain function and development, and severe iron deficiency can cause retarded mental development, which may be irreversible [79]. Recently, iron supplementation of children has been shown to increase morbidity and possibly mortality among non-iron-deficient individuals in malaria-endemic areas [80, 81]. It is likely that the harmful effects of iron supplementation have to do with the formulation and higher amounts of iron, and it is conceivable that dietary sources of highly available iron are not harmful.

Dietary iron is present in foods in two main forms: heme iron only in foods of animal origin (with high amounts in liver and red meat) and nonheme iron in both animal and plant foods, mostly in the ferric state. Heme iron and nonheme iron are absorbed through different mechanisms. Heme iron is transported into the enterocyte by the heme receptor, whereas nonheme iron uses the divalent metal transporter (DMT1), which means that dietary ferric iron (Fe^{3+}) must be reduced to ferrous iron (Fe^{2+}) before uptake [82]. Absorption of nonheme iron can be enhanced or inhibited by various dietary components and thus depends on the meal composition. An overview of dietary factors inhibiting or enhancing absorption of nonheme iron is given in **table 5**. The absorption of heme iron is much higher than the absorption of nonheme iron: about 25% for heme iron and less than 10% for nonheme iron. Iron absorption is also influenced by the total iron content in the diet (lower iron content increases absorption efficiency) and by the iron status and physiological state of the individual (low iron stores and pregnancy increase absorption efficiency).

Milk has low iron content, and the absorption of iron from milk is relatively poor. Older studies suggested that calcium in milk had a negative effect on iron absorption, but more recent studies have suggested that this is not the case [83, 84]. Some studies have suggested that cow's milk can induce occult intestinal bleeding in young infants, which may contribute to the negative effect of milk on iron status [85]. However, it seems that the process involved in drying milk eliminates this effect, so that milk products based on powdered milk do not cause bleeding [86].

Zinc

Zinc is essential to growth, synthesis, and maintenance of lean body mass and to the immune functions. Through its position in metalloenzymes, zinc plays a major role in vital processes such as nucleic acid synthesis, protein digestion and synthesis, carbohydrate metabolism, bone metabolism, oxygen transport, and antioxidative defense. Zinc is often the limiting growth nutrient (type II nutrient) in diets in populations with a high prevalence of malnutrition [4]. Accordingly, several studies have shown that zinc supplementation has a positive effect on linear growth [88]. A more recent review could not show a significant effect, but this could be because zinc might not be a limiting nutrient in all the studies included in the meta-analysis [89]. The positive effects of animal-source foods on linear growth in many studies may be partly explained by widespread growth-inhibiting zinc deficiency and the high zinc content and bioavailability in animal foods. Thus, zinc is a key nutrient in diets for children with moderate malnutrition. The absorption of zinc is enhanced at low dietary intakes of zinc.

Good dietary sources of zinc include seafood, meat, nuts, and dairy products. There is a high zinc content in whole-grain cereals, but because of the high content of phytic acid, a strong chelator of zinc, the bioavailability is typically low. Calcium also has a negative effect on zinc availability. Golden has recommended a nutrient density for zinc in food-based diets for moderately malnourished children of 13 mg/1,000 kcal. This level is very high and can be difficult to achieve. Only small freshwater fish (**table 25**) contain more than this level of zinc. Meat and large fish (**tables 24** and **25**) typically have a zinc content considerably below the level of 13 mg/1,000 kcal, and milk has a zinc content of about 6 mg/1,000 kcal. Starchy roots and legumes typically contain between 9 and 12 mg/1,000 kcal. Thus, the nutrient density suggested by Golden [4] can only be reached by supplementation or fortification.

TABLE 5. Dietary compounds that influence the absorption of nonheme iron[a]

Food	Degree of effect	Active substance
Inhibiting		
Whole-grain cereals and maize	– – –	Phytate
Tea, green leafy vegetables	– – –	Polyphenols
Spinach	–	Polyphenols, oxalic acid
Eggs	–	Phosphoprotein, albumin
Cereals	–	Fiber
Enhancing		
Liver, meat, fish	+++	"Meat factor"
Orange, pear, apple	+++	Vitamin C
Plum, banana	++	Vitamin C
Cauliflower	++	Vitamin C
Lettuce, tomato, green pepper	+	Vitamin C
Carrot, potato, beetroot, pumpkin, broccoli, tomato, cabbage	++/+	
Fermented foods	++	Acids

a. Source: modified from Michaelsen et al. [87].

Phosphorus

Phosphorus (or phosphate) forms part of the phospholipids, an essential functional component of cell membranes, and part of high-energy phosphate compounds such as adenosine triphosphate (ATP) and creatine phosphate, the biological energy conservation molecule that is essential to all vital processes. Phosphorus is also an essential component of hydroxyapatite, the main structural bone mineral. Deficiency of phosphorus is common in malnourished children, and severe hypophosphatemia is associated with increased mortality in kwashiorkor [90], although causality has not been shown. Phosphorus deficiency is also likely to cause rickets-like bone changes in malnourished children [4]. Phosphorus is likely to be a limiting nutrient in the treatment of children with moderate malnutrition.

Absorption of dietary phosphorus is high (55% to 70%), relatively independently of dietary composition, and does not appear to be up-regulated at low intakes. Dairy products, meat, poultry, eggs, fish, nuts, and legumes are generally good sources of highly available phosphorus. However, the main form of phosphorus from plant material is phytate, which is resistant to digestion unless enzymatically degraded by phytase. Thus, phosphorus from phytate is only absorbed to a minor degree under normal conditions, and the phytate fraction of phosphorus should therefore be discounted from calculations of total phosphorus requirements [4].

Iodine

Iodine is an essential constituent of the thyroid hormones, which are key components of development and growth. Iodine deficiency causes disorders ranging from enlarged thyroid gland (goiter) to severe irreversible mental and congenital retardation (cretinism). The risk and severity of cretinism are, however, determined by iodine deficiency during fetal life. Milder manifestations of iodine deficiency, including mild mental impairment in childhood, may be reversible by iodine supplementation. Most foods have naturally low iodine contents, since their iodine contents depend on the iodine content of the soil. Seafoods, including seaweeds, are good sources of iodine. Dairy products are also good sources when cattle feed is fortified with iodine. Universal iodization of salt is recommended as the only effective way of controlling iodine deficiency, but providing moderately malnourished children with iodine from salt is a problem, as salt intake should be kept low in children with moderate malnutrition. A better option is therefore to fortify other foods with iodine. An alternative approach in situations where fortified complementary foods are not available is to give infants and young children from 7 to 24 months of age an annual dose of iodized oil supplement [91].

Selenium

Selenium deficiency is prevalent and important in children with moderate malnutrition. Selenium protects against oxidative stress, as the main antioxidant enzyme gluthatione peroxidase is selenium dependent [4]. Selenium deficiency seems to play a role in the development of kwashiorkor, and the prognosis of the disease seems to be related to selenium status [4]. Both plant- and animal-source foods contain selenium in several different forms, which generally are well absorbed. However, the content of selenium in both plant- and animal-source foods depends very much on the content in the soil. It is therefore not possible to give advice as to which foods are important to provide a sufficient selenium intake.

Potassium and magnesium

Malnourished children may have a low potassium and magnesium status, especially if they have lived on a diet with few foods other than rice or highly refined wheat and have suffered from diarrhea, which increases the loss of these minerals [4]. Both potassium and magnesium are growth (type II) nutrients, and deficiency has a negative influence on growth. Deficiency of potassium or magnesium interferes with protein utilization; magnesium deficiency increases the risk of developing potassium depletion, and supplementation with magnesium has shown to improve recovery from malnutrition [4, 92].

These two minerals are mainly situated in the outer layers of cereals, and the levels are reduced considerably by milling. In a study of the potassium and magnesium contents of food commodities used for relief feeding, the potassium content was about 350 to 390 mg/100 g in whole-meal wheat flour and only about 115 to 150 mg/100 g in white wheat flour [93]. The corresponding figures for magnesium were about 100 and 25 mg/100 g, respectively. For comparison, wheat–soy blend and oat meal had potassium and magnesium values close to those of whole-meal wheat flour, and rice had values close to those of white wheat flour. When these values are compared with the recommended nutrient densities suggested by Golden (1,400 mg/1,000 kcal for potassium and 200 mg/1,000 kcal for magnesium), whole-meal wheat flour has a potassium content of about three-quarters and a magnesium content about double these recommended densities, while white wheat flour has values far below these recommended densities.

Vitamins

Water-soluble vitamins

Thiamine. Thiamine plays a central role in normal metabolism of energy, particularly carbohydrate. Thiamine is also involved in neural function. Since the body does not have any storage capacity for thiamine, it needs to be part of the daily diet. Thiamine is widely distributed in foods. Whole-grain cereals, meat, and fish are rich sources, whereas highly refined cereals such as polished rice are poor sources of thiamine. Thus, monotonous diets based on highly refined cereals are associated with a high risk of thiamine deficiency.

Vitamin B_{12}. Vitamin B_{12} is the generic name for a group of compounds called cobalamins. Vitamin B_{12} is essential for normal blood formation and neurological function. It plays an indirect but essential role in the synthesis of purines and pyrimidines, formation of proteins from amino acids, transfer of methyl groups, and carbohydrate and fat metabolism. Through its role in the transfer of methyl groups, it is involved in the regeneration of folate. Therefore, folate deficiency and vitamin B_{12} deficiency may have some of the same signs, but vitamin B_{12} deficiency also has neurological consequences.

Vitamin B_{12} occurs almost exclusively in foods of animal origin. Severe deficiency can cause irreversible developmental delay, including irritability, failure to thrive, apathy, and anorexia [94], which may contribute to the development and manifestations of moderate malnutrition and hinder its treatment.

Vitamin C. Vitamin C (ascorbic acid) is essential for enzymatic hydroxylation and thereby stabilization of collagen. It is an important antioxidant and enhances absorption of nonheme iron. Scurvy, the manifestation of vitamin C deficiency, is common among those not consuming fruits or vegetables, such as refugees. The most important symptoms are nausea and poor appetite and bleeding from gums and joints, as well as joint pains and poor wound healing.

An important aspect of low vitamin C levels in the diet of children with moderate malnutrition is that it is associated with low iron absorption, increasing the risk of iron deficiency. Vitamin C is easily oxidized to inactive forms by exposure to air and to some degree by heat treatment. Thus, postharvest storage and cooking of fruits and vegetables decrease the vitamin C content of the foods dramatically. The best source of vitamin C is fresh fruit.

Fat-soluble vitamins

Vitamin A. Vitamin A is essential to vision, cell differentiation, and the immune response. It occurs in foods as two different groups of compounds: preformed biologically active vitamin A and provitamin A carotenoids. Preformed biologically active vitamin A (retinol, retinoic acid, and retinaldehyde) is only present naturally in foods of animal origin. However, biologically active forms (retinyl palmitate) are used to fortify foods such as margarine, dairy products, and sugar with vitamin A. The provitamin A carotenoids require enzymatic cleavage before they are converted into biologically active forms of vitamin A. These compounds occur in orange- and yellow-colored fruits and vegetables and in dark-green leafy vegetables. Given the poor ability of provitamin A–rich green leaves to improve vitamin A status in humans [95], the vitamin A activity of carotenoids was re-evaluated in the late 1990s [95, 96], and in 2000 the IOM [97] revised the conversion factors and introduced a new retinol activity equivalent (RAE), to replace the former retinol equivalent (RE) (**table 6**). It is still debated whether the bioavailability of vitamin A in green leafy vegetables is even lower [98]. Many food-composition tables use RE as the conversion factor for the carotenoids and thus probably overestimate the contribution of vitamin A from vegetable sources. However, in 2003 *Sight and Life* supported the construction of an updated food-composition table for vitamin A [99], which is available on-line [100].

TABLE 6. Provitamin A conversion factors[a]

Compound	µg/µg RAE[b]	µg/µg RE[c]
All-*trans*-β-carotene, dissolved in oil	2	2
Dietary all-*trans*-β-carotene	12	6
Other dietary provitamin A carotenoids	24	12

a. Source: Institute of Medicine [97].
b. Amount (µg) of provitamin A equivalent to 1 µg of retinol activity equivalent (RAE).
c. Amount (µg) of provitamin A equivalent to 1 µg of the formerly used retinol equivalent (RE).

The bioavailability of provitamin A depends on the food matrix and processing; the bioavailability of carotenoids from raw orange-fleshed fruits is higher than that from cooked yellow or orange vegetables, which is higher than that from raw green leafy vegetables [101]. However, detailed information is not available to include in dietary composition software. In addition, zinc may be required for the conversion of provitamin A carotenoids to vitamin A [102].

Vitamin D. Vitamin D is important for normal bone metabolism, but also for the immune system and other body functions. Vitamin D deficiency is associated with growth retardation and rickets and may be a risk factor for tuberculosis [103]. Sources of vitamin D are sun exposure and dietary intake [87, 103]. In many areas, the most important source is sun exposure. However, in sunny countries, factors such as cultural clothing habits (especially among females) [104], skin pigmentation, and air pollution [105] may reduce the value of sun exposure as a source of vitamin D. As mentioned by Golden [4], atmospheric dust in desert areas may reflect most of the UV-B radiation except for the time around noon, when most people are indoors. Therefore, hypovitaminosis D and rickets are very common even in many sunny countries, and people depend on intake of vitamin D through naturally vitamin D–containing foods, food fortification, or supplementation.

Few food items contain more than small amounts of vitamin D. The best dietary sources are fatty fish (salmon, mackerel, herring, sardines, and oil from fish), eggs, liver, and, where available, vitamin D–fortified foods such as milk and margarine [87, 103]. WHO recommends an intake of 10 µg of vitamin D daily to prevent hypovitaminosis D [87]. For children with moderate malnutrition, the recommended vitamin D density is 13 µg/1,000 kcal [4].

Conclusions and recommendations on minerals and vitamins

» The content and bioavailability of minerals and vitamins are often poor in diets of children with moderate malnutrition and should be improved.
» The bioavailability of minerals is influenced by various dietary components that may act as either enhancers or inhibitors.
» The content of phytate in foods has a strong negative effect on the bioavailability of important minerals, and food-processing methods that reduce the phytate content of foods should be promoted.
» Fortification or supplementation may be needed to cover the high mineral and vitamin requirements of those with moderate malnutrition.

Research recommendations

» Research is needed to clarify the effect of the food matrix and food processing on mineral and vitamin availability.

Bioactive substances

Many foods also contain bioactive substances, which are substances that do not meet the definition of a nutrient, but have effects on health outcomes. Among children with moderate malnutrition, the most important bioactive factors are milk peptides, the "meat factor," and phytoestrogens.

Milk peptides

The biological activity of some of the milk peptides has been examined in many animal studies and some human intervention studies. Most of the proposed effects of milk peptides are related to the immune or digestive system [106].

The enzymatic digestion of protein begins in the stomach, once the proteins have been denatured by the gastric acid. It has been speculated that some of the effects of whey or other milk proteins could be caused by peptides formed after digestion in the gastrointestinal tract [107–111].

β-Lactoglobulin constitutes about half of the total whey protein in cow's milk, but it is absent in human milk [112]. Several biological roles of β-lactoglobulin have been suggested but not fully proven. Aside from binding calcium and zinc, it appears that β-lactoglobulin may act as a carrier for retinol. β-Lactoglobulin can protect retinol against oxidation by binding it in a hydrophobic pocket; this action furthermore promotes transport of retinol through the stomach to the small intestine, where it can be transferred to another retinol protein. Another physiological role of β-lactoglobulin is its ability to bind free fatty acids, thus promoting lipolysis [113].

α-Lactalbumin represents around 20% of whey protein in bovine milk and is the major protein in breastmilk (20% to 25% of total protein). α-Lactalbumin has a high content of tryptophan and is a good source of branched-chain amino acids, which may be the reason some studies show that whey can stimulate muscle synthesis (see section on whey powder). Infants fed a protein-reduced formula enriched with α-lactalbumin had satisfactory growth and biochemical values, suggesting adequate protein nutrition from the α-lactalbumin–rich formula, despite its lower total protein content [114]. During the digestion of α-lactalbumin, peptides that have antibacterial and immunostimulatory effects appear to be transiently formed and thereby may aid in protection against infection [115].

The concentration of immunoglobulins is very high in colostrum but is lower in mature milk. The whey fraction of milk seems to contain considerable amounts of immunoglobulin, approximately 10% to 15%, including IgG1, IgG2, IgA, and IgM, whose physiological function is to provide various types of immunity for the calf [113]. Several studies have focused on the effects of treating diarrhea with colostrum-derived bovine immunoglobulins. Positive results have been found in children with acute rotavirus diarrhea and in children suffering from both severe chronic *Cryptosporidium parvum* diarrhea and AIDS. Both groups had significantly less stool output and reduced stool frequency, and the latter group required a smaller amount of oral rehydration solution [116, 117]. Cow's colostrum also improved gut maturation and protected against necrotizing enterocolitis in a model of the immature vulnerable gastrointestinal tract using preterm pigs [118].

Even though lactoferrin represents a rather small portion of whey (0.1 g/L). it may have several significant biological functions. Lactoferrin is an iron-binding protein that can bind two ferric ions and thereby function as a carrier of iron. Lactoferrin has important antibacterial and antiviral properties, which are mainly linked to its iron-binding capacity, thus depriving bacteria of iron essential for growth [119]. Furthermore, lactoferrin has been suggested, based on *in vitro* studies, to have antiviral activity against several human pathogens, including HIV [120–122]. In addition to binding iron, the peptide fragment of lactoferrin has direct bactericidal activity. Finally, lactoferrin has antioxidant activity, which may be due to its ability to bind iron. Free iron contributes to the generation of reactive oxygen species [113].

Whey has a high content of bioactive factors, and it has been suggested that whey could have a beneficial effect, especially on the immune system and on muscle tissue, but there is little evidence from vulnerable groups [23].

The "meat factor"

Meat contains the easily absorbed and highly bioavailable heme iron [123]. In addition, meat proteins (from beef, veal, pork, lamb, chicken, and fish) have been reported to increase nonheme iron absorption, and even relatively small amounts of meat (about 50 g in adults) have been demonstrated to enhance nonheme iron absorption from a low-iron-availability meal with a high phytate content [124]. The enhancement of nonheme iron bioavailability is not an effect of animal protein per se, since casein and egg albumin decrease nonheme iron absorption [125]. The "meat factor" effect originates from the digestion of meat proteins to cysteine-containing peptides, but the exact mechanism by which meat has an enhancing effect on iron absorption has not yet been elucidated. The effect is believed to be caused either by a chelation of iron to minimize precipitation and interaction with absorption inhibitors such as phytic acid, or by a reduction of the insoluble ferric iron to the more soluble and thereby bioavailable ferrous iron, which is more efficiently absorbed by the intestinal epithelial cells [126].

Phytoestrogens

Phytoestrogens are a diverse group of naturally occurring nonsteroidal plant polyphenoloic compounds that have estrogenic and antiestrogenic effects because of their structural similarity to estradiol (17β-estradiol).

Soybean products are the most important source of phytoestrogens, but other legumes, flaxseed and other oilseeds, nuts, and some cereals also contain compounds with phytoestrogenic properties. In soybeans, the dominant compounds with phytoestrogenic properties are isofloavones, mainly genistein, daidzein, and glycitein. Lignans are the primary source of phytoestrogens; they are found in nuts and oilseeds as well as in cereals, legumes, fruits, and vegetables. The isoflavone content of defatted soy flour is about 60% of that of full-fat flour. Soy protein isolate and soy protein concentrate have about half as much total isoflavones as full-fat, roasted soy flour. Soy protein concentrate based on alcohol extraction can remove more than 90% of the isoflavones [127].

Consumption of phytoestrogens (isoflavonoids) may have some hormonal effects, although it is difficult to make firm conclusions from the studies available. Excess consumption of isoflavones during childhood may have a negative effect on male fertility [128] by altering the hypothalamic-pituitary-gonadal axis. However, such a hormonal effect seems to be minor [129]. Consumption of soy-based infant formula has been found to have no adverse effects on growth, development, or reproduction in some studies [130, 131]. One study found that the proportion of female infants with breast-bud tissue during the second year of life was higher among those given soy-based formula than among those who were breastfed or given cow's milk formula. Thus, the decline in infantile breast tissue that was seen in breastfed infants and those fed cow's milk did not occur in the infants fed on soy formula, but the long-term implication of this finding is not known [132]. In recent comments from both the European Society for Paediatric Gastroenterology, Hepatology and Nutrition (ESPGHAN) and the American Academy of Pediatrics Committees on Nutrition, it was emphasized that infant formula based on soy protein has only very limited medical indications as an alternative to cow's milk-based infant formula in nonbreastfed infants. They also concluded that there is no firm evidence of negative effects, but the long-term effects are unknown and should be investigated further [133, 134].

Conclusions and recommendations on bioactive substances

» Specific milk proteins and whey protein, which contains many peptides and specific proteins, could have potential relevant beneficial effects, but this has to be proven in children with moderate malnutrition.

» The "meat factor" improves iron absorption considerably, which is an additional benefit of including meat in the diet of children with moderate malnutrition.

» Children with a high intake of legumes, especially soybeans, will have a high intake of phytoestrogens. Although there is no firm evidence of negative effects, the long-term effects are unknown. The content of phytoestrogens should be measured in relevant soybean-containing foods and potential negative effects among children with moderate malnutrition should be studied.

Research recommendations

» Research is needed to determine the potential benefits of adding specific milk proteins to the diets of children with moderate malnutrition.

Antinutritional factors

Antinutritional factors are food constituents that have a negative impact on the solubility or digestibility of required nutrients and thereby reduce the amounts of bioavailable nutrients and available energy in the foods. Food constituents with antinutrient properties may also have beneficial health properties, and the significance of each antinutritional factor has to be considered in the context of the specific diets and the specific nutritional problems in a population.

The most important antinutritional food constituent in diets in low-income countries—in terms of negative nutritional impact—is phytate, which is primarily contributed from cereal staples and secondarily from legumes and other plant foods. Phytate forms insoluble complexes with a range of nutrients and thereby inhibits the absorption of proteins and minerals, in particular iron, zinc, and calcium. Other important antinutritional factors in foods that have a negative nutritional impact in low-income countries are polyphenol compounds, which are present in different forms in fruits, vegetables, pulses, and cereals. One of the most widespread groups of polyphenols with antinutritional properties is the soluble tannins, which are present in, for example, tea. The antinutritional effect of polyphenols is complex formation with iron and other metals and precipitation of protein, which reduces absorbability. In addition, a number of more specific food components are present in some foods and may have more isolated negative nutritional impacts in specific populations eating specific foods.

Phytate (phytic acid)

Inositol phosphates consist of an inositol ring and at least one phosphate group. Inositol hexaphosphate (IP6), which is phytate, functions as a storage compound for phosphorus in seeds and is essential for release of phosphorus during germination. The content of phytate in selected plant-derived foods and the distribution within the grain are shown in **table 7** and **table 8**. In a dietary context, the significance of inositol phosphate as an important antinutrient in cereal and leguminous foods is due to this phosphorus storage function in plant seeds. In seeds, phytate may account for as much as 80% of the total phosphorus content and 1.5% of the dry weight. During germination, phytate is hydrolyzed by endogenous phytase to release phosphate and inositol [135]. In a physiological context, phytate and other phosphorylated inositols (IP1 through IP5) are not alien compounds to humans, as these and other inositol deviates are widely present in very small amounts in most mammalian cells, where they are involved in multiple functions related to cell signaling pathways [136]. The antinutritional effect of phytate in a human diet is caused by the inability of the human digestive system to degrade phytate. The phosphate groups in phytate strongly bind divalent cations of Ca, Fe, K, Mg, Mn, and Zn. The complex of iron and other metal ions with IP4 and IP5 is weaker than that with IP6, and lower inositols have an insignificant inhibiting impact on mineral absorption [137, 138].

Phytate and lower phosphorylized inositols may be hydrolyzed to lower inositols by enzymatic removal of phosphate groups. Phytases involved in enzymatic dephosphorylation are present in plant seeds, where they can mobilize the stored phosphorus, and phytases are also found in the intestines of some animals, such as rats. However, humans have evolved to have insignificant intestinal phytase activity [140], and the consumption of a phytate-rich diet leaves phytate largely undigested and thus phosphorus unreleased for absorption, and other important nutrients immobilized due to complex formation.

The inhibiting effect of phytate on iron absorption is nonlinear, and the phytate content needs to be reduced to below a threshold phytate content of 100 mg [141] (**fig. 1**) or below a phytate:iron molar ratio of 1:1 [142] to have a significant positive effect on iron absorption. The inhibiting effect of phytate on zinc absorption has recently been modeled based on data from human absorption studies [143], predicting that the inhibiting effect of dietary phytate on zinc absorption is

TABLE 7. Phytate contents in selected plant-derived foods[a]

Food	Phytate (mg/g dry matter)
Cereal-based	
Wheat	
Refined white wheat bread	0.2–0.4
Whole-wheat bread	3.2–7.3
Unleavened wheat bread	3.2–10.6
Maize	
Flour	9.8–21.3
Maize bread	4.3–8.2
Unleavened maize bread	12.2–19.3
Rice	
Rice (polished, cooked)	1.2–3.7
Other cereals	
Oat porridge	6.9–10.2
Sorghum	5.9–11.8
Legumes and others	
Chickpeas (cooked)	2.9–11.7
Cowpeas (cooked)	3.9–13.2
Black beans (cooked)	8.5–17.3
White beans (cooked)	9.6–13.9
Kidney beans (cooked)	8.3–13.4
Tempeh	4.5–10.7
Tofu	8.9–17.8
Lentils (cooked)	2.1–10.1
Peanuts	9.2–19.7
Sesame seeds (toasted)	39.3–57.2
Soybeans	9.2–16.7
Soy protein isolate	2.4–13.1
Soy protein concentrate	11.2–23.4

a. Source: Greiner and Konietzny [139].

TABLE 8. Phytate distribution in morphological components of cereals and legumes[a]

Food	Morphological component	Distribution (%)
Peas	Cotyledon	88.7
	Germ	2.5
	Hull	0.1
Wheat	Endosperm	2.2
	Germ	12.9
	Bran	87.1
Maize	Endosperm	3.0
	Germ	88.9
	Hull	1.5
Brown rice	Endosperm	1.2
	Germ	7.6
	Pericarp	80.0

a. Source: O'Dell et al. [154], Beal and Mehta [155].

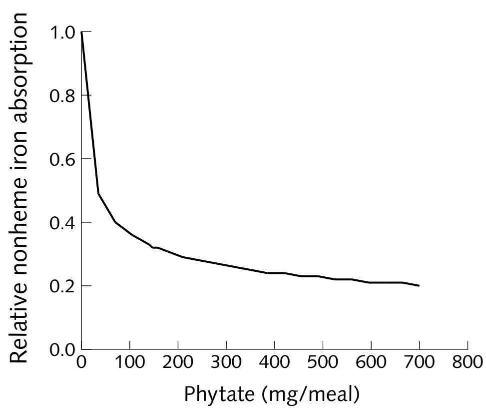

FIG. 1. Effect of phytate content on nonheme iron absorption in a meal without meat or ascorbic acid, expressed relative to a phytate-free meal. Based on algorithms for nonheme iron absorption [141]

linear with no upper threshold for the inhibitory effect [144]. Modeling absorbed zinc as a function of dietary phytate:zinc molar ratios emphasizes the potential benefits of phytate reduction and zinc fortification in diets that are habitually high in phytate.

A plant-based diet has been categorized to have "moderate" zinc availability when the molar phytate:zinc ratio is between 5 and 15 and "low" zinc availability when the molar ratio exceeds 15 [145]. A reduction of the phytate:zinc molar ratio in a maize-based diet from 36 to 17 was shown to significantly improve zinc absorption [146], indicating that—unlike iron absorption—any reduction in phytate may potentially contribute to improving zinc absorption.

Various traditional processing methods can reduce the phytate content in cereals and legumes. The potential impact of traditional processing methods, thermal processing, mechanical processing, fermentation, soaking, and germination (malting) on improving the bioavailability of micronutrients in a plant-based diet was reviewed by Hotz and Gibson [147]. Soaking of cereals and legumes can promote diffusion of phytate into the soaking water. Soaking unrefined maize flour reduced the phytate content by approximately 50% [147], and soaking of legume seeds (peas, peanuts, and pigeon peas) has been reported to reduce phytic acid by about 20% [148, 149]. Soaking may also wash out soluble vitamins and minerals into the soaking water.

Fermentation can reduce phytate by up to as much as 90%, depending on species and pH [147], as a result of the enzymatic activity of microbial phytase originating from the microflora in the fermentation culture, either present on the surface of the fermented foods (spontaneous fermentation) or added as a starter culture. Fermentation can also contribute to activating endogenous phytase in the cereal or legume being processed, especially in fermentation processes producing low-molecular-weight organic acids such as lactic acid, as many endogenous cereal phytases have optimum activity at pH 6 or below [135].

The stimulation of germination of cereals and legumes will activate endogenous phytase as a step in the process of releasing the phosphorus that the plant has stored as phytate. The endogenous phytase activity is higher in wheat and in other nontropical cereals such as rye and barley than in tropical cereals such as maize, millet, and sorghum [150]. Therefore, mixing wheat and maize, for example, in a germination process may stimulate a higher initial phytase activity and lead to higher reduction of phytate as compared with germination of pure maize.

The nutritional benefits of reducing phytate content through processing depend on the ability to reach a sufficiently low level of phytate to improve iron absorption. Dephytinization will also benefit zinc absorption [142] and possibly protein utilization.

In a community-based trial of 6- to 12-month-old children, a complementary food based on millet, beans, and peanuts was phytate reduced by soaking and germination. The phytate content was reduced by 34%, but the molar phytate:iron ratio remained high, being above 11 in the processed food. No impact on iron status in the intervention group was found [151].

In addition to reducing phytate in a plant-based diet through traditional processing technologies, the potential of reducing phytate content in cereal-based foods by adding commercially produced phytase needs to be explored. Commercial phytases have been developed and are commercially available for monogastric animal feed. In particular, in pig production phytase is a widely used additive to enhance protein and phosphorus absorption and thereby growth. The application of commercial phytases to foods for children with moderate malnutrition to reduce phytate and thereby increase nutritional value, particularly mineral bioavailability, is unexplored, and research is needed to clarify the potential for applications, as also pointed out in the reviews in this issue by Golden [4] and by de Pee and Bloem [152]. In a recent study among women, iron absorption from a whole-maize porridge was increased if phytase was added to the porridge [153].

In conclusion, it is important that foods used for rehabilitation of children with moderate malnutrition should have a low content of phytate, especially if there are few or no animal-source foods in the diet. This can be achieved by avoiding unrefined cereals and legumes with high phytate content and by using food-processing methods that reduce the phytate content.

Polyphenols

Polyphenols are classified according to the polyphenolic groups. A major group with antinutritional significance because of inhibition of mineral absorption consists of the phenolic acids classified as hydrolyzable (or soluble) tannins and cinnamic acid derivates (**table 9**). Isoflavones are polyphenols with estrogenic effect (see Phytoestrogens, above), and condensed tannins, another group of flavonoids, have dietary significance by adding an astringent taste, as well as possessing the ability for complex formation with metals similar to soluble tannins.

Soluble as well as condensed tannins are located in the seed coats of dark-colored cereals, such as sorghum and millet, and in beans and other legumes. The tannin content in beans varies with color, with darker beans having a higher content. The tannin content of legumes ranges from a high value of 2,000 mg/100 g in faba beans to a low value of 45 mg/100 g in soybeans.

The antinutritional properties of tannins in human diets are due to complex formation with proteins and with a range of metals, of which complex formation with iron and zinc is the most important in the context of feeding malnourished children. The complex formation immobilizes nutrients for digestion and absorption

TABLE 9. Polyphenol classes[a]

Polyphenol class	Examples of compounds	Examples of sources	Polyphenol content (mg/kg wet weight)	Nutritional significance
Phenolic acids				
Benzoic acid derivates	Hydrolyzable (soluble) tannins, e.g., gallic acid	Tea	Up to 4,500	Inhibitor of mineral absorption
Cinnamic acid derivates	Caffeic acid Chlorogenic acid Ferulic acid	Coffee Fruits Cereals	350–1,750 70–310	Inhibitor of mineral absorption
Flavonoids				
Flavonols	Quercetin	Onion, fruits	350–1,200	
Flavanones	Apigenin	Citrus fruits	200–600	
Isoflavones	Genistein, daidzein, glycitein	Soybeans	580–3,800	Inhibitor of mineral absorption. Estrogenic or/and antiestrogenic effects
Flavanols	Catechin Condensed tannins (proantocyanidins)	Green tea Beans, fruits, wine	100–800 350–550	Astringent taste, inhibiting mineral absorption
Lignans	Linseed			Minor importance

a. Source: modified from Manach et al. [156].

and thereby reduces the nutritional value of the food [157–159]. The tannin complex formation with proteins also inhibits the enzymatic activities of pectinase, amylase, lipase, proteolytic enzymes, β-galactosidase, and those microbial enzymes involved in fermentation of cereal grains [157].

Tannins in legumes reduce ionizable iron absorption by acting as a natural iron-chelating agent. About 50 mg of legume tannin binds about 1 mg of ionizable iron from food [160].

Some condensed tannins possess an astringent taste, which may contribute to a decreased intake of foods containing tannins. Tannin-rich diets have been shown to decrease growth rates in rats, chickens, and ducklings [158], but to what degree this can be a problem in children is not known.

Tannins are heat stable, and thus heat processing does little to reduce the tannin content in plant foods. Soaking in water or in salt solution prior to household cooking significantly reduces the tannin content (by 37.5% to 77.0%), provided the water used for soaking is discarded [158].

Black tea contains high levels of soluble tannins that have a strong inhibiting effect on iron absorption. A study in adult women quantified the inhibition of iron absorption by one cup of tea drunk with a rice meal to be 50%, and drinking two cups reduced absorption by 66% [161]. In some populations, tea, with or without milk, is given to infants and young children. This should be discouraged, and tea should not be given to children with moderate malnutrition.

Other antinutrients

α-Amylase inhibitors

α-Amylase inhibitors are present in many cereals and legumes [162]. Amylase is necessary to hydrolyze starch and is present in the saliva and in the pancreatic secretion. α-Amylase inhibitors reduce starch digestion and energy availability through the inhibition of amylase. Therefore, significant α-amylase inhibitor levels in the diet may prevent required starch digestion, with the result that undigested starch is metabolized in the large intestine as soluble fibers and turned into short-chain fatty acids with lower energy efficiency. α-Amylase inhibitors are relatively resistant to boiling [162]. In a study of rats fed diets with purified α-amylase inhibitors, the utilization of protein and lipids was reduced, the weight of the pancreas was increased, and growth was reduced [163]. To what degree α-amylase inhibitors can also impair growth in children is not known.

Protease inhibitors

Trypsin and chymotrypsin are endopeptidases that break specific bonds in the middle of an amino acid chain, i.e., protein. They are secreted from the pancreas into the small intestine where they reduce large proteins into medium-sized peptides that are further degraded by exopeptidases, which break off amino acids from the ends of the chain. Inhibitors of trypsin and chymotrypsin are present in most legume seeds. Among ordinary food products, soybeans are the most concentrated source of trypsin inhibitors. Trypsin inhibitors may inhibit other proteases beside trypsin [164]. High levels of protease inhibitors may result in increased size of the pancreas and inhibition of growth [165]. Food processing can reduce the content of trypsin inhibitor activity considerably.

Lectins (phytohemagglutinins)

Lectins, also known as phytohemagglutinins are carbohydrate-binding proteins or glycoproteins that are widely distributed in the plant kingdom and are found in most legumes and cereals, primarily localized in the protein bodies of the cotyledon cells.

Lectins are characterized by their ability to agglutinate (clump) red blood cells in various species of animals [165]. They have a unique property of binding carbohydrate-containing molecules [163, 166], thus inhibiting growth by impairing nutrient absorption [165]. In addition, about 60% of the lectins survive transit through the intestinal tract and become bound to the intestinal epithelium, causing disruption of the brush border, atrophy of the microvilli, and reduction in the viability of the epithelial cells. This markedly increases nutrient requirements by the gut. Lectins can also facilitate colonization of the gut by bacteria, including pathogens [167], and can cause bacterial overgrowth of the gut [168]. Like the protease inhibitors, lectins are readily destroyed by moist heat treatment but are quite resistant to inactivation by dry heat treatment or to degradation by digestive enzymes and bacteria [165].

Saponins

Saponins are a large family of structurally similar compounds present in many plants. There has been a special interest in the content in soybeans [169] because of the potential use of saponins as herbal medicine. Saponins have a bitter taste and are characterized by their hemolytic activity and foaming properties. They are hydrolyzed by bacterial enzymes in the lower intestinal tract. Saponins have negative effects on the permeability of the small intestinal mucosa and have been found to impair active nutrient transport in animal and cell models [170, 171]. Whether this effect on the gastrointestinal tract is also relevant for children with moderate malnutrition is not known.

Lysinoalanine

Certain processing methods, such as heat and alkaline treatment, produce lysinoalanine, a cross-linked amino acid. Lysinoalanine is widely distributed in cooked foods, commercial food preparations, and food ingredients. Lysinoalanine may exert a toxic effect via mineral binding in the renal tubules. Conversion of lysine to lysinoalanine may lead to a decrease in the digestibility of the protein and a decrease in biologically available lysine [172, 173], which is important if lysine is the limiting amino acid of a diet. Particular attention has been given to sterilized milk and milk powders, as low-quality milk powders can contain rather large amounts of lysinoalanine [174].

Cyanogenic glycosides

Cyanides are found in many foods and plants and are produced by bacteria, fungi, and algae [175, 176]. Cyanogenic cassava roots (“bitter cassava”) are of particular concern [177]. Cyanide is highly toxic and must be removed. Flour of cyanogenic cassava roots can be soaked in water for activation of enzymatic breakdown of the cyanide compounds. Consumption of insufficiently processed cassava may cause the paralytic disease known as “konzo.”

Conclusions and recommendations on antinutrients

» The contents of antinutrients in plant-based diets given to children with moderate malnutrition are likely to have a major negative impact on nutrient availability and growth.

» Animal-source foods have no or very low contents of antinutrients, and a diet with a high content of animal foods will therefore have a low content of antinutrients.

» Phytate is the most important antinutrient in foods for children with moderate malnutrition because it impairs the bioavailability of iron and zinc and its phosphorus is unreleased for absorption, actions that have a negative effect on growth.

» In selecting cereals, legumes, and processing methods for diets for children with moderate malnutrition, a low phytate content in the final product should be given high priority.

» Among the polyphenols, tannins are the most important antinutrients. Legumes and cereals with high contents of tannins should not be given to children with moderate malnutrition. Black tea should not be given to children with moderate malnutrition because of its tannin content.

» A number of other antinutrients, such as α-amylase inhibitors, protease inhibitors, lectins, saponins, and lysoalanine, can also have a negative effect on growth, although there is a lack of data from malnourished children

» Cyanides are highly toxic. Cassava should not be given to children with moderate malnutrition, both because of its high cyanide content and because of its low contents of protein and other nutrients.

Research recommendations

» Commercially produced phytases added to cereals and legumes have been very effective in improving growth in animals, especially in pigs. Their potential for use in foods given to children with moderate malnutrition should be studied.

» There is an urgent need to perform more research on the potential negative effects of antinutrients in malnourished children, e.g., through observational

studies and animal studies.
- Effective processing methods should be identified and the Codex Alimentarius should provide guidance on acceptable antinutrient contents.

Contaminants

Infants and young children, especially those being treated for wasting, have a very high energy intake per kilogram of body weight and will therefore ingest large amounts of contaminants if they are given food that is contaminated. Furthermore, it is plausible that infants and young children with moderate malnutrition are more vulnerable to the negative effects of pesticides and heavy metals because of their rapid growth and development, but evidence for this is scarce. The use of pesticides is widespread in many low-income countries, and control measures are scarce or lacking. Adulteration of foods is another aspect of contamination with potential serious effects. This recently became evident when it was discovered that melamine had been added to milk in China to increase the nitrogen content and thereby artificially increase the apparent protein content [178]. Melamine can cause urinary calculus, acute renal failure, and death in infants.

Aflatoxins

Aflatoxin is a thermoresistant toxin produced by some molds, especially *Aspergillus flavus*. Aflatoxin may be ingested in contaminated food, inhaled, or absorbed through the skin [179]. Exposure can result in both acute toxicity with lethal outcome or more prolonged effects, such as hepatocarcinosis, depending on the dose ingested [179]. A possible relation between kwashiorkor and aflatoxin exposure has been suggested [179–181]. Studies have also found an association between aflatoxin intake and growth retardation in children [179, 182, 183]. However, a causal relation has not been confirmed [179]. It has been suggested that aflatoxin may have immunosuppressing abilities and synergistic effects with infectious diseases such as malaria and HIV [179].

It is not possible to avoid aflatoxin completely, and the goal is therefore to reduce the contamination and intake as much as possible [179]. Like industrialized countries, several African countries in 2003 had specific mycotoxin regulations to reduce exposure [180]. Some studies from sub-Saharan Africa have shown aflatoxin concentration above the Codex Alimentarius limits in staple foods such as maize and peanuts [180]. Poisoning can still be a serious problem, as illustrated by the large aflatoxinosis outbreak in Kenya in 2004 that resulted in many deaths [179].

High temperature and humidity provide the best environment for fungal growth, conditions that are normal in many tropical countries. With the right conditions, fungi can grow in many different foods and feeds [180]. Typical staples with high risk of contamination are maize and groundnuts [179, 180]. Prevention of aflatoxin exposure, therefore, is primarily accomplished through good agricultural practices, with better handling of crops both before and after harvest, e.g., early harvesting, proper drying, removal of crops from earlier harvest, and proper storage [179, 184].

Conclusions and recommendations on contaminants

- It is especially important that foods used for children with moderate malnutrition have low levels of aflatoxin, as it is likely that these children are more vulnerable to the toxic effects.
- The levels should be at least below the levels allowed by the Codex Alimentarius.
- In programs and teaching material aiming at the treatment of children with moderate malnutrition, it should be emphasized that foods with a high risk of contamination should be avoided.

Food processing

The reasons for processing food include preservation of foods for use in times of shortage; increasing shelf-life; removal of toxins; removal of antinutrients, which will improve digestibility and availability of nutrients; and improvement of palatability. As part of food processing, it is also possible to fortify foods. Food preservation is done in order to reduce the contents of microorganisms and enzymes or to decrease their activity, which can be done by heating, removing water, or adding a preservative such as acid, sugar, or salt.

Processing will typically decrease the contents of vitamins and minerals, but some methods, such as fermentation and germination, can increase the contents of some nutrients, such as vitamins B and C. As processing will also decrease the contents of antinutrients, it will have a positive effect on the availability of vitamins and minerals [185]. Different food processes can have different effects on a number of nutritional qualities. Mensah and Tomkins have written a comprehensive review of how household technologies can be used to improve the nutritional value and safety of complementary foods [186]. They have given a crude rating of how some of the most important of these household methods can have beneficial effects on complementary foods, which is shown in **table 10**. However, more research is needed to fully document the potential benefits of fermentation and other food technologies in treating moderately malnourished children.

In this review, the focus will be on methods used for processing staple foods and legumes and how they influence the contents and availability of nutrients and the contents of fibers and antinutrients, topics that are of special interest for selecting foods for children with moderate malnutrition. There is a wide range of methods from industrial- to household-level methods, and

TABLE 10. Benefits of household food-processing technologies[a]

Benefit	Dehulling	Decortication	Roasting	Soaking	Malting	Fermentation
Organoleptic properties	–	+	+++	+++	++	+++
Detoxification	–	+++	–	+++	–	+++
Energy density	–	+	+	++	+++	+++
Viscosity	–	+	+	++	+++	++
Nutritive value	–	–	+	++	+++	+++
Acceptability	++	++	++	++	+++	+++
Stability	–	–	+++	–	–	+++
Safety	++	+++	++	–	–	+++

a. – No benefit; + below average; ++ average; +++ above average. Source: Mensah and Tomkins [186].

the effect on the nutritional value depends on the kind of staple, the specific food-processing methods, and the intensity of treatment. Some of the most important methods and principles will be explained, and examples of how they influence the nutritional value of the foods will be given. Aspects of food processing will also be covered in the sections on Antinutritional Factors, above, and on Starchy Vegetable Foods, below.

Mechanical methods

Dried staple crops are processed into flours or powders in many different ways, from traditional pounding with pestle and mortar followed by winnowing to advanced industrial milling. The overall principle is to remove the outer layers of the grains, which are either inedible or contain substances that are not wanted because they have negative sensory qualities or antinutritional effects, are toxic, or may have a negative effect on shelf-life.

Most cereals are milled into flour or meal with removal of the outer layers of the grain, which reduces the nutritional value. However, removal of the outer layers also makes the grain more resistant to degradation, because the outer layers of the grains contain fats, which are prone to rancidity. The fiber content is also highest in the outer layers, and milling will therefore reduce the amount of fiber, with lower fiber content with increased milling. The extraction rate is the percentage of the amount of whole-grain cereal that is left after milling. Because the nutrients in cereal grains are unevenly distributed, with higher contents in the outer layers of thiamine, niacin, iron, and calcium especially, milling results in substantial losses of nutrients but also in a reduction in the contents of antinutrients such as fiber, tannins, and phytate (**table 8**). Processing will also reduce the relative content of protein (the protein energy percentage) (**table 12**), as the outer layers of the grain have a higher protein content. The quality of the protein can also be reduced, as the protein in the outer layers can have a high lysine content.

Dehulling or dehusking and decortication are other mechanical methods to remove the outer layers of grains. Dehulling and decortication are often used as synonyms, although strictly speaking dehulling refers to the removal of the outer layer only, whereas decortication removes more layers than only the outer layer.

The optimal degree of milling or the extraction rate is a balance between keeping as much of the nutrients in the finished product as possible and at the same time removing as many of the unwanted substances, such as antinutrients, as possible. It is possible that the optimal extraction rate is different for malnourished children than for the general population, as malnourished children might be more vulnerable to the potential negative effects of antinutrients and fibers. However, because there is a lack of studies evaluating the negative effects of fibers and antinutrients in diets for children with moderate malnutrition, there is a need for studies evaluating how different processing methods for staple foods influence the growth of malnourished children. Milling of the various cereals—wheat, rice, maize, sorghum, and millet—is described in the sections describing the individual cereals below.

Heat processing

Heat can increase the digestibility of protein, carbohydrates, and other nutrients, thereby enhancing the nutritive value of the food. It can also inactivate some of the naturally occurring enzymes, such as pectinase and lipoxygenase, in fruits and vegetables, thereby protecting against off flavors, loss of color, and poor texture in the food product. The heat can release vitamins such as vitamin B_6, niacin, folacin, and certain carotenoids from poorly digested complexes and thereby enhance the bioavailability of these vitamins. Another advantage of thermal processing is inactivation of antinutrients in certain foods. However, thermal processing also has several adverse effects. During thermal processing and subsequent storage, thiamine and ascorbic acid are especially susceptible to depletion due to leaching and thermal degradation. In addition to the Maillard reaction, a chemical reaction between an amino acid and a reducing sugar, forming a variety of molecules responsible for a range of odors and flavors, thermal processing at high temperatures can also cause other undesirable reactions to protein, such as oxidation of amino acids, and formation of new amino acid structures or dipeptides that cannot be digested or absorbed through the normal process [187].

The simplest way of heat-treating cereals, legumes, or tubers is to boil them, but legumes in particular need boiling for a long period to be acceptable for eating, which is a resource-consuming process. This is one of the reasons why cereals and legumes are often heat-treated by roasting. Roasting, also called toasting, is a high-temperature dry treatment that is often used for preparing cereals and legumes for blended foods. Typically the whole grain is heat-treated in a hot drum in which the grain comes into contact with the hot wall. The process reduces some of the antinutrients and reduces the level of protease inhibitors and volatile glycosides [186]. Roasting improves flavor and enhances digestibility of the starch. The attractive "roasted" taste is due to the Maillard reactions in the outer layers of the grain. The process reduces the viscosity of porridge made from roasted flour as a result of dextrinization and starch breakdown [186]. A newer method of roasting, also called "micronizing" or "infrared roasting," brings the heat directly into the grain, somewhat similarly to the microwave principle, and provides a more controlled roasting.

Extrusion cooking (heating under pressure) is an energy-efficient industrial process used widely in the production of blended foods. It is a much more controlled process than roasting and takes only 30 to 60 seconds. This process "precooks" cereals and legumes by breaking down starches and denaturing proteins, thereby improving digestibility. After extrusion cooking, typically at 130° to 140°C and under high shear, the blended food or cereal can be used as an "instant food," which only needs to be mixed with water before eating. However, often it is advised to bring the water to the boiling point before making the porridge or to cook the porridge or gruel for a few minutes in case the water used for mixing is contaminated.

Another important quality of extrusion-treated flours is that the nutrient density is improved because of the lower viscosity, which means that less water is needed to obtain an acceptable viscosity. The lower viscosity is caused by dextrinization, which shortens the starch molecules. Extrusion cooking can only be used for flours or blended foods with a fat content below about 10% if low-cost dry extruders are used, but fat can be added to the product after extrusion.

Extrusion cooking has both positive and negative effects on nutritional value. Positive effects include destruction of antinutritional factors. However, extrusion cooking at very high temperatures and low water content aids Maillard reactions and reduces the nutritional value of the protein. It may also increase the formation of resistant starches, which may lead to intestinal discomfort. Furthermore, heat-labile vitamins may be lost to varying extents [188], but they can be added after extrusion. Lysine is the most sensitive amino acid due to its free ε-amino group, but arginine, cysteine, tryptophan, and histidine may also be affected [189]. Lysine is the limiting amino acid in most cereal proteins, and the fate of this amino acid during extrusion cooking is therefore important.

In a study of healthy adult volunteers receiving a test meal with corn-soy blend cooked for 15 minutes at 80°C, with or without previous extrusion cooking, there was no significant effect on starch digestibility [70]. Furthermore, it was suggested that extrusion-cooked foods caused increased bacterial fermentation in the colon, presumably through the solubilization of insoluble fibers, which may depress appetite. Extrusion cooking has potential advantages when used for blended foods, but the effect of the process on gastrointestinal function in infants and young children with malnutrition needs to be investigated in more detail.

Soaking

Both whole grain and flours can be soaked. Usually the process lasts for 1 or 2 days, but soaking for some hours may also have beneficial effects, such as reduction of phytate content [186]. Soaking of flours results in diffusion of water-soluble minerals but also reduces the content of phytate [147]. The extent of the phytate reduction depends on the type of cereal or legume, the pH, and the length and conditions of soaking. Soaking of unrefined maize flour can reduce phytate content by up to 50%, and most of this reduction takes place during the first few hours of soaking [147]. The contents of other antinutrients, such as saponins, trypsin inhibitors, and polyphenols, are also reduced during soaking [186].

Soaking of grains before milling can improve flavor. If unsafe water is used for soaking, enteropathogenic microbes might multiply and result in a contaminated product. It is therefore important that such foods be boiled long enough to ensure that pathogens are killed.

Germination and malting

Legumes and grains can be soaked in water for up to 24 hours and allowed to germinate or sprout (grow a new shoot). The grains are then dried, dehusked, and milled. In this malting process, some of the starch in the grains is degraded into sugars, protein quality and digestibility are improved, the contents of riboflavin, niacin, and vitamin C are increased, and the contents of antinutrients are reduced [14, 186]. In one study, the content of phytate in a maize flour was reduced by 46% after germination [147]. Malting produces α-amylase, which converts starch into sugars and thereby makes the porridge or gruel less thick. This is of special importance for children with moderate malnutrition, as it allows more cereal or legume to be added, thereby increasing the energy and nutrient density. Several studies have shown that the energy and nutrient intake can be improved if germinated amylase-rich flour is used for porridges or if some of this flour is added to a porridge [20, 186, 190]. Soaking, which is part of the germination and malting processes, can add pathogens to the product, so it should be ensured that the gruel or porridge is heated sufficiently before consumption [186]. In conclusion, germination and malting result in a number of beneficial effects, of which the most important are increased energy and nutrient contents and reduced levels of antinutrients.

Fermentation

Fermentation is one of the oldest and most effective methods of producing and preserving foods. It is a process in which microorganisms, typically lactic acid bacteria or yeast, multiply and produce a number of enzymes, such as amylases, proteases, and lipases, which affect the taste, viscosity, and nutritional value of the product. A crude overview of the beneficial effects of fermentation is given in **table 11**, but some of the effects are not investigated in detail. A very important and well-documented effect is that on food safety, as the low pH and the microorganisms produced during fermentation protect against the multiplication of pathogens.

Fermentation breaks down protein to peptides or amino acids; starch is broken down to simple sugars and phytase is produced, which breaks down phytate. Many foods can be fermented, such as cereals, legumes, roots, fish, meat, and milk. Traditionally and in the household the process is spontaneous, initiated by the microorganisms present in the foods, but in industrial production starter cultures are often used. Fermentation of cereals and animal products is mainly done by bacteria. Molds (multicellular fungi) are used to process cheeses and legumes, whereas yeasts (single-celled fungi) are mainly used in the fermentation of breads.

The fermentation process influences the nutritional quality of foods in a number of ways, e.g., by increasing energy density and increasing the amount and bioavailability of nutrients [191] (**table 11**). Fermentation of cereal gruels can improve protein digestibility. Fermentation of sorghum gruels improved protein digestibility—measured in *in vitro* systems—in gruels made from white (nontannin) as well as colored (high-tannin) sorghum varieties. The relative improvement in protein digestibility due to the fermentation was better in the high-tannin gruels than in gruels made from white sorghum and also than in maize gruels. Protein digestibility increased from 30% to 50% in gruel prepared from dehulled high-tannin sorghum, from 65% to 80% in white sorghum gruel, and from 80% to 85% in maize gruel [191]. Fermentation of cereals has been found to improve the contents of certain B vitamins (thiamine, riboflavin, and niacin). For example, fermentation increased the thiamine content in sorghum from 20 to 47 µg/g and the riboflavin content in pearl millet from 0.19 to 0.36 µg/g [191]. Fermentation can induce degradation of phytate to lower inositol phosphates through microbial phytase enzymes and by activation of endogenous phytases [185]. Fermentation improves the bioavailability of iron and other minerals by reducing phytate content and by lowering the pH. In addition to the beneficial effect of direct fermentation of cereals on mineral absorption, it has been shown that the addition of small amounts of fermented vegetables (specifically, carrots and onions) to a cereal meal (wheat roll) almost doubles the relative iron bioavailability from the meal [191].

In conclusion, fermented foods have many advantages as foods for children with moderate malnutrition and should be promoted where possible.

TABLE 11. Effects of fermentation on food and potential health benefits

Effect on food	Potential health benefit
Breakdown of starch by amylases	Reduces bulk and increases energy intake
Reduction of phytic acid	Improved absorption of minerals and protein
Decrease in pH	Improved absorption of minerals Improved food safety
Reduction in lactose content (only milk products)	Better tolerance in individuals with lactase deficiency
Increase in lactic acid bacteria	Better food safety Improved gut integrity Potential probiotic effects
Synthesis of B vitamins	Better vitamin B status

Cooking in iron pots

Cooking meals in cast-iron pots has been suggested as a sustainable way of providing absorbable iron from meals. Two intervention trials with infants and young children showed that those randomly assigned to eating meals cooked in iron pots had a decreased prevalence of anemia after 8 to 12 months as compared with those assigned to eating meals cooked in noniron pots [192, 193]; however, a more recent study showed no effect of cooking in iron pots on anemia prevalence [194]. An *in vitro* study of the release of iron into a maize porridge prepared in a cast-iron pot showed that both a low pH and the presence of organic acids increased the amount of absorbable iron released from the pot [195]. With low pH and addition of citrate, as much as 26.8 mg of iron/100 g of porridge was released. Even with a neutral pH and with no addition of organic acids, 1.7 mg/100 g porridge or 34 mg/1,000 kcal was released, assuming an energy density of the porridge of 0.5 kcal/g. Thus, the use of cast-iron pots for cooking food for moderately malnourished children has the potential of providing a low-cost, sustainable supply of dietary iron. However, the acceptability of using cast-iron pots in households, the risk of providing too much iron if iron pots are used for fermented foods with low pH, and the risk of heavy-metal contamination should be investigated further.

Conclusions and recommendations on food processing

- » Food processing, especially of staple foods such as cereals, legumes, and roots, can have important beneficial effects on the nutritional value of foods given to children with moderate malnutrition.
- » The outer layers of grains typically have a high content of both nutrients and antinutritional factors such as phytate, tannins, and fibers. Processes such as milling will therefore remove both nutrients and antinutrients. The optimal degree of milling is therefore a balance between keeping a high content of nutrients and removing as many of the antinutrients as possible, and it is likely that the optimal balance is different for moderately malnourished than for well-nourished children.
- » Methods such as soaking, malting, and fermentation increase the nutritional value of foods, e.g., by reducing the content of antinutrients.
- » As part of food processing, it is possible to fortify foods with minerals and vitamins.

Relevant foods and ingredients

Starchy vegetable foods

Cereals

Cereals are mainly grasses cultivated for their edible grains or fruit seeds. Cereals are the cheapest way to provide energy. In low-income countries, these foods provide 70% or more of the energy intake [196]. The most important staple foods in terms of global production are maize, wheat, and rice.

Cereal grains supply energy mainly as starch. They are also an important source of protein, supplying most of the protein intake in many populations. They contain from 6 to 14 g of protein/100 g dry weight, and from 7% to 14% of the energy comes from protein. The amino acid composition of cereals is in most cases not optimal, typically being deficient in lysine. There is some calcium and iron, but the absorption of these minerals is not high. They are important sources of B vitamins but contain no vitamin C and no provitamin A, except for whole yellow maize. The amount of fat in cereals is generally low, with a predominance of n-6 PUFAs. Whole grains contain high levels of dietary fiber and antinutrients, which can be reduced by food-processing methods such as milling. The outer layers of cereal grains contain the highest amounts of nutrients, fibers, and antinutrients. Processing methods such as milling will therefore typically reduce the contents of all these three constituents. The degree of processing is therefore a balance between reducing the negative factors (antinutrients and fibers), which is important for young children, especially if they are malnourished, and not removing too much of the nutrients. This balance is different for each cereal and will be discussed in the sections below. It is possible that the optimal extraction rate is different for malnourished children than for the general population, as malnourished children might be more vulnerable to the potential negative effects of antinutrients and fibers. If a large fraction of the whole grain is removed, such as in white wheat flour where 30% to 40% of the whole grain is removed, this will also influence the price of the product.

Some cereals, especially wheat, rye, and barley, contain gluten, which can cause celiac disease, a form of gluten allergy. Oats may contain very small amounts of gluten. Most other cereals, including maize, the most widely used cereal in food aid, do not contain gluten. Until recently it was believed that celiac disease or gluten intolerance only affected people of European origin. However, new studies have shown that celiac disease is also a problem in populations in Southern Asia, the Middle East, North, West, and East Africa, and South America whose main staple food is wheat [197]. In a study of the prevalence of celiac disease in Egypt, 4.7% of children admitted with diarrhea or failure to thrive had celiac disease [198]. Thus, gluten intolerance should also be considered in children with moderate malnutrition from populations with a high intake of wheat. In such populations, the use of diets with no gluten should be considered if the prevalence of celiac disease is high.

Wheat

Wheat is one of the cereals that are produced in the highest quantities in the world, and it is also the main staple food in some low-income countries, e.g., in North India and North Africa [196, 199]. The protein content is about 10 g/100 g, i.e., the protein content constitutes about 12% of the energy. However, the quality of the protein is lower than in other cereals, with a relatively low PDCAAS (**table 2**). Lysine is the limiting amino acid.

Milling of wheat increases the proportion of starch and sugars and lowers the proportion of other nutrients. Mineral content decreases with the refining process, and the contents of dietary fiber, protein, and fat also decrease significantly (**tables 12** and **13**). For example, the contents of potassium and magnesium, which are important growth (type II) nutrients, are reduced by two-thirds in white flour [93]; this is discussed in more detail in the section on Minerals, above. Refined flour contains no lignin and has much less insoluble fiber than whole-grain flour [200] (**table 12**). The extraction rate of whole-wheat flour is typically 85%, whereas white flour has an extraction rate of about 60%. In white flour, most of the fibers are lost.

TABLE 12. Macronutrients and energy in cereal staples (values/100 g)[a]

Cereal	Energy				Protein	Lipids			Carbohydrates		
	Total (kcal)	Protein (E%)	Fat (E%)	Carbo-hydrates (E%)	Total (g)	Total (g)	PUFA (g)	n-6:n-3 wt/wt ratio	Total (g)	Dietary fiber (g)[b]	Insoluble fiber (g)[c,d]
Wheat											
Flour, whole-meal (85% extraction)	341	11.9	6.0	82.1	10.7	2.4	1.1	14.6	74.1	11.6	1.0[d]
Flour, white (60% extraction)	354	10.8	4.0	85.2	9.6	1.6	0.7	14.6	76.0	3.7	—
Rice											
Brown, raw	368	9.7	7.1	83.2	9.0	2.9	1.0	37.7	76.6	2.4	—
White polished, raw	364	9.3	3.0	87.7	8.4	1.2	0.4	37.3	79.0	0.7	0.2[d]
White parboiled, raw	364	7.8	1.2	79.8	7.4	1.2	0.4	36.9	79.8	0.9	—
Maize											
Meal, whole-grain, white/yellow[e]	362[e]	8.7[e]	8.8[e]	82.5[e]	8.1[e]	3.6[e]	1.6[e]	—	76.9[e]	7.3[e]	—
Meal, degermed, white/yellow[e]	369[e]	8.1[e]	4.5[e]	87.4[e]	7.3[e]	1.8[e]	0.7[e]	—	79.2[e]	4.0[e]	—
Oats											
Rolled	366	13.7	15.3	71.0	13.2	6.5	2.7	29.9	68.2	10.1	—
Sorghum											
Whole-grain	355[d]	11.7[d]	8.6[d]	79.7[d]	10.4[d]	3.4[d]	1.4[e]	—	71.0	6.3[e]	2.0[d]
Flour	353[d]	11.3[d]	6.3[d]	82.4[d]	10.0[d]	2.5[d]	—	—	73.0	—	1.5[d]
Millet											
Pearl, whole-grain	363[d]	12.0[d]	12.3[d]	75.7[d]	11.0[d]	5.0[d]	2.1[e]	—	69.0	8.5[e]	2.0[d]
Pearl, flour	365[d]	9.8[d]	7.4[d]	82.8[d]	9.0[d]	3.0[d]	—	—	76.0	—	1.0[d]
Finger, whole-grain	336[d]	7.1[d]	4.0[d]	88.9[d]	6.0[d]	1.5[d]	—	—	75.0	—	3.0[d]
Finger, flour	332[d]	6.6[d]	2.2[d]	91.2[d]	5.5[d]	0.8[d]	—	—	76.0	—	2.4[d]

E%, energy percent; PUFA, polyunsaturated fatty acid

a. Source: National Food Institute (Denmark)[28], unless otherwise noted.

b. Dietary fibers are determined by different methods.

c. Insoluble fiber roughly is equivalent to crude fiber, whose definition is based on an outdated analysis method: the edible part of the plant that is insoluble in strong acids and alkalis.

d. Source: Platt [203]

e. Source: US Department of Agriculture [27].

TABLE 13. Energy and nutrient densities in cereal staples[a]

Cereal	Total energy (kcal/ 100 g)	Nutrient density/1,000 kcal							
		Folate (µg)	Vitamin B_1 (mg)	Calcium (mg)	Phosphorus (mg)	Iron (mg)	Zinc (mg)	Iodine (µg)	Phytate (mg)
Recommended nutrient density/1,000 kcal[b]	NA	220	0.6	600	600	9	13	200	NA
Wheat									
Flour, whole-meal (85% extraction)	341	147	1.1	88	918	9.7	7.6	7.9	890[c]
Flour, white (60% extraction)	354	51	0.5	48	331	3.3	2.3	5.4	190[c]
Rice									
Brown, raw	368	144	1.3	32	1,005	3.5	4.3	12.2	—
White polished, raw	364	85	0.2	145	357	3.3	4.7	6.0	130[c]
White parboiled, raw	363	50	1.7	357	471	3.3	4.7	6.1	
Maize									
Meal, whole-grain, white/ yellow[d]	362	69	1.1	16	666	9.5	5.0	—	900[c]
Meal, degermed, white/ yellow[d]	369	81	0.4	8	285	3.0	1.9	—	—
Oats									
Rolled	366	126	1.1	491	1,243	10.7	8.3	1.4	880[e]
Sorghum									
Whole-grain[f]	355	—	1.4	90	809[d]	13	—	—	1,080[e]
Flour[f]	353	—	1.1	56	—	11	—	—	—
Millet									
Pearl, whole-grain[f]	363	83	0.8	69	661	8.3	9.4	14	830[e]
Pearl, flour[f]	365	—	0.5	41	—	5.5	—	—	—
Finger, whole-grain[f]	336	—	0.9	1,042	—	15	—	—	—
Flour[f]	332	—	0.5	1,115	—	12	—	—	—

a. Source: National Food Institute (Denmark)[28] unless otherwise noted.
b. Values from Golden [4].
c. Source: Egli et al. [142].
d. Source: US Department of Agriculture [27].
e. Source: Egli et al. [150].
f. Source: Platt [203].

An extraction rate of about 80% is a prudent balance between not reducing the nutrient content too much and reducing the fiber content.

Rice

Rice is the main staple food of over half the world's population [201]. Rice proteins have a higher content of lysine than most other cereal proteins, and rice protein is considered to be of high quality, with one of the highest PDCAAS among cereals. However, rice has one of the lowest protein contents among cereals, and despite a relative high lysine content, the limiting amino acids are lysine and threonine [201, 202]. Brown rice (in which only the hull is removed) has higher energy content due to a higher fat content and also a higher vitamin B content, but it also has a higher content of fiber. The loss of vitamin B in milled rice can be partly prevented by parboiling [201, 202].

Parboiling is a process in which the whole grain is soaked, steamed, and dried. During soaking, the water-soluble nutrients become more evenly distributed throughout the whole grain and are hardly removed during dehulling. During drying, the outer coat of the grain is hardened by the heat so that when the grain is stored it is more resistant to insect invasion.

Rice is rarely ground to flour. However, it is often milled into a highly refined product, losing a high proportion of vitamins and other important nutrients in the process. The primary objective in rice milling is to remove the hull and the bran with minimum breakage of the endosperm. This is achieved by cleaning, shelling or dehulling, and milling. In brown rice, only the hull is removed. The traditional method of pounding rice in a wooden mortar and winnowing it results in the loss of about half of the outer layers and germ [196].

Maize

Maize, or corn, is used as a staple food mainly in the Americas and in Africa. The major nutritional component in maize is starch in the form of amylose and amylopectin. The maize kernel contains about the same amount of protein as other cereals, but with a lower content of lysine and tryptophan. The fat content is high, about 9% of the energy in whole-grain maize. Maize oil has a high content of PUFAs, mainly linoleic acid (24%), and thereby a high n-6/n-3 fatty acid ratio [204]. Whole-grain maize has a low content of niacin, even compared with wheat and rice. Furthermore, it is in a form with reduced availability [196]. In South America, maize is often treated with lime water, which makes niacin better available.

In the late 1930s, Cicely Williams made the first description of kwashiorkor and reported that it was associated with a maize diet [205]. However, since most of the children had a history of deficient breastfeeding and only received maize as supplementary food, it may not have been a characteristic of maize that caused kwashiorkor in that setting.

Milling of maize reduces the nutritional value, as in other cereals. The milling of maize yields a variety of products. There are two methods of milling maize: dry and wet milling [204]. Wet milling produces starch, syrups, and dextrose for use in the food industry. The most common process used in low-income countries is dry milling. In dry milling, the hull and germ are stripped from the endosperm and can be totally separated from the endosperm [206]. Degermed and dehulled maize has an extraction rate of 60%, which almost doubles the price compared with whole-meal flour. Traditional methods using stones or pestle and mortar are still common in many low-income countries. With these methods, the grains lose some of their outer coat but retain some of the lipid-rich outer layers. Because of the fat content, the products become rapidly rancid, and milling has to be done frequently [207].

Oats

Oats are grown mainly in cold areas and are not considered an important crop in the diets of most low-income countries. Oats have a high nutritional value. Oats have a higher protein content (13 g/100 g) than maize, rice, and wheat and also have a high lysine content and thereby a high PDCAAS. However, there is also a considerable quantity of phytic acid. The lipid concentration of oats is higher than that of other cereals, with a favorable ratio of unsaturated to saturated fatty acids compared with other cereals. Oats are appropriate for children with moderate malnutrition, but because of price and availability they are often not a realistic option.

Sorghum and millets

Sorghum and the several millet species are grasses with an ancient history of cultivation in Africa and Asia (**table 14**). They are relatively drought-resistant crops and are suitable for production under difficult agronomic conditions. Sorghum and millets for human consumption are mostly grown in Africa and India, although their production is declining as they are being replaced by maize and rice. Sorghum and millets are often grown for subsistence use and are therefore important crops for local food security in some arid and semiarid regions. Sorghum and millets are used in a range of traditional foods and beverages, such as thin and stiff porridges, unleavened flatbreads, and beverages.

There are white and colored varieties of sorghum and millet species. The colored varieties contain tannins and have some agronomic advantages because they are more resistant to bird and pest attacks, but the tannins have a negative impact on the nutritional value because of their antinutrient properties.

Millets are various species of small seeded grasses, of which the major species for human consumption are pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*). The nutritional quality, including

TABLE 14. Origins and common names of sorghum and millets[a]

Scientific name	Common names	Suggested origin
Sorghum bicolor	Sorghum, great millet, guinea corn, kafir corn, aura, mtama, jowar, cholam. kaoliang, milo, milo-maize	Northeast quadrant of Africa (Ethiopia-Sudan border)
Pennisetum glaucum	Pearl millet, cumbu, spiked millet, bajra, bulrush millet, candle millet, dark millet	Tropical West Africa
Eleusine coracana	Finger millet, African millet, koracan, ragi, wimbi, bulo, telebun	Uganda or neighboring region
Setaria italica	Foxtail millet, Italian millet, German millet, Hungarian millet, Siberian millet	Eastern Asia (China)
Panicum miliaceum	Proso millet, common millet, hog millet, broom-corn millet, Russian millet, brown corn	Central and eastern Asia
Panicum sumatrense	Little millet	Southeast Asia
Echinochloa crus-galli	Barnyard millet, sawa millet, Japanese barnyard millet	Japan
Paspalum scrobiculatum	Kodo millet	India

a. Source: FAO [208].

the protein and fat contents, varies with the species and varieties. Both sorghum and millet species in general have high fiber contents. The total dietary fiber content is reported as 17% to 20% in millets and 14% in sorghum [208].

Industrially and home-based processing of sorghum and millets includes mechanical milling to obtain dehulled, refined flour. Milling of sorghum removes 10% to 30% of the original weight. Traditional processing of sorghum and millets includes fermentation, soaking, and germination,which can contribute to improving the nutritional quality by reducing the contents of tannins and fibers.

Sprouts of germinated sorghum contain a cyanogenic glucoside that can be hydrolyzed to highly toxic cyanide (HCN) [209], and the fresh shoots and roots of germinated sorghum must therefore never be consumed.

Quinoa

Quinoa is grown as a crop primarily for its edible seed. It is a pseudo-cereal rather than a true cereal, as it is not a grass. Its leaves are also eaten as a vegetable. Quinoa originates from South America and is still mainly grown there [210]. Quinoa has a balanced content of essential amino acids and thus a high protein quality [211]. It is also a source of vitamin E, thiamine, iron, zinc, and magnesium [212, 213]. Quinoa has a coating of bitter-tasting saponins, which can be removed by soaking [214].

Teff

Teff is grown mainly in Ethiopia and Eritrea and to a lesser extent in India and Australia. The grain has a high content of several nutrients, including calcium, phosphorus, iron, copper, and thiamine. Teff also has a good amino acid composition and has lysine levels higher than those of wheat. In Ethiopia and Eritrea, teff is mainly used in enjera, a fermented thin, flat pancake, which is consumed mainly by adults. The high contents of important nutrients, combined with the advantages of fermentation (**table 11**) (see section on Fermentation, above), make enjera a potentially valuable food for malnourished children, but the tradition is to feed infants and young children porridge and pancakes made from unfermented teff. Teff is considerably more expensive than other cereals.

Conclusions and recommendations on cereals

» Cereals are important ingredients in diets for children with moderate malnutrition, as they provide easily available and low-cost energy, protein, and important nutrients.

» In choosing the best cereal types for treating children with moderate malnutrition, the contents of nutrients, fibers, and antinutrients, especially phytate, should be taken into consideration.

» A high extraction rate will reduce the contents of fibers and antinutrients, but also the contents of nutrients. Thus, the optimal extraction rate is a balance that differs according to the type of cereal and the target population

» White rice, wheat flour with a 85% extraction rate, and maize flour with a 60% extraction rate are prudent choices for feeding children with moderate malnutrition.

Legumes and pulses

Legumes are plants from the family Fabaceae or the fruits of these plants. Well-known legumes include peas, beans, and peanuts. The FAO has defined "pulses" as legumes harvested solely for the dry grain. This definition excludes green beans and green peas, which are considered vegetable crops. Crops that are grown mainly for oil extraction (oilseeds such as peanuts and soybeans) are also excluded. Legumes play an important role in the diets of people in Asia, India, South and Middle America, and to some extent in Africa.

Legumes have a high nutritional quality. The protein content is high, typically from 20 to 35 g/100 g, or a protein energy percentage of 20 to 30. The quality of the protein is not high because of a low content of methionine. The lysine content is high compared with cereals, and therefore legumes complement the low lysine content of cereals, resulting in a high PDCAAS in foods containing both cereals and legumes. The fat content is low, about 1% to 3%, with the exception of whole peanuts and soybean, which contain about 43 and 18 g of fat/100 g, respectively.

The total content of fiber is generally high, typically around 5 to 15 g/100 g dry weight, of which 4 to 5 g/100 g is insoluble fiber (**table 15**). The content of phytate is high in legumes, at the same level as in whole-grain cereals (**tables 13** and **16**). However, in cereals the phytate is located mainly in the outer layers and can be removed more easily during processing, which is not the case with legumes. Therefore, the phytate content is higher in legumes. An analysis of complementary foods from Indonesia found that legumes typically had phytate contents three to four times higher than those in cereals [215]. Colored legumes also have high levels of polyphenols.

Legumes often contain high amounts of indigestible oligosaccharides (stacchiose and rafinose) that are rapidly fermented in the colon and can cause undesired flatulence [216]. This gas production may play a role in the acceptability of legumes, including soybean products, as a major food source for humans [217–220].

Lentils

Lentil is a plant of the legume family with lens-shaped seeds. Lentils are used to make daal, a traditional dish with cooked lentils. Lentils can be white, yellow, red,

TABLE 15. Macronutrients and energy in starchy roots and legumes (values/100 g)[a]

Food	Energy				Total protein (g)	Lipids			Carbohydrate		
	Total (kcal)	Protein (E%)	Fat (E%)	Carbohydrates (E%)		Total (g)	PUFA (g)	n-6:n-3 wt/wt ratio	Total (g)	Dietary fiber (g)[b]	Insoluble fiber (g)[c]
Legumes											
Kidney bean	339	28.3	4.5	67.2	24.0	1.7	—	—	57.0	—	4.0[d]
Mung bean, raw, dry	312	27.0	3.3	69.7	24.2	1.3	—	—	62.6	15.0	4.6[d]
Brown bean, dry	314	21.8	5.2	73.0	18.9	2.0	—	—	63.4	17.8	—
Red lentil, raw, dry	361	29.5	7.1	63.4	27.3	2.9	1.1[e]	—	58.5	6.2	4.0[d]
Brown lentil, raw, dry	340	28.0	5.0	67.0	25.1	2.0	0.5[e]	—	60.1	11.2	4.0[d]
Soy flour, full fat	449	31.6	42.5	25.9	37.2	22.2	12.6	7.1	30.5	10.4	—
Soy flour, defatted	375	45.4	20.0	34.6	45.5	8.9	3.9	—	34.9	16.0	—
Peanut, dry	557	16.7	64.3	19.0	24.9	42.7	14.5	∞	28.4	7.7	3.0[d]
Starchy roots[e]											
Cassava, raw	120	10.0	2.9	87.1	3.1	0.4	0.1	1.9	26.9	2.5	1.0[d]
Sweet potato, raw	71	6.9	3.6	89.6	1.3	0.3	0.1	5.5	17.0	3.0	1.0[d]
Yam, raw	119	5.0	1.5	93.5	1.5	0.2	0.1	5.3	27.9	1.0	0.5[d]
Potato, raw	82	9.1	3.2	87.7	1.9	0.3	0.2	0.8	18.3	1.4	0.4[d]
Other[e]											
Plantain, raw	122	3.8	2.4	93.8	1.3	0.4	0.1	—	31.9	2.3	0.3[d]

E%, energy percent; PUFA, polyunsaturated fatty acid

a. Source: National Food Institute (Denmark) [28] unless otherwise noted.

b. Dietary fibers are determined by different methods

c. Insoluble fiber roughly is equivalent to crude fiber, whose definition is based on an outdated analysis method: the edible part of the plant that is insoluble in strong acids and alkalis.

d. Source: Platt [203].

e. Source: US Department of Agriculture [27].

green, brown, or black. Red, yellow, and white lentils have had their skins removed, i.e., they are decorticated. Some lentils contain a toxin that can cause latyrism, a neurological condition with paralysis [221]. The amount of toxin can be reduced by soaking, heating, and fermentation.

Beans

Beans are large seeds of plants of the family Fabaceae. There is a great variety of bean types that are produced in large parts of the world. Grams are a group of legumes that includes pigeon peas, chick peas, green grams, and mung beans [196].

The protein content of beans is between 20% and 30%. The PDCAAS is reasonably good, although their overall value is reduced by their lower digestibility [222]. Beans are generally very low in fat, containing about 2% to 5% of energy as fat, and the dietary contribution of beans to the intake of n-3 fatty acids, due to the content of α-linolenic acid, is generally minor [223]. Beans are an excellent source of folate. Even though beans have relatively high contents of both calcium and iron, they are not a very good iron source because of the low bioavailability of iron from legumes [224–227]. Beans provide a large amount of dietary fiber.

Beans contain several antinutrient factors, of which the most important are trypsin inhibitors, phytate, and lectins. The phytate content of beans is between 1% and 2%, which contributes to the poor bioavailability of minerals in beans [228, 229].

Soybean

Soybeans are an important crop, providing primarily high contents of oil and protein. Soybeans occur in various colors: black, brown, blue, green, and yellow. The oil and protein contents together account for about 60% of the weight of dry soybean flour (protein 37% and oil 22%) (**table 15**).

The protein content is of high quality. It contains all the essential amino acids. With the exception of the sulfur amino acids, cysteine and methionine, in which soybeans are deficient, other essential amino acids are present in sufficient quantities; noteworthy is the high amount of lysine, which distinguishes soybeans from other legumes and cereals [230, 231], and provides soy protein with a high PDCAAS. For this reason, soybeans are a good source of protein, especially for those living on a diet low in animal-source foods.

TABLE 16. Nutrient densities in starchy roots and legumes[a]

Food	Total energy (kcal/100 g)	Nutrient density/1,000 kcal						Phytate (mg/ 100 g)[b]	Phytate ratio (molar)[b]	
		Folates (µg)	Vitamin B_1 (mg)	Calcium (mg)	Phos-phorus (mg)	Iron (mg)	Zinc (mg)		Phyt:Fe ratio	Phyt:Zn ratio
Recommended nutrient density/1,000 kcal[c]		220	0.6	600	600	9	13	—	—	< 15
Legumes										
Kidney bean[d]	339	—	1.5	325	—	23.6	—	—	—	—
Mung bean, raw, dry	312	1,041	1.2	282	1,266	24.7	8.v6	833[e]	15.2[e]	28.5[e]
Brown bean, dry	314	446	1.1	245	1,519	15.9	6.4	—	—	—
Red lentil, raw, dry	361	565[f]	1.4[f]	114	1,019	20.9[f]	10.8[f]	—	—	—
Brown lentil, raw, dry	340	1,409[f]	2.6[f]	206	1,097	22.2[f]	14.1[f]	115[g]	—	—
Soy flour, full fat	449	1,782	1.7	334	1,237	8.9	11.1	763[e]	11.3[e]	19.1[e]
Soy flour, defatted[e]	375	813	2.9	760	1,800	21.9	10.9	—	—	—
Peanut, dry	557	190	1.6	100	734	3.4	5.6	814[e]	10.6[e]	23.7[e]
Starchy roots										
Cassava, raw	120	183	1.9	758	583	30.0	2.1	—	—	—
Sweet potato, raw	71	199	1.0	638	397	12.8	2.8	—	—	—
Yam, raw	119	193	0.9	143	462	4.2	2.0	—	—	—
Potato, raw	82	441	0.7	86	673	12.7	3.7	—	—	—
Other										
Plantain, raw[e]	122	180	0.4	24.6	278.7	4.9	1.1	—	—	—

a. Source: National Food Institute (Denmark) [28], unless otherwise noted.
b, Phytate (mg/100 g) is based on the sum of IP5 and IP6.
c. Values from Golden [4].
d. Source: Platt [203].
e. Source: Chan et al. [215].
f. Source: US Department of Agriculture [27].
g. Source: Egli et al. [150].

The oil content is of high quality, as soy oil contains a high proportion of unsaturated fatty acids, with a high content of the n-3 fatty acid α-linolenic acid and thereby a favorable n-6/n-3 PUFA ratio of about 7. The fatty acid content of soybeans is discussed in more detail in the section on Oils and Fats, below.

On average, dry soybeans contain about 35% carbohydrates. The insoluble carbohydrates in soybeans include cellulose, hemicellulose, pectin, and a trace amount of starch. Soybeans contain both water-soluble and fat-soluble vitamins. The water-soluble vitamins are mainly thiamine, riboflavin, niacin, pantothenic acid, and folic acid. Soybeans also contain vitamin C, but the amount is negligible in mature soybeans, although it is present in measurable amounts in both immature and germinated seeds [231]. The fat-soluble vitamins in soybeans are vitamins A and E, with essentially no vitamins D and K. Vitamin A is present mainly as the provitamin β-carotene, and the content is negligible in mature seeds.

As in most legumes, there is an abundance of potassium but not of sodium, and soybeans are a very good source of phosphorus, although a significant proportion of it is present as phytic acid phosphorus, which has only partial biological availability. Soybeans are also a good source of calcium and magnesium, but they are poor in iron. The amounts of zinc, iron, and iodine are minimal [231]. Soybeans contain antinutritional factors, of which the most important are protease inhibitors, lectin, and phytates.

A range of soy products are used for vulnerable and undernourished populations. The most common products are whole soybeans or grits, full-fat soy flour, and defatted soy flour [232]. In corn–soy blend, nondehulled and dehulled soybeans and defatted and toasted soy flour have been used [152]. Other more refined products are soy protein concentrates and soy protein isolates, the latter used in infant formula. The difference between defatted soy flour, soy concentrates, and soy isolates is not only the carbohydrate content, which is 32%, 21%, and 3% respectively, but also the content of fiber and antinutrients which is reduced, although important quantities are left even in soy isolates [127, 218, 233, 234].

In conclusion, soybeans have exceptionally high contents of both protein and fat. The quality of protein is high, with a balanced amino acid composition and thereby a high PDCAAS, and the quality of fat is also good, with a relatively high contribution from n-3 PUFAs and thus a favorable n-6/n-3 fatty acid ratio. On the other hand, soybeans also contain high levels of antinutrients, especially phytate, and high levels of phytoestrogens (see section on Phytoestrogens, above). There is a lack of studies on the potential negative effects of the antinutrients in soybeans in malnourished infants and young children. Studies of growth in weanling pigs have shown that growth is better on a milk-based diet than a corn–soy diet [23]. But whether that is due to beneficial effects of milk or antinutritional effects of the soy and corn is not known. There is an urgent need to perform studies of the effects of different preparations of soybeans with different contents of antinutrients on growth.

Peanuts

The peanut is also known as groundnut and is one of the most nutritious seeds and one of the world's most popular legumes or pulses. In Africa peanuts are prepared as fresh boiled peanuts or roasted. They may also be ground or milled, and ground peanut is often available at markets to prepare peanut sauce [196, 235].

With more than 40% fat, peanuts contain more fat than other legumes. The protein content is about 25%, but peanuts are deficient in lysine and methionine. The amount of carbohydrate is relatively low at about 28%. Peanuts have little or no carotene but are a good source of vitamin E, niacin, and folate [236]. The fatty acid composition is discussed in the section on Oils and Fats, below. Peanuts have higher levels of phytate than most other legumes (**tables 7** and **15**) and also contain α-galactosides.

Conclusions and recommendations on legumes and pulses

» Legumes and pulses are important foods for children with moderate malnutrition because they have a high content of protein with an amino acid composition that complements the amino acid profile of cereals.
» The content of fibers and antinutrients is high, and optimal processing to reduce the amounts is important.
» Soybeans are used extensively as a commodity with a high protein content and quality at a reasonable price. However, the contents of fibers and phytate differ considerably between different soybean products.
» Soybeans have a high content of fat, with a high content of PUFAs and an optimal n-6/n-3 balance.

Research recommendations

» There is a need to examine the potential growth-inhibiting effect of different soy preparations with different degrees of processing.

Roots

Roots provide primarily energy in the human diet in the form of carbohydrates. In low-income countries, the main nutritional value of roots is their potential ability to provide one of the cheapest sources of energy in the form of carbohydrates. Both protein and fat contents are very low.

Cassava

Cassava is a starchy root that is an essential part of the diet of more than half a billion people. It is originally from South America but is now grown in many places. Cassava is also known as manioc or tapioca. It is drought resistant, needs little attention, and gives a high yield. Both the tubers and the leaves are used as food sources. The tubers are an important staple food in many low-income countries of Africa, South and Central America, India, and Southeast Asia, providing a cheap carbohydrate source. About 90% of the energy content in cassava comes from carbohydrates, mainly starch. Cassava is deficient in protein, with only about 3% of the energy coming from protein and only 1% from fat. Cassava species contain varying amounts of toxic cyanogenic glycoside, which can cause the paralytic disease konzo and can interfere with the function of the thyroid gland and cause goiter [177, 237]. The cyanide content can be reduced by soaking or boiling, but fermentation is more effective. Cassava leaves have high contents of carotene, vitamin C, iron, and calcium. The leaves contain more protein than the tubers, but they lack methionine [196, 238].

Potatoes and sweet potatoes

Potatoes belong to the nightshade family (Solanaceae) and have a high protein content (9 E%) with a high protein quality (PDCAAS) (**table 2**), higher than that of any of the cereals or other roots. The content of fibers is low, and the contents of vitamin C and potassium are high. During the last decade, there has been a marked increase in potato production in many developing countries. Because of the potential role of potato production in food security and poverty reduction, the United Nations and the FAO declared 2008 as the year of the potato (www.potato2008.org). Sweet potatoes are starchy roots belonging to the bindweed family (Convolvulaceae) that are widely grown as staple foods in parts of Africa and Asia. Sweet potatoes have the same energy content as potatoes but a lower protein content, equivalent to about 7 E%. The yellow forms of sweet potato (orange-fleshed sweet potatoes) contain higher amounts of provitamin A carotenoids than the white forms and have been promoted as a dietary supplement to improve vitamin A status in vitamin A–deficient children [239, 240].

Plantain

Plantain is a form of banana and thus a fruit, not a root, but it is often classified with starchy roots, as it has a nutritional composition close to that of starchy roots. Plantains contain more starch than bananas and are either boiled or fried or made into a flour after sun-drying [196].

Conclusions and recommendations on roots

» Roots are typically cheap sources of energy, but the protein and fat contents are low and they are therefore not optimal as foods for children with moderate malnutrition.
» Potatoes are a valuable food with a high content and quality of protein and a low content of fibers and phytate.

Vegetables

A vegetable is not botanically defined, as it may be any edible part of a plant, such as the root, stem, leaves, or fruit. Many vegetables, such as carrots, onions, tomatoes, pumpkins, okra, aubergines, and green peas, can be valuable ingredients in diets for children with moderate malnutrition. In addition to the energy and nutrients they provide, they bring taste, color, and variability to the diet. Although vegetables typically shrink when cooked, they are often not very energy dense and can contribute to the bulkiness of the meal. They may also contain considerable amounts of fiber, which is part of the bulk problem. Many vegetables contain important amounts of micronutrients, especially provitamin A, vitamin C, and iron. Although the bioavailability of minerals in vegetables can be low because of antinutrients, the high amounts of vitamin C may improve the mineral bioavailability of the whole meal. Vegetables such as green leaves and fruits can be grown in home gardens or gathered from fields or bushes at the village level. Some vegetables, such as tomatoes, can be sun-dried and used later in cooked meals. Vegetables may therefore be affordable and valuable ingredients in diets for children with moderate malnutrition.

Conclusions and recommendations on vegetables

» Many vegetables are affordable and nutritionally valuable ingredients in diets for children with moderate malnutrition.

Green leafy vegetables

Dark-green leafy vegetables such as kale, spinach, and leaves of cassava, pumpkin, amaranth, and taro are widely available and are consumed as part of the normal diet in many populations. Green leafy vegetables are rich sources of provitamin A, vitamin C, iron, and calcium (**tables 17** and **18**). They are almost always cooked before consumption, which causes them to shrink in volume and become more nutrient dense. However, cooking may affect the bioavailability and activity of the nutrients. Cooking destroys 50% to 80% of vitamin C but improves the bioavailability of β-carotene [98].

TABLE 17. Macronutrients and energy in selected green, leafy vegetables (values/100 g of raw, edible portion)[a]

Vegetable	Energy (kcal)	Protein (g)	Lipid (g)	Protein (E%)	Lipid (E%)
Pumpkin leaves	19	3.15	0.40	68	19
Kale	50	3.30	0.70	27	13
Amaranth leaves	23	2.46	0.33	43	13
Spinach	23	2.86	0.39	50	15
Taro leaves	42	4.98	0.74	48	16

E%, energy percent
a. Source: US Department of Agriculture [27].

TABLE 18. Nutrient densities per 1000 kcal in selected green, leafy vegetables[a]

Vegetable	Vitamin A (µg RAE)	Vitamin B_1 (mg)	Vitamin B_{12} (µg)	Vitamin C (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	Phosphorus (mg)
Recommended density/1,000 kcal[b]	960	0.6	1.0	75	600	9	13	600
Pumpkin leaves	5,137	0.5	<0.01	583	2,066	117.6	10.6	5,508
Kale	15,469	0.2	<0.01	2,414	2,716	34.2	8.9	1,126
Amaranth leaves	6,298	0.1	<0.01	1,868	9,274	100.1	38.8	2,157
Spinach	20,230	0.3	<0.01	1,212	4,270	116.9	22.9	2,114
Taro leaves	5,697	0.5	<0.01	1,229	2,529	53.2	9.7	1,418

RAE, retinol activity equivalents
a. Source: US Department of Agriculture [27].
b. Values from Golden [4].

Even though the conversion of provitamin A carotenoids is less effective than previously believed [98], green leafy vegetables consumed daily are still a valuable source of vitamin A, even with a low intake of dietary fat [241]. Since green leafy vegetables can be grown at home at low cost, they may serve as a reasonable alternative to vitamin A–rich animal-source foods. Home gardening of green leafy vegetables combined with nutrition education in rural South Africa improved the vitamin A status of 2- to 5-year-old children compared with children in a control village [242].

The iron content of most green leafy vegetables is relatively high, although the bioavailability of iron is compromised by a high content of tannins and oxalates [243].

Overall, consumption of green leafy vegetables improves the nutrient quality of cereal-based diets, although the bioavailability of vitamin A as well as that of iron is low.

Moringa leaves

The tropical drought-resistant tree *Moringa oleifera* is native to India but has been introduced to Africa and South America. The leaves are consumed raw, cooked like other green leaves, or as a dried, concentrated powder. Moringa is suitable for home gardening, as it is easy to grow and its fresh leaves can be harvested continuously. It has been claimed to have unusually high contents of calcium, iron, vitamin A [244], and high-quality protein and low contents of antinutrients such as tannins and oxalates [245]. Moringa leaves have therefore been promoted as a potential low-cost, high-quality food. Published data on the nutrient content of moringa leaves are, however, inconsistent [244, 246, 247], probably reflecting different pre- and postharvest procedures, varieties, leaf age, etc. There is limited information on the bioavailability of nutrients from moringa leaves, although they were effective in improving vitamin A status in depleted rats [248]. Systematic nutrient analyses and human intervention trials assessing the effects of consumption of moringa leaves are needed before the potential effects of the moringa tree can be estimated.

Conclusions and recommendations on green leafy vegetables

» Green leafy vegetables contain iron and provitamin A and can be valuable ingredients in diets for moderately malnourished children.

Research recommendations

» Leaves from the moringa tree may be rich in minerals and provitamin A, but the actual contents and bioavailabilities need to be assessed. The value for children with moderate malnutrition should be examined further.

Fruits

Most fruits contain readily available energy in the form of simple sugars, mainly fructose. Those with orange- or yellow-colored flesh are rich in provitamin A (**tables 19** and **20**). Fresh fruit is an excellent source of vitamin C and should be consumed with plant-based meals to enhance absorption of iron. In addition, the bioavailability of provitamin A is relatively high from fresh fruits [96]. Most children like the natural sweetness of fruits, so the addition of fresh fruit to a meal may increase its perceived palatability and thus increase the intake of the whole meal. Avocado has an exceptionally high content of fat, about 15 g/100 g, with about two-thirds being monounsaturated fat. The energy density is therefore high, more than 1.6 kcal/g. Therefore, if available and affordable, avocadoes are valuable in the diet of children with moderate malnutrition. Banana is also a high-energy food, with an energy density around 0.9 kcal/g. Ripe bananas have a high sugar content and thus provide an easily available energy supply. Unripe bananas have a high fiber content and are thus unsuitable for children with moderate malnutrition.

TABLE 19. Macronutrients and energy in selected fruits (values/100 g raw, edible portion)[a]

Fruit	Energy (kcal)	Protein (g)	Lipid (g)	Protein (E%)	Lipid (E%)
Apricot	48	1.0	0.0	8	0
Avocado	167	2.0	15.4	5	84
Banana	89	1.1	0.3	5	3
Fig	74	0.8	0.3	4	4
Guava	68	2.6	1.0	15	13
Orange	47	0.9	0.1	8	2
Mango	65	0.5	0.3	3	4
Passion fruit	97	2.2	0.7	9	7
Pineapple	50	0.5	0.1	4	2

a. Source: US Department of Agriculture [27]

TABLE 20. Nutrient densities per 1000 kcal in selected fresh fruits[a]

Fruit	Vitamin A (μg RAE)	Vitamin B_1 (mg)	Vitamin B_{12} (μg)	Vitamin C (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)	Phosphorus (mg)
Recommended nutrient density/1,000 kcal[b]	960	0.60	1.0	75	600	9	13	600
Apricot	2,000	0.63	<0.01	208	271	8.1	4.2	479
Avocado	42	0.45	<0.01	53	78	3.7	4.1	323
Banana	34	0.35	0.34	98	56	2.9	1.7	247
Fig	95	0.81	<0.01	27	473	5.0	2.0	189
Guava	456	0.99	<0.01	3,357	265	3.8	3.4	588
Orange	234	1.85	0.85	1,132	851	2.1	1.5	298
Mango	585	0.89	<0.01	426	154	2.0	0.6	169
Passion fruit	660	0.00	<0.01	309	124	17	1.0	701
Pineapple	60	1.58	0.40	956	260	5.8	2.4	160

RAE, retinol activity equivalent

a. Source: US Department of Agriculture [27].

b. Values from Golden [4].

Conclusions and recommendations on fruits

» Most fruits are good sources of vitamin C and should be consumed raw with plant-based meals to enhance iron absorption.

» Yellow- and orange-fleshed fruits are good sources of provitamin A.

» Fruits add sweetness and color to a meal, factors that will improve perceived palatability and often increase dietary intake among children.

» The intake of fruits should be promoted, as they currently have low status in many settings.

Algae

Algae are aquatic photosynthetic organisms that are classified into macro- and microalgae based on their size. The macroalgae are a group of larger aquatic plants to which the common name seaweeds is applied. The microalgae (phytoplankton, Cyanophyceae) are unicellular microscopic aquatic plants. Many species are edible. Some algae, mainly the seaweed *Porphyra* sp. (nori) and the cyanobacterium *Spirulina* sp., contain large amounts of vitamin B_{12} [249]. However, the majority of algal vitamin B_{12} appears to be widely nonbioavailable in humans [249], and therefore algae cannot be recommended as an alternative to animal-source foods as a vitamin B_{12} source.

Many algal species contain essential amino acids (histidine, leucine, isoleucine, and valine), and thus they represent a potential reservoir of protein appropriate for human consumption [250]. However, the algal protein is not readily available for humans, as algae are surrounded by an indigestible cellulose wall.

Seaweeds

Consumption of seaweeds is rarely seen as part of the food culture outside East Asia, and its acceptance may be limited in other settings. However, several seaweeds have high contents of iron, calcium, and iodine in particular [250] (**table 21**). Iodine and calcium in particular are of potential nutritional importance, whereas the bioavailability of iron is compromised by a high content of polyphenols.

In addition, seaweeds have a high content of soluble

TABLE 21. Mineral contents of seaweeds (values/100 g wet weight)[a]

Scientific name	Common name	Calcium (mg)	Iron (mg)	Iodine (mg)	Zinc (mg)
Ascophyllum nodosum	Egg wrack	575	15	18	—
Laminaria digitata	Kombu	365	46	70	1.6
Himanthalia elongata	Sea spaghetti	30	5	11	1.7
Undaria pinnatifida	Wakame	112	4	4	0.3
Porphyra umbilicalis	Nori	34	5	1	0.7
Palmaria palmata	Dulse	149	13	10	0.3
Chondrus crispus	Irish moss	374	7	6	—
Ulva spp	Sea lettuce	325	15	2	0.9
Enteromorpha spp	Sea grass	104	22	98	1.2

a. Source: MacArtain et al. [250].

fibers [250, 251]. A high content of antioxidants may be an adaptation to sunlight exposure in their natural habitat.

Microalgae

Microalgae were once considered a source of high-quality protein that might meet the protein needs of the growing world population [252]. Algal proteins are of high quality. However, the cellulose cell wall of algae presents a major constraint, as it cannot be digested by humans. Therefore, even microalgae need to be pre-processed, resulting in high production costs, in order to make the nutrients available for human digestive enzymes [252].

Although the algae appear to represent nutritious vegetable food, their use will probably be limited by their sensory characteristics (fishy taste and smell and green, brown, or red color) in populations where they are not part of the habitual diet [252]. Food preferences are conservative in many low-income countries, where the protein quality of the diet is generally low. Unknown food ingredients are not easily accepted, particularly in disadvantaged populations and in crisis situations. However, in East Asia or in coastal regions where algae are accepted, they should not be neglected, as they can provide important nutrients.

Spirulina

Spirulina belongs to the cyanobacteria. Unlike the true microalgae, *Spirulina* does not have cellulose walls, and therefore protein and other nutrients from *Spirulina* are more bioavailable than those from yeasts and unicellular algae [253]. Although the nutritional interest of other microorganisms has faded due to problems of digestibility, the cyanobacterium *Spirulina* may offer simple production of a high-quality nutritional supplement.

The protein quality of *Spirulina* is high, and it is reported to be rich in highly available iron, calcium, potassium, and phosphorus [254]. *Spirulina platensis* has a high content of essential n-6 PUFAs, linoleic acid (C18:2 n-6), and γ-linolenic acid (C 18:3 n-6). The total lipid content is around 6%, of which around 40% is PUFA [255, 256]. With a total energy content of around 340 kcal/100 g, the fat contributes 16 E%.

Spirulina grows naturally in some alkali lakes of Africa and can be produced in tanks appropriate for small-scale industry. However, when produced in ponds or basins it tends to accumulate heavy metals, so that water quality is very important. Alkaline production reduces the risk of contamination or overgrowth of most other microorganisms, as they cannot survive the high pH caused by *Spirulina*.

Spirulina (10 g daily) was used in an 8-week nutritional rehabilitation study of undernourished children in Burkina Faso [257]. Improved weight gain was reported with *Spirulina* as compared with traditional millet meals, particularly for HIV-negative children. Hemoglobin also improved with *Spirulina* supplementation. However, the randomization procedure was poorly described in this study. In another, larger study by the same group, *Spirulina* and misola (millet, soy, peanuts, and sugar) were compared with a two-by-two factorial design for nutritional rehabilitation of severely and moderately underweight children aged 6 to 60 months [256]. Unfortunately, the children receiving the control diet were chosen from those families who refused to be part of the trial. However, it appeared that a combination of *Spirulina* and misola was superior to *Spirulina* or misola alone, and that *Spirulina* or misola alone was superior to the control diet (of unknown composition). In conclusion, although the evidence is sparse, it seems that *Spirulina* deserves attention as a potential natural dietary supplement for use in the nutritional rehabilitation of moderately malnourished children.

Conclusions and recommendations on algae

» Seaweeds are rich in iron, calcium, iodine, and a variety of antioxidants and contain several essential amino acids.
» Seaweeds are traditionally used in East Asian food culture, but due to their sensory characteristics seaweeds may be difficult to introduce into other food cultures.
» In East Asia and in coastal regions where seaweeds are accepted, they could be promoted as a nutritious component of diets for children with moderate malnutrition.
» Microalgae may be good sources of micronutrients and high-quality protein, but availability might be low due to the cellulose content.
» *Spirulina*, a cyanobacterium, seems to have protein and micronutrients with a better bioavailability and has a high content of n-6 PUFAs.

Research recommendations

» Some studies suggest that *Spirulina* could have a role in treating children with moderate malnutrition, but this should be investigated further.

Animal-source foods

Animal products, such as meat, fish, eggs, and dairy products, are energy dense, excellent sources of high-quality and readily digested protein and micronutrients, and they contain virtually no antinutrients. The most important micronutrients in animal products are iron, zinc, calcium, riboflavin, vitamin A, and vitamin B_{12}. It has been concluded that "relatively small amounts of these foods, added to a vegetarian diet, can substantially increase nutrient adequacy" [258].

A number of studies have examined the role of animal-source foods in growth, mental development, morbidity, anemia, and immune function [258–264].

The beneficial role of animal-source foods (meat and milk) in the diets of 18- to 30-month-old children was investigated in the Nutrition Collaborative Research Support Program, conducted from 1983 to 1987 in rural areas of Egypt, Kenya, and Mexico. The estimated intakes of protein from animal sources were 13.5 g/day (11.1 g/1,000 kcal), 3.8 g/day (4.5 g/1,000 kcal), and 8.6 g/day (8.8 g/1,000 kcal), respectively, corresponding to 46%, 19%, and 37% of the recommended protein density of 24 g/1,000 kcal [4]. Positive associations were found between intake of animal-source foods and growth in weight and length, after controlling for socioeconomic factors [265]. Similarly, intake of animal-source foods was associated with linear growth in 12- to 15-month-old children in Peru [266], especially in those with a low intake of complementary foods. In Mexico, consumption of foods of animal origin was positively associated with body size in stunted children at 30 months and with growth rates from 18 to 30 months [267]. The iron, zinc, and vitamin B_{12} contents of animal-source foods, in addition to high protein quality, may have contributed to these findings [261, 268].

In an intervention study in Kenya, 12 schools with 544 children enrolled in class 1 were randomly assigned to meat (60 to 85 g/day), milk (200 to 250 mL/day), energy (isocaloric with the milk and meat, 240 to 300 mL/day), or no food supplement for a 2-year period [264, 269]. Children receiving meat had a greater increase in arm muscle area than children in the milk and energy groups, who had greater increases than children in the control group. The effect of milk on arm muscle area was not significantly greater than that of energy supplementation. There were no main effects of any of the supplements on linear growth. However, among children with low height-for-age z-scores at baseline, those receiving milk gained more height than children in the other groups [264]. Height gain during the intervention period was positively predicted by intakes of energy from animal-source foods, both milk and meat [263].

Other studies, from both industrialized and from developing countries, have suggested that milk has a specific stimulating effect on linear growth [270]. Observational and intervention studies from industrialized countries suggest that intake of cow's milk stimulates insulin-like growth factor 1 (IGF-1) secretion, which has a direct effect on linear growth [271, 272]. Equivalent amounts of protein in meat did not have an effect on IGF-1 levels [272].

Many studies have shown an impact of childhood malnutrition on cognitive function, physical activity, and school attendance and performance. Positive associations have been found between intake of animal-source foods and cognitive performance and verbalization in toddlers [273, 274], and school-age children receiving meat had better verbal and performance test results, were more attentive to classroom work, and showed leadership behavior [275, 276].

An overview of the characteristics of animal foods that are likely to cause the beneficial effects seen after intake of animal-source foods is given in **table 22**.

Milk

Cow's milk

Cow's milk is a good source of many nutrients and has a high content of high-quality protein, containing all essential amino acids. The PDCAAS is typically 120%, depending on the exact amino acid distribution, with tryptophan as the limiting amino acid. Mature bovine milk contains about 3.2% to 3.5% protein by weight, equivalent to about 20% of the energy. The main protein fractions of bovine milk are casein and whey, which account for approximately 80% and 20% of the protein, respectively. Whole cow's milk provides a good supply of energy (266 kJ/100 g), with 45% coming from fat, whereas skimmed milk provides only 151 kJ/100 g. Cow's milk also contains high levels of important nutrients, such as calcium, available phosphorus and magnesium, and several B vitamins and bioactive factors and proteins that may have growth-promoting abilities (see Bioactive Substances: Milk Peptides, above). However, cow's milk is a poor source of iron because of low iron content and poor bioavailability.

Because of its stimulating effect on linear growth, milk may have an important role in the prevention and treatment of stunting, especially during the first 2 years of life. However, it is also important in the treatment of moderate wasting, as a high-quality protein source with high levels of micronutrients and no antinutrients is likely to be important for lean body mass accretion.

The successful treatment of severely malnourished children is based on products with either 100% (F100) or about 50% (RUTFs) of the protein coming from milk. Milk should also be considered a key ingredient in the foods used for treatment of children with

TABLE 22. Characteristics of animal foods compared with plant foods to which the beneficial effects can be attributed

Higher content of micronutrients important for growth and cognitive development (e.g., zinc, iron, and vitamin B_{12})
Higher protein content and protein quality
No antinutrients
High energy density
High fat content
Higher content of n-3 PUFA

PUFA, polyunsaturated fatty acid

moderate malnutrition. There is no firm evidence to determine the minimum amount of milk that would have an impact in treatment of children with moderate malnutrition. Based on the available data of the effects of interventions with animal foods, it seems likely that a diet with 25 to 33% of the protein coming from milk would have a significant effect. However, there is need for studies to determine the minimum amount of milk that will have a significant effect. The amounts of milk equal to 25% to 33% of the recommended protein intake for children with moderate malnutrition (24 to 26 g/1,000 kcal [4]) are about 200 to 250 mL of liquid milk or 15 to 20 g of milk powder or whey protein powder (skimmed-milk powder or whey protein concentrate 34%) per 1,000 kcal.

Milk products

There are many different types of cow's milk products available, and in the following section the benefits and problems of using the different types of milk products in the treatment of children with moderate malnutrition will be discussed.

Liquid milk, i.e., either raw, pasteurized, or ultra-high-temperature (UHT)-treated milk, is suitable to give to children with moderate malnutrition. It should preferably be whole milk to provide a suitable balance between protein and fat intake. Skimmed milk or milk with a reduced fat content (< 2%) should not be given unless it is balanced with a fat intake that reaches the recommended level. Milk with reduced fat content also has a high renal solute load in relation to the energy content. A problem with pasteurized or UHT-treated milk is the high price. In soured and fermented milks such as yogurt, a *Lactobacillus* culture converts nearly all the lactose into lactic acid and a curd is formed. Apart from that, the nutritional content of soured milk is almost the same as that of the fresh milk from which it is made. Fermented milk or yogurt has many advantages. It keeps better, and the risk of growth of pathogenic bacteria is reduced. The content of lactic acid bacteria can have probiotic effects, for example through an influence on the gastrointestinal immune system, and may reduce the risk of diarrhea. Furthermore, the low pH will improve absorption of iron, and the reduction in lactose content during fermentation will reduce the effects of lactose intolerance, if present.

Powdered milk is often cheaper and more easily available than liquid milk. The most important problem with the use of powdered milk is the risk that the powder will be mixed with contaminated water when it is made into liquid milk. Since milk is a good growth medium, pathogens will easily multiply and can cause severe diarrhea. If milk powder is used for liquid milk, it should be mixed with boiled water and used within 1 to 2 hours to avoid contamination and bacterial proliferation. This problem of contamination is the main reason that many UN organizations [277] and international NGOs [278] have a policy of never distributing powdered milk as a take-home commodity. Another reason for not distributing powdered milk is that liquid milk in some situations may be perceived to be an infant formula and thereby have a negative effect on breastfeeding. The most common types of powdered milk available in areas with high levels of moderate malnutrition are whole-milk powder, which is often widely available in tins in local shops, and skimmed-milk powder, which is typically only available in large quantities (e.g., bags of 25 kg) for producers of food, UN organizations, and NGOs. Because of its high fat content, the shelf-life of whole-milk powder is limited to a year or less, depending on how it is packaged, whereas skimmed-milk powder can keep for several years if it is not fortified with vitamin A. Whole-milk powder can be used for liquid milk if food safety precautions are followed. Skimmed-milk powder should be used only as an ingredient in other foods, such as blended foods, and should not be used for making liquid skimmed milk. If skimmed-milk powder is used to make a drink without replacing the fat, the drink will be unsuited for infants and young children for the same reasons as skimmed milk. The relative contents of protein and minerals, and thus the renal solute load, will be too high if the fat is removed. This can be harmful, especially for infants and the youngest children [279].

"*Filled milk*" is a powdered product based on skimmed milk and vegetable oil that is sold in some low-income countries. Typically it is sold in small sachets sufficient for one glass of milk. The main advantage is that it is cheaper than whole-milk powder. The replacement of milk fat by vegetable oil could be beneficial from a nutritional point of view, depending on which vegetable oil is added.

Whey powder (13% protein) or whey protein concentrate (whey protein concentrate with 34% or 80% protein) is made from the liquid part of milk that remains after casein has coagulated in cheese production. It is often not easily available locally, but it can be used in programs in the preparation of special foods or blends for malnourished children, for example. Since it is a product left after cheese production, it is typically 20% to 30% cheaper than skimmed-milk powder per unit protein, which is an important aspect in the treatment of children with moderate malnutrition. Whey has a high content of both lactose and minerals. In whey powder (13% protein), the lactose content is about 70%. Whey contains many peptides and proteins with potential beneficial effects on the immune system and muscle synthesis, but this needs to be confirmed in studies of children with moderate malnutrition [23]. Because whey is a surplus product, it has been used extensively in feeding of weanling pigs. It is well documented that the growth of young weanling pigs is better on a whey-based diet than on a diet based on cereals and legumes [23]. There are not sufficient studies to evaluate whether the effect of whey is different from the effect of skimmed-milk powder, as the pig studies have focused on whey because it was cheaper.

Evaporated milks are normally full-cream milks with some water removed, although sometimes the milk fat is replaced with vegetable oil. Condensed milks are evaporated milks that may be made from whole milk or from milk from which the fat has been removed. They have a high concentration of sugar (about 45% by weight), which reduces the relative concentrations of protein and other nutrients and makes the milk unsuitable for use as a drink for infants and young children (see Sugar, below). Some evaporated and condensed milk is fortified with vitamins A and D. Both types of milk are sold in tins, are expensive, and should not be used as a drink. However, they can be mixed into porridge and other foods.

In *hard cheeses*, most of the whey is removed from the casein curd during processing. Therefore cheese has a low content of lactose and of all water-soluble vitamins, as they are removed with the whey. If made from whole milk, these cheeses contain vitamin A, a little vitamin D, and most of the original calcium. Cheese is expensive and therefore is not a relevant food for children with moderate malnutrition.

Milk from other domestic animals

Most of the animal milk consumed by humans is from cattle. The second highest amount is from buffalo. Buffalo milk is more concentrated than cow's milk, with higher energy, protein, and fat contents. Milk from many other domesticated animals is used for drinks or foods. **Table 23** shows the composition of milk from domesticated animals [280]. A general pattern is that some milks are more concentrated than others, with higher contents of energy, protein, and fat. This should be taken into account when calculating the amount to be given to children with moderate malnutrition. Some vitamin A and a little vitamin D is present in all milk fats. Some milk, such as goat's milk, has little or no folate compared with other milks. The concentration and availability of iron in all milks are low.

Conclusions and recommendations on milk

- » Liquid milk and milk powder are good sources of high-quality protein and micronutrients important for growth.
- » The minimum amount of milk protein needed to improve growth in children with moderate malnutrition is not known, but a milk content providing 25% to 33% of the protein requirement is likely to have a positive effect on weight gain and linear growth. However, studies should be conducted to determine the amount that is cost-effective.
- » 200 to 250 mL of milk or 15 to 20 g of milk powder or whey protein powder (skimmed-milk powder or whey protein concentrate 34%) per 1,000 kcal will provide 25% to 33% of the recommended protein intake (24 to 26 g/1,000 kcal).
- » Milk is likely to be more effective than meat in treating moderate stunting, as milk has a special effect on linear growth through stimulation of IGF-1 production.
- » Powdered milk with reduced milk fat, such as skimmed-milk powder or whey protein, should never be used for preparing liquid milk, because of the high protein content and risk of infection if mixed with contaminated water, but it can be mixed with blended foods or other foods that are cooked

TABLE 23. Composition of milk from domestic animals, compared with human milk[a]

Species	Energy (kcal/100 mL)	Protein (g/100 mL)	Lactose (g/100 mL)	Fat (g/100 mL)
Cow (*Bos taurus*)	61	3.2	4.6	3.7
Cow (*Bos indicus*)[b]	70	3.2	4.9	4.7
Yak	94	5.8	4.9	6.5
Musk ox	81	5.3	4.1	5.4
Water buffalo	88	4.3	4.9	6.5
Sheep	94	4.1	5.0	7.3
Goat	61	2.9	4.7	3.8
Ass	37	1.4	6.1	0.6
Horse	47	1.9	6.9	1.3
Camel	51	4.3	—	4.3
Dromedary	70	3.6	5.0	4.5
Llama	60	2.5	4.7	3.9
Human milk	78	1.0	7.5	4.2

a. Source: Jensen [280].
b. Zebu or humped cattle.

or heated.

» Whey contains peptides and proteins that have been suggested to have positive effects compared with skimmed-milk powder, but these effects have not been documented in children with moderate malnutrition.
» The effects of using whey instead of skimmed-milk powder in the treatment of children with moderate malnutrition should be tested in intervention trials, both because whey protein concentrate is cheaper than skimmed-milk powder and because of the potential beneficial effects of whey.
» Whole-milk powder should be used as a drink for children with moderate malnutrition only if it is prepared under strictly controlled and hygienic conditions.
» If milk is the only animal-source food given, sufficient iron should be provided in the diet.
» Fermented milk products should be promoted, as they have advantages over other milk products.

Research recommendations

» Research is needed to determine the amount of milk protein that has optimal cost-effectiveness in promoting growth.
» Research is needed to determine if there are any advantages of using whey instead of skimmed-milk powder in the treatment of children with moderate malnutrition.

Meat

The word "meat" refers to skeletal muscle and related fat. Muscle tissue has a very high content of protein, about 20% in fresh and 80% in dried meat. Its protein contains all of the essential amino acids, and it is a good source of zinc, phosphorus, iron, vitamin B_{12}, selenium, niacin, vitamin B_6, and riboflavin (**table 24**). Furthermore, it contains the "meat factor" (described in the section on Bioactive Substances), which enhances nonheme iron absorption. Meat contains no fiber, has a negligible content of carbohydrates, and has a relatively high content of fat. However, the fat content of meat can vary, depending on the type of animal and how it was raised, the feed, and the part of the body. Game meat is typically leaner than meat from farm animals and has a more favorable fatty acid composition, with more n-3 fatty acids.

Meat is an expensive food, but the price varies considerably depending on local availability, whether it comes from cattle, sheep, goats, or pigs, and the cut of the meat. In some countries, dried meat is available as an alternative to fresh meat. Meat is a very valuable ingredient in diets for children with moderate malnutrition. The most important characteristic of meat, as compared with the other important animal-source food, milk, is its positive effects on iron and zinc status.

Offal

The edible parts of animals can be divided into meat (i.e., skeletal muscle) and other (nonmeat) parts, collectively called offal. The offal includes internal organs and external parts. The internal organs comprise the heart, liver, kidneys, spleen, tongue, and lungs (red offal), and also the brain, marrow, stomach and intestines, testicles, and thymus (white offal). External parts include the ears, eyes, snout, palate, tail, and feet. The most important organs are the liver, kidney, and intestines.

Liver is a rich source of iron and zinc, most of the B vitamins including folate, and vitamins A and D and also has a high content of the "meat factor" (**table 24**). Liver can also have a high content of contaminants. If liver is available and affordable, it is highly recommended that small amounts be added to the diet of children with moderate malnutrition. Even if it is not possible to supply liver daily, it will still be a valuable ingredient even if it is only given one or two times a month. In a study from Peru, the use of liver in complementary food was an important part of an educational intervention aimed at parents of infants and young children [281]. Those randomized to the intervention had higher intakes of iron and zinc, better weight and length gain, and less stunting. The extent to which offal is used for human consumption differs between cultures. What is considered a delicacy in one culture may be considered unacceptable in another culture. In low-income countries, better utilization of all edible parts of animals may considerably increase the intake of important nutrients. Offal typically has a low market value, and most offal has a high nutritional value. Greater use of acceptable and appropriate offal in feeding of infants and young children should be considered, especially if there is no or very low intake of animal-source foods.

Blood

Blood from animals is used in foods in some cultures, either as an ingredient in sausages or as a drink with milk in some populations, whereas it is not accepted in other populations for cultural reasons. Dried blood or serum has been produced commercially as an ingredient but has not been widely used. However, where blood or serum is culturally acceptable, it can be a nutritious and cheap ingredient in food for infants and children with moderate malnutrition, as it is a good source of iron, vitamin B_{12}, protein, and other nutrients (**table 24**). In Chile a cereal fortified with bovine hemoglobin concentrate (14 mg of iron/100 mg of powder) seemed to reduce the risk of iron deficiency when given to healthy breastfed infants from the age of 4 months to the age of 12 months [282]. Among early-weaned pigs, supplementation with different fractions of spray-dried plasma from pigs as well as cows improved dietary intake and growth, and the IgG fraction was considered to be responsible for the beneficial effects [283]. In a

TABLE 24. Macronutrient and energy contents and nutrient densities of selected meats and other animal products (values/100 g)

Animal product	Macronutrients and energy					Nutrient density/1,000 kcal							
	Energy total (kcal/100 g)	Protein (g/100 g)	Lipid (g/100 g)	Protein (E%)	Lipid (E%)	Protein (g)	Vitamin A (μg)	Vitamin B_{12} (μg)	Vitamin B_1 (mg)	Folate (mg)	Calcium (mg)	Iron (mg)	Zinc (mg)
Recommended nutrient density/1,000 kcal[a]						24	960	1.0	0.6	220	600	9	13
Beef													
Lean[b]	126	21.7	3.5	69.0	25.1	173	45	2.7	0.4	5.7	4.0	3.0	6.8
Fat [b]	317	16.4	28.4	20.7	80.7	52	18	1.1	0.2	2.3	3.0	2.3	2.9
Blood	92	21.1		92.1	—	230	0	—	0.1	—	5.2	115	—
Heart	102	19.2	2.4	75.4	21.2	188	16	23	1.2	9.3	21	11.7	4.7
Liver	146	22.2	3.5	60.7	21.5	152	29,000	179	0.5	368	11	11.1	7.7
Stomach	97	16.1	3.6	66.1	33.3	165	2	—	0.0	24.4	37	4.6	6.6
Pork													
Lean[b]	107	22.2	1.9	83.3	16.0	208	0	1.3	1.8	4.7	16	1.6	8.0
Fat [b]	200	28.7	9.6	57.4	43.2	144	8	0.8	0.7	3.6	8.3	3.0	4.9
Poultry													
Chicken[b]	167	31.2	4.6	74.8	24.8	187	34	0.5	0.1	24.3	16	1.1	3.6
Duck (meat)[b]	119	18.3	5.1	61.5	38.6	154	48	0.8	0.7	96.0	22	2.4	2.7
Others													
Goat	190	27.1	9.2	56.9	43.5	142	40	—	0.1	6.3	11	2.3	3.3
Goat blood	98	21.4	0.3	87.7	2.8	219	0	—	0.0	—	15	14.1	—
Rabbit[b]	187	26.9	8.9	57.5	42.8	144	4	13	0.1	10.2	15	1.8	1.5
Mutton lean[b]	179	27.0	7.9	60.3	39.7	151	60	0.0	6.6	29.3	28	3.1	7.4

a. Values from Golden [4].

b. Source: National Food Institute (Denmark) [28] study among 6- to 7-month-old Guatemalan infants, those receiving a daily supplement with a bovine serum concentrate (as a source of immunoglobulins) for 8 months had the same growth and morbidity as those receiving a whey protein concentrate [284].

Conclusions and recommendations on meat, offal, and blood

» The intake of meat or offal should be promoted.
» Meat is an excellent source of high-quality protein and several important micronutrients and has a particular positive effect on iron status.
» Meat is expensive and, in many settings, not easily available, and it has to be prepared in special ways (e.g., by mincing) to be acceptable to young children.
» Liver is an exceptionally rich source of iron, zinc, vitamin A, and other nutrients and should be promoted as an important part of the diet.
» The potential of increasing the use of offal and blood should be explored, where culturally acceptable, as these may be a low-cost source of animal food.

Eggs

Eggs from chickens and other birds have a very high nutritional value, as they provide all the nutrients necessary for a bird embryo to develop. Eggs are often more easily available at the community level than milk and meat, have a lower cost, and can be bought in small quantities. More than half the energy in eggs comes from the fat in the yolk; 100 g of chicken egg contains approximately 10 g of fat. An average chicken egg contains about 5 to 6 g of protein and 4 to 5 g of high-quality fat. About 20% of the fatty acids are PUFAs, with a favorable n-6/n-3 fatty acid ratio of 4 to 5. Eggs contain a significant amount of cholesterol, about 0.5 g/100 g. However, this is not likely to have negative effects in infants and young children. Breastmilk also contains high levels of cholesterol, which may play a role in early development. Egg white consists primarily of water and protein (13%) and contains little fat and carbohydrate. Egg protein is of very high quality, with a PDCAAS of 118%. The most important micronutrients are vitamin A, thiamine, and riboflavin, and also some vitamin D. Egg contains iron, but the availability is poor, and egg white also seems to have a negative effect on absorption of nonheme iron from other foods [285]. Giving one or two eggs a day to a child with moderate malnutrition will be a valuable contribution to the requirements.

Conclusions and recommendations on eggs

» Eggs contain high amounts of high-quality protein and fat, preformed vitamin A, and other important micronutrients.
» Eggs are a valuable food to give to moderately malnourished children and should be promoted.

Fish

All fish are a rich source of high-quality protein and provide a range of other important nutrients, depending on species and processing. The fat content in fish species ranges from less than 1 to more than 30 g of fat/100 g of raw fish. Fatty fish are a valuable source of n-3 LCPUFAs. Small, soft-boned fish that are eaten with the bones are an excellent source of calcium and phosphorus. Furthermore, fish is a good source of zinc and bioavailable iron, and fish enhances nonheme iron absorption due to the "meat-factor" effect.

In all parts of the world, there is a general consumer preference for large-sized fish. Consequently, small fish generally have a relatively low market price and are therefore more accessible to the poor. In general, small-sized fish are nutritionally superior to large fish because the edible parts of small fish include more diverse tissues, such as the head, bones, and viscera, as compared with large fish, where muscle tissue contributes most to the edible parts [286].

In coastal areas and in regions with rich inland water resources, such as the large river basins of Asia and Africa (Ganges, Mekong, Nile, etc.), fresh fish is widely available, strongly impacted by seasonal and annual variation. In such areas, fish is often the main or only accessible animal food for poor households [287]. The fish species found in the diet in these regions reflect the biological diversity of the natural environment and typically include a variety of small fish species. As an example, poor rural households in Bangladesh typically consume more than 50 different fish species over a year, and a single meal can include mixed batches of 5 to 10 different fish species [286]. Fresh fish is a highly perishable commodity, and the price is highly fluctuating according to availability, market structure, and the quality of the fish.

Nutritional contribution

The energy density in fish is determined mainly by the fat content and ranges from 80 kcal/100 g of raw fish in lean fish such as cod and other species with less than 1% fat, to 360 kcal/100 g of raw fish in fatty fish such as eel, reaching to more than 30% fat in raw fish [288]. In addition to interspecies variation in fat content, the specific content in fish is also influenced by physiological conditions (e.g., reproductive cycles) and feeding conditions. For example, the fat content in Peruvian anchovy (*Engraulis ringens*) after a stress period due to the El Niño phenomenon fell from 11% fat to less than 1% in raw fish [289].

The protein content in fish species, with few exceptions, is in the range of 15% to 25%, and most species are in the range of 18% to 20%. The protein quality is in general high. The PDCAAS has been reported for a few species as being similar to that of meat, i.e., in the range of 70% to 100%.

The fatty acid composition of freshwater fish varies between different aquatic environments (due to diet, temperature, salinity, etc.) [290]. No data on the fatty acid composition of small freshwater fish species are available, but the lipid quality of the larger tropical freshwater fish is comparable to that of temperate freshwater fish [290]. Roughly estimated, the PUFA content of freshwater fish is around 25% of the fat, one- third of which is n-3 PUFA, and half of the n-3 PUFA is long-chain PUFA.

Fish is a good dietary source of micronutrients, especially iron and zinc. A proportion of the iron, ranging from 30% to 80%, is present in highly bioavailable forms, such as heme iron or other high-molecular-weight organic compounds, such as ferritin [291]. In general, the iron content in fish is less than that in red meat and is similar to the content in chicken and pork [292]. The specific iron content varies with species and with the cleaning practices that determine which parts of the fish are edible [292–294]. Some small freshwater fish species of the genus *Esomus* have been found to have an iron content (12 mg/100 g of edible parts) four to five times higher than that of other small species from the same aquatic environment [291].

Small, soft-boned fish are a good calcium source. The bioavailability of calcium from the soft-boned species *Amblypharyngodon mola,* which is one of many commonly consumed small fish species in South Asia, has been shown to be similar to the bioavailability of calcium from milk [295]. The acceptability of consumption of bones is determined by the "hardness" of the bones, and "hard-boned" small fish species contribute less dietary calcium because the bones are discarded as plate waste [296]. In **table 25**, the calcium contribution from small fish is corrected by a "plate waste factor" to compensate for the measured calcium content of bones discarded as plate waste.

Fish liver is well known as a rich source of vitamin A and D, while fish muscle tissues have low contents of these vitamins. The vitamin A content in small fish has been shown to vary by a factor of more than 100 between species. In vitamin A–rich species, a large proportion of the vitamin A is located in the eyes of the fish, and the traditional cleaning practices as a determinant of the edible parts are therefore a crucial parameter for the dietary contribution of vitamin A from such species [293, 297]. Vitamin A in fish is present in two forms: vitamin A_1 (retinoids) and vitamin A_2 (dehydroretinoids). The biological function of vitamin A_2 is calculated as 40% of that of vitamin A_1.

There are only a few intervention studies with fish in children. In a study in Ghana, moderately malnourished children were fed a maize-based complementary diet with powdered dried fish (20% on a dry weight basis) added to either a traditional maize porridge, koko, or a complementary food, Weanimix, which contained 75% to 80% maize, 10% to 15% soybeans or cowpeas, and 10% peanuts [298]. Other groups received either Weanimix alone or Weanimix with a micronutrient supplement. The children were fed the diet from 6 to 12 months of age. The growth of the children was similar in all groups, but they all received a diet with improved protein quality. Also, powdered dried fish did not improve the iron stores of the children. In a recent study from South Africa, schoolchildren were given a bread spread with fish flour from a marine source or a placebo spread [53]. Those receiving the fish spread had an improvement in verbal learning and memory.

Processed fish

Processing technologies to expand the shelf-life of fish are drying, salting, smoking, and fermentation. Icing and freezing for preservation of fish are rarely an option in low-income countries, and if a cooling chain is available, there is an inherent problem of ensuring that it is intact from the producer to the end user. All fish-processing methods affect the organoleptic qualities (taste, smell, and appearance) as well as the nutritional quality of the fish.

Sun-drying. Sun-drying of fish is widely practiced in Asia and Africa, and dried fish is in most cultures an accepted ingredient in mixed dishes. The organoleptic quality of traditional sun-dried fish is highly variable, and caution should be exercised to identify suppliers of products of good quality The nutritional value of dried fish is similar to that of fresh fish for protein, fat, and minerals (iron, zinc, and calcium), whereas for species with a high vitamin A content, the vitamin A is almost totally destroyed by sun-drying [297].

Small dried fish can be ground to powder and added to foods such as porridge. Dried fish is available in many settings and is an affordable animal food that can be added to diets of children with moderate malnutrition.

Salting. Salting is widely used for preservation. The salt in fish can be washed out before use, and the original nutritional composition is largely reconstituted. The food safety of salted fish is a concern, as contamination with pathogenic bacteria is a risk, particularly when the fish is processed in a warm climate without cooling opportunities. Even if most of the salt is washed out, there will still be a relatively high content of salt, making salted fish an inappropriate food, since the salt content in the diet of malnourished children should be kept low [4] .

Fermenting. A large number of traditional fermented fish products are known in most fish-producing regions in the world. Traditional processing methods are highly variable, ranging from light salting of products with a few days of shelf-life to processing with a higher level of salting of products that are preserved for several months. The nutritional value of fermented fish products is comparable to that of fresh fish. However, the suitability of fermented fish in diets for children

TABLE 25. Macronutrient and energy contents and nutrient densities in freshwater and marine fish species (values/100 g raw fish)

	Energy and macronutrients							Nutrient density/1,000 kcal						
Fish species	Energy (kcal)	Protein (E%)	Lipid (E%)	Protein (g)	Lipid (g)	PUFA (%)	n-6:n-3 (g:g)	Vitamin A (µg RAE)[a]	Vitamin B_{12} (µg)	Calcium in raw, edible parts (mg)[b]	Calcium corrected for plate waste (mg)[c]	Iron (mg)	Zinc (mg)
Recommended nutrient density[d]								960	1.0	600	600	9	13
Marine species[b]													
Herring (*Clupea harengus*)	201	36	65	18	14.5	2.7	0.1	151	46.1	249	—	6.5	4.2
Saithe/pollock (*Pollachius virens*)	81	96	35	19	3.1	0.1	> 0.1	37	16.1	99	—	2.5	3.7
Haddock (*Melanogrammus aeglefinus*)	85	89	11	19	1.0	0.5	> 0.1	0	11.7	211	—	7.0	3.5
Small freshwater species[e]													
Mola (*Amblypharyngodon mola*)	112	69	16	16–18	4.4	—	—	23,937	—	7,619	6,931	51.0	28.6
Darkina (*Esomus danricus*)	113	68	16	16–18	4.5	—	—	7,801	—	7,899	6,871	106	35.5
Puti (*Puntius sophore*)	135	57	21	16-18	7.1	—	—	446	—	8,697	5,823	22.0	23.0
Cultured freshwater species[e]													
Rui (*Labeo rohita*)	111	69	16	—	4.3	25[f]	0.9[f]	—	—	7,712	774	—	—
Silver carp (*Hypophthamichthys molitrix*)	112	69	16	—	4.4			—	—	8,065	322	51.6	—
Common carp (*Cyprinus carpio*)	123	63	19	18	5.7	30[g]	1.5	309	12.5	—	334	10.0	12.0
Tilapia (*Oreochromis niloticus*)	89	86	8	20	1.7	23[h]	2.8	336	17.7	—	112	6.0	3.7

PUFA, polyunsaturated fatty acid; RAE, retinol activity equivalent

a. Vitamin A contents in fish species are calculated as RAEs from contents of retinoids (vitamin A_1) and dehydroretinoids (vitamin A_2) [297].
b. Source: US Department of Agriculture [27].
c. Corrected according to Roos et al. [296].
d. Values from Golden [4].
e. Values from Roos et al. [286] and unpublished data, unless otherwise noted.
f. Values from Ackman [306].
g. Carp in Beysehir Lake in Turkey contain from 29% to 43% PUFA, depending on the time of year [307].
h. Tilapia from the Nile contain 20% PUFA [308], while tilapia from Lake Chamo in Ethiopia contain around 26% PUFA [290].

with moderate malnutrition has to be considered in terms of the organoleptic qualities of the products and the cultural habits for the specific local products, and in terms of food safety issues. Food safety is related to the risk of growth of pathogenic bacteria, and also in some regions, especially in Asia, to the risk of infections with fishborne zoonotic parasites such as liver flukes [299]. The risk of infections with fishborne zoonotic parasites is eliminated by heating the fish and is therefore relevant only if a fish product is consumed raw or insufficiently heated. Raw, fermented fish may contain thiaminase, which can reduce the effect of thiamine pyrophosphate. Thiaminase is destroyed by heating [300].

Tinned fish. Tinned fish is a convenient substitute for fresh fish. Fat fish such as tuna and mackerel are energy dense, especially when preserved in oil. The nutritional profile of tinned fish is largely similar to that of fresh fish, but the lipid profile can change slightly in the tinning process [301] and after 3 to 6 months of storage [302]. Tinned fish cannot be stored after opening because of the risk of bacterial contamination [303].

Fish protein concentrate. Fish protein concentrate is a powdered product made from whole fish, with a high protein concentration. However, fish protein concentrate is not well adapted for human consumption, because the taste and smell are unacceptable, even in refined products. Decades ago, fish protein concentrate was considered for use as a protein supplement for malnourished children. In one early study, fish protein concentrate was compared with skimmed milk for the ability to induce weight gain and rehabilitation in children suffering from kwashiorkor [304]. It was concluded that fish protein concentrate had an impact largely comparable to that of skimmed-milk powder, but the fish protein concentrate diet was not well accepted by the majority of the children. In a similar study in measles-infected children, the tolerance of the fish protein concentrate diet was reported to be acceptable, and the nutritional value was comparable to that of milk powder [305]. However, at present, there are no practical applications of fish protein concentrate in feeding children with moderate malnutrition, due to its organoleptic qualities.

Contamination

The accumulation of mercury in fatty fish is a potential health risk. Some high-income countries have issued guidelines for restricted intake of fatty fish by pregnant women and children to avoid exposure to toxic substances such as mercury. Accumulation of polychlorinated biphenyls (PCBs), lead, arsenic, and cadmium in fish stocks may pose a health hazard. Fish originating from polluted environments may be safe for consumption, especially lean fish with a short life cycle that are less likely to accumulate contaminants. The main contamination risks are from carnivorous fatty fish with long life cycles, such as tuna; in feeding children with moderate malnutrition, caution should be exercised to avoid high and frequent intake of tinned tuna or mackerel, for example, unless the product is known to have a low level of contamination. Many small freshwater and coastal fish are lean with short life cycles, which prevents the accumulation of most potential contaminants.

The use of pesticides in agricultural production may be hazardous to fish living in rice fields. It is usually not a major problem in other settings. Caution should be exercised in the use of toxic substances in local postharvest preservation, such as the use of DDT to prevent insect infestation during sun-drying of fish or the use of diluted formalin for preservation of “fresh” fish. These contamination risks should be avoided by using trustworthy suppliers.

Conclusions and recommendations on fish

» Fish is a good source of high-quality protein, n-3 fatty acids, and micronutrients.
» Small fish that are consumed whole are an especially good source of highly bioavailable calcium, iron, zinc, and vitamin A.
» Vitamin A is not preserved in sun-dried fish.
» Fillets from large fish have low to moderate levels of iron and zinc.
» Fish enhances absorption of nonheme iron. The enhancing effect is about half that of meat.
» Fish is beneficial to add to the diet as an animal-source food, replacing meat. The nutritional impact of adding small amounts of fish (10 to 50 g) to a meal remains to be documented.
» The issues of food safety and contamination should be considered if fish are used in the diets of children with moderate malnutrition.

Other animal-source foods

Lack of animal-source foods in the diet of people in low-income populations contributes to undernutrition and especially the widespread deficiencies of iron, zinc, and vitamin A. Conventional animal-source foods (eggs, meat, and organs from cows, goats, sheep, pigs, poultry, and fish) are often inaccessible or unaffordable.

Other animal-source foods with high contents and bioavailability of important micronutrients may be readily available and affordable but underutilized. Some of these foods cannot be promoted, as they may be culturally unacceptable or come from animals at risk of extinction. Foods that could be promoted include low-valued parts of domestic animals, as well as snakes, rodents, frogs, snails, and insects from fields, uncultivated land and forest, and aquatic environments.

For example, insects have constituted a fundamental part of the diet among previous and contemporary hunter-gatherers [309]. Although entomophagy (insect-eating) declined with the development of agriculture in most regions, reinforced by modern prejudice against insects, it has remained part of traditional knowledge among subsistence farmers [310]. Insects are still occasionally collected and eaten, especially in times of drought when modern crops fail. For example, more than 65 species of insects have been reported as food in the Democratic Republic of the Congo [310].

The nutritional importance of entomophagy has not been fully appreciated, since the focus has been on protein content. However, the very high contents of important micronutrients in insects, in particular iron and zinc, may be of considerably greater importance. The bioavailability of iron and zinc in insects, and whether insects may have the "meat factor" effects, remains to be studied. A survey among elderly Luo in western Kenya identified five commonly eaten insect species, including ants, termites, and crickets [311]. The iron and zinc contents were up to 1,562 and 341 mg/100 g dry matter, respectively. Although most insects are only available for short periods in specific seasons, they can be dried and kept for later use. In South Africa, it has been estimated that 16,000 tonnes of dried mopane caterpillars are sold each year.

Even relatively small amounts of insects may contribute considerably to the intake of protein and important micronutrients in complementary diets and in diets for malnourished children, including those with HIV infection, where a high nutrient density is required.

Conclusions and recommendations on other animal-source foods

» Snakes, rodents, frogs, snails, and insects may in some settings constitute an important and underutilized resource.
» Insects may have a very high content of protein as well as of minerals such as iron and zinc.
» Small amounts of these other animal-source foods can provide an important contribution to the diets of children with moderate malnutrition, if culturally acceptable.

Oils and fats

Vegetable oils and fats are important ingredients in the diet of children with moderate malnutrition. They are expensive ingredients, and often the intake is low in populations with high rates of malnutrition. Apart from being low in fat, the basic diet of malnourished children appears to be specifically low in n-3 PUFAs, whereas many of the oils and staple foods supply some n-6 PUFAs (**Tables 12, 15,** and **26**). These aspects are discussed in the sections on Fat Composition of the Diet which also include the recommendations for intakes of n-6 and n-3 PUFAs for moderately malnourished children (5 g of n-6 PUFA/1,000 kcal and 0.55 g of n-3 PUFA/1,000 kcal). In this section, the characteristics and the role of oils and fats in diets for moderately malnourished children are discussed.

The potential health effects of an optimal intake of

TABLE 26. Fatty acid composition of common edible fats and oils (values in g/100g)[a]

Fat or oil	SFA	MUFA	PUFA	n-6 PUFA	n-3 PUFA	n-6/n-3	Dominant FA (>10%)
Plant source							
Coconut oil	86.5	5.8	1.8	1.8	0.0		12:0 and 14:0
Palm oil	49.3	37.0	9.3	9.1	0.2	45.5	16:0 and 18:1
Olive oil	13.8	73.0	10.5	9.8	0.8	12.8	18:1
Sunflower oil, high oleic	9.7	83.6	3.8	3.6	0.2	18.8	18:1
Sunflower oil (LA < 60%)	10.1	45.4	40.1	39.8	0.2	199	18:1 and 18:2
Sunflower oil (LA approx. 65%)	10.3	19.5	65.7	65.7	0.0		18:2 and 18:1
Groundnut/peanut oil	16.9	46.2	32.0	32.0	0.0		18:1 and 18:2
Grapeseed oil	9.6	16.1	69.9	69.6	0.1	696	18:2 and 18:1
Sesame oil	14.2	39.7	41.7	41.3	0.3	138	18:2 and 18:1
Maize/corn oil	13.0	27.6	54.7	53.2	1.2	45.8	18:2, 18:1. and 16:0
Soybean oil	15.7	22.8	57.7	50.4	6.8	7.4	18:2, 18:1. and 16:0
Canola/rapeseed oil	6.4	55.4	33.2	22.1	11.1	1.9	18:1 and 18:2
Flaxseed oil	9.4	20.2	66.1	12.7	53.3	0.2	18:3, 18:1. and 18:2
Animal source							
Butter, salted	51.4	21.0	3.0	2.7	0.3	8.8	14:0, 16:0, 18:0. and 18:1
Lard	39.2	45.1	11.2	10.2	1.0	10.2	16:1, 16:0. and 18:0
Fish oil	29.1	23.7	42.3	3.6	38.7	0.09	22:5n-3, 16:0. and 22:6n-3

FA, fatty acid; LA, linoleic acid (18:2n-6); MUFA, monounsaturated fatty acid; PUFA, polyunsaturated fatty acid; SFA, saturated fatty acid

a. Fatty acids are given as number of carbon atoms in chain:number of double bonds. Sources: US Department of Agriculture [27], NutriSurvey [315].

PUFAs and the large variation in PUFA content of different vegetable oils make the source of vegetable oil used in foods for children with moderate malnutrition important. Food declarations often do not mention the kind of vegetable oil that is used. This is not satisfactory. The source and amount of fat should be declared in processed foods used for children with moderate malnutrition.

Some of the oils that are frequently used in low-income countries, such as palm oil and coconut oil, have a high content of saturated fatty acids. These fatty acids provide a good source of energy but do not provide essential fatty acids. The potential negative effect of a high intake of saturated fat, which is a concern in high-income countries, is not likely to be a problem in the treatment of malnourished children. Palm oil is characterized by a high content of palmitic acid (about 45%) and has a very low content of n-3 PUFAs and thus a high n-6/n-3 PUFA ratio of about 45. Unheated palm oil is red because of a high content of β-carotene. Palm kernel oil, which is made from palm seeds and not palm fruit, as is palm oil, has a very different fatty acid composition. As in coconut oil, more than 80% of the fatty acids in palm kernel oil are saturated fatty acids; most of these are the medium-chain fatty acids lauric and myristic acid, and only about 8% is palmitic acid. Compared with red palm oil, palm kernel oil and coconut oil have much lower contents of oleic acid and PUFAs.

Most other common vegetable oils have a high content of either oleic acid (18:1n-9), linoleic acid (18:2n-6), or both (**table 26**). Oleic acid acts as a competitor in the metabolic processing of the essential fatty acids, linoleic acid and α-linolenic acid (18:3n-3), and as such can to some extent possibly spare the essential fatty acids for their essential functions [312]. The oleic acid–rich oils may thus be a good choice to use with other more essential fatty acid rich oils. Only a few of the common vegetable oils contain a significant amount of α-linolenic acid; the most common is soybean oil, but canola (rapeseed) oil, walnut oil, and flaxseed oil also contain significant amounts. However, none of these vegetable oils contain n-3 LCPUFAs (eicosapentaenoic acid and docosahexaenoic acid), which are only supplied in large quantities from marine foods. The n-3 PUFA–containing oils may be the best choice for malnourished children. The needs for n-3 PUFAs could be fulfilled either by giving soybean oil as the main fat source or by supplying some flaxseed oil in combination with a vegetable oil that is available and affordable. To supply the 0.55 g of n-3 PUFA/1,000 kcal needed, 5 mL of rapeseed oil/1,000 kcal or 8 mL of soybean oil/1,000 kcal is needed. To cover the requirements of n-3 PUFA with other vegetable oils with lower n-3 PUFA content is not realistic. For corn oil it would take 70 mL of oil/1,000 kcal, and the recommended n-6/n-3 ratio would never be reached if large quantities of corn oil were used.

Soybean oil is of high quality, as it contains a high proportion of unsaturated fatty acids; the most important ones being: PUFAs; linoleic acid, α-linolenic acid, and oleic acid (18:1n-9). Soybean oil contains a high amount of n-6 PUFA, less n-3 PUFA, but compared with other oils a relatively high content of n-3 PUFA (100 g of soybean oil contain 7 g α-linolenic acid and 51 g of linoleic acid) resulting in an n-6/n-3 PUFA ratio of 7, close to the recommended ratio of 6 [4]. In comparison, flaxseed oil, also called linseed oil, has a very high n-3 PUFA (α-linolenic acid) content and thereby a n-6/n-3 PUFA ratio of 0.2. The n-3 PUFA content of rapeseed oil (canola oil) is between the two with respect to the ratio between n-3 PUFA and n-6 PUFA; it has a high content of oleic acid and is used increasingly as the main vegetable oil in many European countries. Corn oil, sunflower oil, grapeseed oil, and peanut oil are unbalanced sources of essential fatty acids, with high amounts of n-6 PUFA and only a little n-3 PUFA. Using these oils will make the essential fatty acid intake more unbalanced.

Rapeseed oil may have high levels of erucic acid, which may have negative health effects, but some types of rapeseed oil, such as canola oil, have low levels of erucic acid. The European Union directive for the composition of infant formula states that the amount of erucic acid should not be above 1% of the total fat content. It therefore seems reasonable to adopt the same limit for infants and children with moderate malnutrition. Flaxseed oil has traditionally been used for wood finishing but is now becoming a more common food supplement sold in health-food shops. It is rapidly oxidized and may produce toxic oxidation products if antioxidants are not added. Although flaxseed oil is a rich source of n-3 PUFA, it should not be used for infants and young children before potential negative effects have been examined further.

Palm oil, soybean oil, and rapeseed oil are among the oils produced in the largest amounts globally. There are only moderate differences in price among the three types of vegetable oil used commonly by the World Food Programme: soybean oil, palm oil, and sunflower oil. Based on prices from January 2009, the cheapest oil was palm oil (about US$800/ton), with soybean oil and sunflower oil being about 20% more expensive and rapeseed oil about 30% more expensive. To cover the PUFA requirements, soybean oil or rapeseed oil, which at present is only about 10% more expensive than palm oil, are the best choices.

Vegetable oils can be hydrogenated to produce a solid or a semisolid fat, which can have technical advantages in food production, such as in baking. When a vegetable oil is hydrogenated, the unsaturated fat is transformed into saturated fat, which increases the melting point of the fat. If the vegetable oil is only partially hydrogenated, *trans*-fatty acids are produced, which seem to have several adverse health effects, especially on cardiovascular risk factors, and may counteract the effects of *cis*-unsaturated fatty acids [313]. Partially hydrogenated fat is not allowed in the Codex Alimentarius standard for cereal-based infant foods [314]. Thus, partially hydrogenated vegetable oils should not be used in diets for children with moderate malnutrition.

The most common animal fats include butter, ghee, lard, and fish oil. Ghee is boiled, clarified butter without the protein from the butter, and lard is pure fat from the pig. Lard has considerably more n-3 PUFA than butter (**table 26**), and both lard and butter have n-6/n-3 ratios of 9 to 10, which is within the recommended range. However, it is not realistic to cover the requirements of PUFA from these fat sources, since too large amounts would be needed. Fish oil has a very high content of n-3 PUFA, about 35%. To cover the recommended intake of n-3 PUFA, only about 1.5 mL of fish oil/1,000 kcal is needed. Since fish oil contains n-3 PUFA in its long-chained forms, docosahexaenoic acid and eicosapentaenoic acid, this amount is likely to be more effective than equivalent doses of n-3 PUFA with only α-linolenic acid.

Conclusions and recommendations on oils and fats

» Vegetable oils are important ingredients in diets for malnourished children, as they supply both energy and essential fatty acids.
» Soybean and rapeseed oil are the oils that best cover the requirements of PUFAs at a reasonable cost.
» Adding about 15 mL (1 tablespoon) of soybean oil daily to the diet of a malnourished child will cover the requirements of essential fatty acids and will supply about 10% of the energy requirements.
» If vegetable oils with low contents of n-3 PUFAs are used, the n-3 PUFA requirements could be covered by adding small amounts of fish oil.
» The source of vegetable oil used in processed food for children with moderate malnutrition should be declared.
» Partially hydrogenated vegetable oils should not be used in diets for children with moderate malnutrition because of potential adverse effects of *trans*-fatty acids.

Research recommendations

» The effects of an optimal n-3 fatty acid intake in children with moderate malnutrition should be studied.

Sugar

Sugar contributes only energy and no other nutrients, such as vitamins or minerals. Brown sugar, which typically is a mix of white sugar and molasses, contains some iron and calcium. Molasses contains 4.7 mg of iron and 205 mg of calcium per 100 g [27], but it constitutes only about 5% of brown sugar and is not available at a reasonable price. The energy content of sugar is a little less than half that of fat. Still, added sugars have a relatively high energy density compared with many other foods, since the water content of sugar is zero. Adding sugar to foods increases the energy density but at the same time decreases the nutrient density and increases the osmolarity. The higher energy density is likely to have a positive influence on energy intake, an effect that is worrying in high-income societies with a growing prevalence of obesity. In the treatment of children with wasting who have an increased energy need, this increase in energy intake is an advantage. Adding a high sugar content to diets for children with moderate stunting who need treatment over a long period may impose a risk of overweight. Another important aspect of added sugar is how it affects taste. The sweet taste is likely to improve the palatability and thereby the acceptability of the food. Adding sugar may therefore help to increase energy intake both through increased energy density and through an improved taste, an effect that may be especially important in situations where bulky foods are fed or appetite is poor. However, when sugar is used for a longer period of time, there is a risk of reinforcing a preference for sweet foods, resulting in too high an energy intake later in life.

Adding sugar to a food or a diet reduces the nutrient density, as it provides no vitamins and minerals. Studies from high-income countries have shown that a high sugar intake (above 15 E%) has a negative influence on certain important nutrients, such as zinc, where the nutrient density (mg/10 MJ) was below the recommended level [316, 317]. In 2003, the report of a Joint WHO/FAO Expert Consultation on Diet, Nutrition and Prevention of Chronic Diseases [318] recommended that added sugar intake should not go above 10 E% at the population level. There are no firm scientific data to support the level of 10 E%, but rather it has been chosen as a prudent level. In treating children with moderate malnutrition, 10 E% seems to be a reasonable maximum level. If more than 10 E% is added to a food or diet, there is a need to ensure that the content of vitamins and minerals is sufficient. In treatment of moderate wasting for a limited period, a content higher than 10 E%, but not more than 20 E%, may be acceptable. Sugar adds considerably to the osmolarity of the food, which should also be taken into consideration.

A high and frequent intake of sugar over a long time may increase the risk of caries, especially in situations with poor oral hygiene [318]. However, this may not be important during shorter periods of rehabilitation. Giving a diet with a high sugar content over a long period may also make it difficult for the child later to accept a diet with no or very low sugar content. This problem, which has been observed after treatment of severe malnutrition, should be investigated further.

Conclusions and recommendations on sugar

» Adding sugar increases energy intake by increasing energy density and improving taste but reduces the nutrient density of the food.
» Adding sugar may increase the risk of caries.
» The amount of sugar should generally not exceed 10 E%, although 20 E% for up to a few weeks may be acceptable for treatment of wasted children.

Research recommendations

» It should be investigated whether children have difficulties accepting a normal diet with no or very little sugar after a period of treatment with a high sugar intake.

Salt

Malnourished children have only a low requirement of sodium, since they are in a sodium-retaining state [4]. A high sodium intake will increase the renal solute load, which may result in hypernatremic dehydration. Furthermore, a high sodium intake may result in heart failure. Sodium adds taste to a meal, but this is not likely to be important for infants and young children. Thus, there is no need to add salt (sodium chloride) to the diet of an infant or child with moderate malnutrition. Salt is used as a vehicle for iodine fortification, but children should have their iodine requirement covered in another way.

Conclusions and recommendations on salt intake

» Salt (sodium chloride) should not be added to the diet of children with moderate malnutrition.

Other issues

Appetite

There are some studies suggesting that different foods have different effects on appetite, apart from the effect of the energy content. This is an area that has been studied in detail in relation to obesity, but it is also an area that is relevant for malnutrition [22]. To our knowledge, there is not much information available on appetite in relation to treatment of malnutrition, although this is an area with potentially high importance. Some studies suggest that a high protein content in a diet will have a negative effect on energy intake [22], which could be an important reason, apart from cost, not to have too high a protein content in diets for malnourished children. It has also been suggested that beans can have a negative effect on appetite, which may be caused by colonic fermentation of oligosaccharides that produces discomfort because of gas production and slowing of gut transit time [319]. This could be another reason for not using or using only small amounts of beans and other legumes in diets for children with moderate malnutrition. Other foods have been suggested to influence appetite less than would have been expected from the energy content. Some studies have shown that liquid sugar, as in soft drinks, and especially fructose–glucose syrup, has a limited effect on appetite and may therefore result in increased energy intake and weight gain [320, 321]. However, liquid sugar is not suitable for long-term use in children with moderate malnutrition.

Conclusions and recommendations on appetite

» Some foods have an influence on appetite (positive or negative) beyond the effect of the energy content.
» Research is needed to assess the effects of different foods, ingredients, nutrients, and dietary diversity on appetite among malnourished children.

Cost

The cost of foods used for treating children with moderate malnutrition is an important aspect to consider. In particular, the differences in price between animal and nonanimal foods are considerable and need to be taken into consideration when deciding which foods to recommend. In balancing the price against the effect, it should be considered that treating moderate malnutrition is likely to have a very important impact on health, by preventing the development of severe malnutrition, reducing morbidity and mortality, and improving mental and physical development. In this balance, it should also be taken into account that the foods used for treating severe malnutrition are based on milk, with 100% milk protein in F100 and 50% milk protein in RUTFs. Another important aspect is how much animal-source food is needed to make an impact. Here it is proposed that providing 25% to 33% of the protein from animal food sources can have an impact on growth. However, there is a need for more research to establish the minimum amount of animal-source food that makes a difference.

It is difficult to obtain comparable prices, since prices differ considerably with location, transport needed, subsidies, market situation, and season. A very rough estimate is that animal foods are 5 to 10 times more expensive, and that corn–soy blend and blended infant food are 2 to 3 times more expensive per energy unit than a basic staple food (Pieter Dijkhuizen, personal communication). In **table 27** we have given some examples of world market wholesale prices of different foods and commodities provided by the World Food Programme and have calculated for each food the price for energy (1,000 kcal) and for protein (24 g, which is the protein requirement per 1,000 kcal for children with moderate malnutrition [4]). Prices for both August

2008 and January 2009 are given, showing the dramatic fluctuations over a short period. The figures give a rough idea of the relative differences between relevant commodities and especially the difference between animal-source foods and other foods, bearing in mind that the difference between retail market prices and wholesale prices can be larger for animal-source foods. Cereals are the cheapest sources of energy, with maize the cheapest. Oils are about double the price, whereas soybeans and other legumes are at a higher level and animal foods are much higher. The cheapest sources of protein are soybeans, wheat, and maize. Interestingly, protein from rice is the same price as protein from chickpeas and green lentils and is about half the price of protein from skimmed-milk powder, which is one of the cheapest animal-source proteins. In estimating the cost of diets for children with moderate malnutrition, it is possible to take the requirements of all macro- and micronutrients into consideration using linear programming [322].

Conclusions and recommendations on cost

» Treating children with moderate malnutrition is important to prevent the development of severe acute malnutrition and severe stunting, which should be taken into consideration when evaluating the cost of the foods and ingredients used.
» An important aspect of the cost of the treatment is determining through intervention studies the amount of animal protein needed to make an impact on recovery.

Conclusions

It is not difficult to design an optimal diet for children with moderate malnutrition if the resources are available. The diet used for the treatment of severe malnutrition with a high content of animal food (milk powder) and a low content of fibers and antinutrients will also be effective in the treatment of moderate malnutrition. However, the ingredients in such a diet are expensive, are not available in most settings, and are not appropriate for a low-cost, sustainable, home-based treatment.

A main issue is to identify a cost-effective balance between the amount of animal foods—which have a high content of minerals important for growth (e.g., phosphate and zinc) and of protein of high quality (PDCAAS), with virtually no antinutrients, but which also have a high cost—and the amount of plant-based foods. This balance is especially important if the plant-based foods are unrefined cereals and legumes with a high content of fibers and antinutrients.

Infants and young children are more susceptible to the negative effects of antinutrients such as phytate and fibers, especially insoluble fibers, than older children. This is particularly crucial for malnourished children, who often have a compromised and thereby more vulnerable gastrointestinal tract.

The most used animal-source foods are milk, meat, and eggs. However, there are several other types of animal food sources that are often cheaper and can be valuable ingredients in the diet of moderately malnourished children if they are culturally acceptable. These include fish, especially small fish that are eaten whole and therefore have a high nutrient content, and

TABLE 27. Crude prices of energy (1,000 kcal) and protein (24 g) in selected commodities[a]

Commodity	Price US$/Mt Aug 2008	Price US$/Mt Jan 2009	Energy content (kcal/100 g)[b]	Protein content (g/100g)[b]	Energy price (US$/1,000 kcal) Jan 2009	Protein price (US$/24 g) Jan 2009
Wheat	340	225	330	12	0.07	0.05
Maize	240	190	360	9	0.05	0.05
Rice	490	340	360	8	0.09	0.10
Corn–soy blend	530	430	380	18	0.11	0.06
Soybeans	800	620	445	37	0.14	0.04
Chickpeas	925	775	364	19	0.21	0.10
Whole green lentils	1,000	825	352	26	0.23	0.08
Skimmed-milk powder	3,800	3,120	360	36	0.87	0.21
Whole-milk powder	4,250	4,250	500	25	0.85	0.41
Beef[c]	4,200	3,200	150	29	2.13	0.26
Soybean oil	1,875	1,150	880	0	0.13	NA
Sunflower oil	2,250	1,150	880	0	0.13	NA
Sugar	440	430	390	0	0.11	NA

Mt, metric ton; NA, not applicable
a. Prices are the median of the different prices given within each commodity from the World Food Programme FOB price lists from July and August 2008.
b. Energy and protein contents are taken from the tables in this review or from the USDA food table [27].
c. Beef prices are from the FAO International Commodity Price List (personal communication Tina van der Briel, November 2008)]

other animal-source foods, such as insects, snakes, and rodents. Offal may also be an underutilized animal-source food. Milk seems to have a special effect in stimulating linear growth through an increased production of IGF-1.

When cereals and legumes constitute a large part of the diet, it is important that the contents of antinutrients and fibers are reduced through food processing. Soaking, malting, and fermentation reduce the contents of antinutrients. Milling also reduces the contents of antinutrients, but as the contents of both nutrients and antinutritional factors are high in the outer layer of grains, extensive milling will also reduce the nutrient density.

The fat content, and thereby the energy density, is typically low in a traditionally plant-based diet, and increasing the content of fat is a well-known and efficient way to increase nutrient density. To obtain an adequate energy density, the fat energy percentage should be at least 30 E% and preferably, especially for wasted children, between 35 and 45 E%. An issue that needs attention is the fat quality in the diets of children with moderate malnutrition. The content of PUFAs, especially n-3 fatty acids, is low in these plant-based diets and also in many oils. Several of the symptoms seen in children with moderate malnutrition could be caused by PUFA deficiency. Diets for moderately malnourished children should contain at least 4.5 E% of n-6 PUFAs and 0.5 E% of n-3 PUFAs. Soybean, rapeseed oil, and fish have high contents of n-3 fatty acids.

Research recommendations

There are still many unresolved aspects of the dietary treatment of children with moderate malnutrition that need to be investigated further, as highlighted in the sections with conclusions and recommendations in this review. Among the most important is a need to identify the minimum quantities of different animal-source foods needed to support the growth and development of children with moderate malnutrition. Furthermore, there is a need to identify appropriate and cost-effective methods for reducing the contents of antinutrients and fibers in plant-based foods. The question of the effect of fat quality on growth and cognitive development in children with moderate malnutrition also needs investigation.

When evaluating which foods are effective in treating moderate malnutrition, weight gain has been the traditional outcome. However, more appropriate outcomes to assess healthy physical development should be included, such as increase in lean body mass and linear growth velocity, and functional outcomes, such as physical activity and psychomotor development.

Acknowledgments

Special thanks to André Briend and Pieter Dijkhuizen, who gave us invaluable comments and suggestions on many sections and with whom we had many inspiring discussions. We are also thankful to those who gave us comments on individual sections and commented on the draft text: Dominique Bounie, Klaus Bukhave, Tina Van Den Briel, Kenneth Brown, Errol Collins, Kathryn Dewey, Daniel Faurholt, Josephine Garvey, Michael Golden, Sandy Huffman, Hans Henrik Huus, Mogens Jakobsen, Anni Larnkjær, Saskia de Pee, Zita Weise Prinzo, Lisa Rogers, Per Sangild, Søren K. Rasmussen, Mette Vittrup Sørensen, and Inge Tetens.

References

1. Shoham J, Duffield A. Proceedings of the World Health Organization/UNICEF/World Food Programme/United Nations High Commissioner for Refugees Informal Consultation on the Management of Moderate Malnutrition in Children under 5 Years of Age. Food Nutr Bull 2009;30:S464–74.
2. Black RE, Allen LH, Bhutta ZA, Caulfield LE, de Onis M, Ezzati M, Mathers C, Rivera J. Maternal and child undernutrition: global and regional exposures and health consequences. Lancet 2008;371:243–60.
3. Shrimpton R, Victora CG, de Onis M, Lima RC, Blossner M, Clugston G. Worldwide timing of growth faltering: implications for nutritional interventions. Pediatrics 2001;107:E75.
4. Golden MH. Proposed recommended nutrient densities for moderately malnourished children. Food Nutr Bull 2009;30:S267–343.
5. World Health Organization. Protein and amino acid requirements in human nutrition. Geneva: WHO, 2007.
6. Treche S, Mbome IL. Viscosity, energy density and osmolality of gruels for infants prepared from locally produced commercial flours in some developing countries. Int J Food Sci Nutr 1999;50:117–25.
7. World Health Organization. Complementary feeding of young children in developing countries: a review of current scientific knowledge. Geneva: WHO, 1998.
8. Brown KH, Sanchezgrinan M, Perez F, Peerson JM, Ganoza L, Stern JS. Effects of dietary energy density and feeding frequency on total daily energy intakes of recovering malnourished children. Am J Clin Nutr 1995;62:13–8.
9. Rahman MM, Islam MA, Mahalanabis D, Biswas E, Majid N, Wahed MA. Intake from an energy-dense porridge liquefied by amylase of germinated wheat—a controlled trial in severely malnourished children during convalescence from diarrhea. Eur J Clin Nutr 1994;48:46–53.
10. Collins S, Sadler K. Outpatient care for severely malnourished children in emergency relief programmes: a retrospective cohort study. Lancet 2002;360:1824–30.
11. Briend A, Lacsala R, Prudhon C, Mounier B, Grellety Y, Golden MH. Ready-to-use therapeutic food for treatment of marasmus. Lancet 1999;353:1767–8.
12. Sandige H, Ndekha MJ, Briend A, Ashorn P, Manary MJ. Home-based treatment of malnourished Malawian children with locally produced or imported ready-to-use food. J Pediatr Gastroenterol Nutr 2004;39:141–6.
13. World Health Organization. WHO technical background paper: feeding of nonbreastfed children from 6 to 24 months of age in developing countries. Food Nutr Bull 2004;25:377–402.
14. Hofvander Y, Cameron M. Manual on feeding infants and young children. 3rd ed. Oxford, UK: Oxford University Press, 1983.
15. World Health Organization. Energy and protein requirements. Geneva: WHO, 1985.
16. Food and Agriculture Organization/World Health Organization/United Nations University. Human energy requirements. Report of a Joint FAO/WHO/UNU Expert Consultation. Rome: Food and Agricultural Organization of the United Nations, 2004.
17. Islam MM, Peerson JM, Ahmed T, Dewey KG, Brown KH. Effects of varied energy density of complementary foods on breast-milk intakes and total energy consumption by healthy, breastfed Bangladeshi children. Am J Clin Nutr 2006;83:851–8.
18. Bajaj M, Dubey AP, Nagpal J, Singh PK, Sachdev HP. Short-term effect of oil supplementation of complementary food on total ad libitum consumption in 6- to 10-month-old breastfed Indian infants. J Pediatr Gastroenterol Nutr 2005;41:61–5.
19. Galpin L, Thakwalakwa C, Phuka J, Ashorn P, Maleta K, Wong WW, Manary MJ. Breast milk intake is not reduced more by the introduction of energy dense complementary food than by typical infant porridge. J Nutr 2007;137:1828–33.
20. Owino VO, Kasonka LM, Sinkala MM, Wells JK, Eaton S, Darch T, Coward A, Tomkins AM, Filteau SM. Fortified complementary foods with or without alpha-amylase treatment increase hemoglobin but do not reduce breast milk intake of 9-mo-old Zambian infants. Am J Clin Nutr 2007;86:1094–103.
21. Food and Nutrition Board, Institute of Medicine. High-energy, nutrient-dense emergency relief food product. Washington, DC: National Academies Press, 2002.
22. Prentice AM. Macronutrients as sources of food energy. Public Health Nutr 2005;8:932–9.
23. Hoppe C, Andersen GS, Jacobsen S, Molgaard C, Friis H, Sangild PT, Michaelsen KF. The use of whey or skimmed milk powder in fortified blended foods for vulnerable groups. J Nutr 2008;138:145S–61S.
24. Schaafsma G. The protein digestibility-corrected amino acid score (PDCAAS)—a concept for describing protein quality in foods and food ingredients: a critical review. J AOAC Int 2005;88:988–94.
25. Schaafsma G. The protein digestibility-corrected amino acid score. J Nutr 2000;130:1865S–7S.
26. Sarwar G. The protein digestibility-corrected amino acid score method overestimates quality of proteins containing antinutritional factors and of poorly digestible proteins supplemented with limiting amino acids in rats. J Nutr 1997;127:758–64.
27. US Department of Agriculture. USDA national nutrient database. Available at: http://www.ars.usda.gov/nutrientdata. 2008. Accessed 27 May 2009.
28. National Food Institute (Denmark). The official Danish food composition table. Available at: http://www.foodcomp.dk/fcdb_default.asp. 2007. Accessed 27 May 2009.
29. Pedo I, Sgarbieri VC, Gutkoski LC. Protein evaluation of four oat (*Avena sativa* L.) cultivars adapted for cultivation in the south of Brazil. Plant Foods Hum Nutr 1999;53:297–304.
30. Rozan P, Lamghari R, Linder M, Villaume C, Fanni J, Parmentier M, Mejean L In vivo and in vitro digestibility of soybean, lupine, and rapeseed meal proteins after various technological processes. J Agric Food Chem 1997;45:1762–9.
31. Millward DJ, Jackson AA. Protein/energy ratios of current diets in developed and developing countries compared with a safe protein/energy ratio: implications for recommended protein and amino acid intakes. Public Health Nutr 2004;7:387–405.

32. Michaelsen KF, Jorgensen MH. Dietary fat content and energy density during infancy and childhood; The effect on energy intake and growth. Eur J Clin Nutr 1995;49:467–83.
33. Dewey KG, Brown KH. Update on technical issues concerning complementary feeding of young children in developing countries and implications for intervention programs. Food Nutr Bull 2003;24:5–28.
34. United Nations High Commissioner for Refugees/UNICEF/World Food Programme/World Health Organization. Food and nutrition in emergencies. Rome: World Food Programme, 2003.
35. Prentice AM, Paul AA. Fat and energy needs of children in developing countries. Am J Clin Nutr 2000;72:1253S–65S.
36. Uauy R, Mize CE, Castillo-Duran C. Fat intake during childhood: metabolic responses and effects on growth. Am J Clin Nutr 2000;72:1354S–60S.
37. Borel P. Factors affecting intestinal absorption of highly lipophilic food microconstituents (fat-soluble vitamins, carotenoids and phytosterols). Clin Chem Lab Med 2003;41:979–94.
38. Nordic Nutrition Recommendations 2004. 4th ed. Copenhagen: Nordic Council of Ministers, 2004.
39. Food and Agriculture Organization, World Health Organization. Fats and oils in Human Nutrition. Rome: FAO; 1994.
40. Codex Alimentarius. Standard for infant formula and formulas for special medical purposes intended for infants. Codex stan 72 – 1981, revision 2007. Available at: www.codexalimentarius.net/download/standards/288/CXS_072e.pdf. Accessed 27 May 2009.
41. Lauritzen L, Hansen HS, Jorgensen MH, Michaelsen KF. The essentiality of long chain n-3 fatty acids in relation to development and function of the brain and retina. Prog Lipid Res 2001;40:1–94.
42. Barbarich BN, Willows ND, Wang L, Clandinin MT. Polyunsaturated fatty acids and anthropometric indices of children in rural China. Eur J Clin Nutr 2006;60:1100–7.
43. Brenna JT, Varamini B, Jensen RG, Diersen-Schade DA, Boettcher JA, Arterburn LM. Docosahexaenoic and arachidonic acid concentrations in human breast milk worldwide. Am J Clin Nutr 2007;85:1457–64.
44. Hansen AE, Haggard ME, Boelsche AN, Dam DJ, Wiese HF. Essential fatty acids in infant nutrition. III. Clinical manifestations of linoleic acid deficiency. J Nutr 1958;66:565–76.
45. Eilander A, Hundscheid DC, Osendarp SJ, Transler C, Zock PL. Effects of n-3 long chain polyunsaturated fatty acid supplementation on visual and cognitive development throughout childhood: a review of human studies. Prostaglandins Leukot Essent Fatty Acids 2007;76:189–203.
46. Richardson AJ. Omega-3 fatty acids in ADHD and related neurodevelopmental disorders. Int Rev Psychiatry 2006;18:155–72.
47. Fleith M, Clandinin MT. Dietary PUFA for preterm and term infants: review of clinical studies. Crit Rev Food Sci Nutr 2005;45:205–29.
48. Smit EN, Muskiet FA, Boersma ER. The possible role of essential fatty acids in the pathophysiology of malnutrition: a review. Prostaglandins Leukot Essent Fatty Acids 2004;71:241–50.
49. Agostoni C, Giovannini M, Sala D, Usuelli M, Livio L, Francescato G, Braga M, Riva E, Martiello A, Colombo C, Marangoni F, Galli C. Double-blind, placebo-controlled trial comparing effects of supplementation of two micronutrient sprinkles on fatty acid status in Cambodian infants. J Pediatr Gastroenterol Nutr 2007;44:136–42.
50. Ambrus JL Sr, Ambrus JL Jr. Nutrition and infectious diseases in developing countries and problems of acquired immunodeficiency syndrome. Exp Biol Med (Maywood) 2004;229:464–72.
51. Tienboon P, Wangpakapattanawong P. Nutritional status, body composition and health conditions of the Karen hill tribe children aged 1–6 years in Northern Thailand. Asia Pac J Clin Nutr 2007;16:279–85.
52. Rocquelin G, Tapsoba S, Kiffer J, Eymard-Duvernay S. Human milk fatty acids and growth of infants in Brazzaville (The Congo) and Ouagadougou (Burkina Faso). Public Health Nutr 2003;6:241–8.
53. Dalton A, Wolmarans P, Witthuhn RC, van Stuijvenberg ME, Swanevelder SA, Smuts CM. A randomised control trial in schoolchildren showed improvement in cognitive function after consuming a bread spread, containing fish flour from a marine source. Prostaglandins Leukot Essent Fatty Acids 2009;80:143–9.
54. Solomons NW, Torun B, Caballero B, Flores-Huerta S, Orozco G. The effect of dietary lactose on the early recovery from protein–energy malnutrition. I. Clinical and anthropometric indices. Am J Clin Nutr 1984;40:591–600.
55. Torun B, Solomons NW, Viteri FE. Lactose malabsorption and lactose intolerance: implications for general milk consumption. Arch Latinoam Nutr 1979;29:445–94.
56. Mahan DC, Fastinger ND, Peters JC. Effects of diet complexity and dietary lactose levels during three starter phases on postweaning pig performance. J Anim Sci 2004;82:2790–7.
57. Aggett PJ, Agostoni C, Axelsson I, Edwards CA, Goulet O, Hernell O, Koletzko B, Lafeber HN, Micheli JL, Michaelsen KF, Rigo J, Szajewska H, Weaver LT. Nondigestible carbohydrates in the diets of infants and young children: a commentary by the ESPGHAN Committee on Nutrition. J Pediatr Gastroenterol Nutr 2003;36:329–37.
58. Ziegler EE, Fomon SJ. Lactose enhances mineral absorption in infancy. J Pediatr Gastroenterol Nutr 1983;2:288–94.
59. Nickel KP, Martin BR, Smith DL, Smith JB, Miller GD, Weaver CM. Calcium bioavailability from bovine milk and dairy products in premenopausal women using intrinsic and extrinsic labeling techniques. J Nutr 1996;126:1406–11.
60. Buleon A, Colonna P, Planchot V, Ball S. Starch granules: structure and biosynthesis. Int J Biol Macromol 1998;23:85–112.
61. Singh N, Singh J, Kaur L, Singh Sodhi N, Singh Gill B. Morphological, thermal and rheological properties of starches from different botanical sources. Food Chem 2003;81:219–31.
62. Chronaiks IS. On the molecular characteristics, compositional properties, and structural-functional mechanisms of maltodextrins: a review. Crit Rev Food Sci Nutr 1998;38:599–637.
63. Sajilata MG, Singhal RS, Kulkarni PR. Resistant starch—a review. Comp Rev Food Sci Food Safety 2006;5:1–17.
64. Scheppach W. Effects of short chain fatty acids on gut

morphology and function. Gut 1994;35:S35–8.
65. Andoh A, Tsujikawa T, Fujiyama Y. Role of dietary fiber and short-chain fatty acids in the colon. Curr Pharm Des 2003;9:347–58.
66. Bjorck I, Nyman M, Asp NG. Extrusion cooking and dietary fiber: effects on dietary fiber content and on degradation in the rat intestinal tract. Cereal Chem 1984;61:174–9.
67. Wong JM, de Souza R, Kendall CW, Emam A, Jenkins DJ. Colonic health: fermentation and short chain fatty acids. J Clin Gastroenterol 2006;40:235–43.
68. Abrams SA, Griffin IJ, Hawthorne KM, Liang L, Gunn SK, Darlington G, Ellis KJ. A combination of prebiotic short- and long-chain inulin-type fructans enhances calcium absorption and bone mineralization in young adolescents. Am J Clin Nutr 2005;82:471–6.
69. Coudray C, Demigne C, Rayssiguier Y. Effects of dietary fibers on magnesium absorption in animals and humans. J Nutr 2003;133:1–4.
70. Meance S, Achour L, Briend A. Comparison of starch digestibility of a blended food prepared with and without extrusion cooking. Eur J Clin Nutr 1999;53:844–8.
71. Rigaud D, Paycha F, Meulemans A, Merrouche M, Mignon M. Effect of psyllium on gastric emptying, hunger feeling and food intake in normal volunteers: a double blind study. Eur J Clin Nutr 1998;52:239–45.
72. Stevens J, Levitsky DA, VanSoest PJ, Robertson JB, Kalkwarf HJ, Roe DA. Effect of psyllium gum and wheat bran on spontaneous energy intake. Am J Clin Nutr 1987;46:812–7.
73. Doherty J, Jackson AA. The effect of dietary pectin on rapid catch-up weight gain and urea kinetics in children recovering from severe undernutrition. Acta Paediatr 1992; 81:514–7.
74. Dagnelie PC, van Staveren WA, Vergote FJ, Burema J, van't Hof MA, van Klaveren JD, Hautvast JGAJ. Nutritional status of infants aged 4 to 18 months on macrobiotic diets and matched omnivorous control infants: a population-based mixed-longitudinal study. II. Growth and psychomotor development. Eur J Clin Nutr 1989;43:325–38.
75. Davidsson L, Mackenzie J, Kastenmayer P, Rose A, Golden BE, Aggett PJ, Hurrell RF. Dietary fiber in weaning cereals: a study of the effect on stool characteristics and absorption of energy, nitrogen, and minerals in healthy infants. J Pediatr Gastroenterol Nutr 1996;22:167–79.
76. Institute of Medicine. Dietary reference intakes for energy, carbohydrate, fiber, fat, fatty acids, cholesterol, protein, and amino acids. Washington, DC: National Academies Press, 2002.
77. American Academy of Pediatrics Committee on Nutrition Carbohydrate and dietary fibre. In: Pediatric nutrition handbook. Elk Grove Village, Ill, USA: American Academy of Pediatrics, 1993:100–6.
78. Dwyer JT. Dietary fiber for children: how much? Pediatrics 1995;96:1019–22.
79. Walker SP, Wachs TD, Gardner JM, Lozoff B, Wasserman GA, Pollitt E, Carter JA, International Child Development Steering Group. Child development: risk factors for adverse outcomes in developing countries. Lancet 2007;369:145–57.
80. Sazawal S, Black RE, Ramsan M, Chwaya HM, Stoltzfus RJ, Dutta A, Dhingra U, Kabole I, Deb S, Othman MK, Kabole FM. Effects of routine prophylactic supplementation with iron and folic acid on admission to hospital and mortality in preschool children in a high malaria transmission setting: community-based, randomised, placebo-controlled trial. Lancet 2006;367:133–43.
81. Iannotti LL, Tielsch JM, Black MM, Black RE. Iron supplementation in early childhood: health benefits and risks. Am J Clin Nutr 2006;84:1261–76.
82. Mackenzie B, Garrick MD. Iron imports. II. Iron uptake at the apical membrane in the intestine. Am J Physiol Gastrointest Liver Physiol 2005;289:G981–6.
83. Grinder-Pedersen L, Bukhave K, Jensen M, Hojgaard L, Hansen M. Calcium from milk or calcium-fortified foods does not inhibit nonheme-iron absorption from a whole diet consumed over a 4-d period. Am J Clin Nutr 2004;80:404–9.
84. Molgaard C, Kaestel P, Michaelsen KF. Long-term calcium supplementation does not affect the iron status of 12–14-y-old girls. Am J Clin Nutr 2005;82:98–102.
85. Ziegler EE, Jiang T, Romero E, Vinco A, Frantz JA, Nelson SE. Cow's milk and intestinal blood loss in late infancy. J Pediatr 1999;135:720–6.
86. Fomon SJ, Ziegler EE, Nelson SE, Edwards BB. Cow milk feeding in infancy: gastrointestinal blood loss and iron nutritional status. J Pediatr 1981;98:540–5.
87. Michaelsen KF, Weaver L, Branca F, Robertson A. Vitamins. Feeding and nutrition of infants and young children. Geneva:WHO Regional Publications, 2000:76–80.
88. Brown KH, Peerson JM, Rivera J, Allen LH. Effect of supplemental zinc on the growth and serum zinc concentrations of prepubertal children: a meta-analysis of randomized controlled trials. Am J Clin Nutr 2002;75:1062–71.
89. Ramakrishnan U, Nguyen P, Martorell R. Effects of micronutrients on growth of children under 5 y of age: meta-analyses of single and multiple nutrient interventions. Am J Clin Nutr 2009;89:191–203.
90. Manary MJ, Hart CA, Whyte MP. Severe hypophosphatemia in children with kwashiorkor is associated with increased mortality. J Pediatr 1998;133:789–91.
91. World Health Organization. Reaching optimal iodine nutrition in pregnant and lactating women and young children. 2007. Available at: http://www.who.int/nutrition/publications/micronutrients/WHOStatement__IDD_pregnancy.pdf. Accessed 27 May 2009.
92. Cadell JL. Studies in protein–calorie malnutrition. II. A double-blind clinical trial to assess magnesium therapy. N Engl J Med 1967;276:535–40.
93. Michaelsen KF, Clausen T. Inadequate supplies of potassium and magnesium in relief food—implications and countermeasures. Lancet 1987;1:1421–3.
94. Dror DK, Allen LH. Effect of vitamin B_{12} deficiency on neurodevelopment in infants: current knowledge and possible mechanisms. Nutr Rev 2008;66:250–5.
95. de Pee S, West CE, Muhilal, Karyadi D, Hautvast JG. Lack of improvement in vitamin A status with increased consumption of dark-green leafy vegetables. Lancet 1995;346:75–81.
96. de Pee S, West CE, Permaesih D, Martuti S, Muhilal, Hautvast JG. Orange fruit is more effective than are dark-green, leafy vegetables in increasing serum concentrations of retinol and beta-carotene in schoolchildren in Indonesia. Am J Clin Nutr 1998;68:1058–67.

97. Institute of Medicine. Vitamin A. In: Medical Research Council, ed. Dietary reference intakes for vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. Washington, DC: Food and Nutrition Board, Institute of Medicine, 2000:162–96.
98. Khan NC, West CE, de Pee S, Bosch D, Phuong HD, Hulshof PJ, Khoi HH, Verhoef H, Hautvast JG. The contribution of plant foods to the vitamin A supply of lactating women in Vietnam: a randomized controlled trial. Am J Clin Nutr 2007;85:1112–20.
99. Erhaerdt J. Development of a new vitamin A table. Sight and Life Newsletter 2003;2:39–40.
100. Sight and Life vitamin A table. Available at: http://www.nutrisurvey.de/vac/vitamin_a_table.pdf. Accessed 27 May 2009.
101. de Pee S, Bloem MW. The bioavailability of (pro) vitamin A carotenoids and maximizing the contribution of homestead food production to combating vitamin A deficiency. Int J Vitam Nutr Res 2007;77:182–92.
102. Dijkhuizen MA, Wieringa FT, West CE, Muhilal. Zinc plus beta-carotene supplementation of pregnant women is superior to beta-carotene supplementation alone in improving vitamin A status in both mothers and infants. Am J Clin Nutr 2004;80:1299–307.
103. Holick MF, Chen TC. Vitamin D deficiency: a worldwide problem with health consequences. Am J Clin Nutr 2008;87:1080S–6S.
104. Narchi H, El Jamil M, Kulaylat N. Symptomatic rickets in adolescence. Arch Dis Child 2001;84:501–3.
105. Agarwal KS, Mughal MZ, Upadhyay P, Berry JL, Mawer EB, Puliyel JM. The impact of atmospheric pollution on vitamin D status of infants and toddlers in Delhi, India. Arch Dis Child 2002;87:111–3.
106. Shah NP. Effects of milk-derived bioactives: an overview. Br J Nutr 2000;84(suppl 1):S3–10.
107. Schlimme E, Meisel H. Bioactive peptides derived from milk-proteins—structural, physiological and analytical aspects. Nahrung 1995;39:1–20.
108. Meisel H. Bioactive peptides from milk proteins: a perspective for consumers and producers. Aust J Dairy Technol 2001;56:83–92.
109. Baldi A, Ioannis P, Chiara P, Eleonora F, Roubini C, Vittorio D. Biological effects of milk proteins and their peptides with emphasis on those related to the gastrointestinal ecosystem. J Dairy Res 2005;72:66–72.
110. Meisel H. Multifunctional peptides encrypted in milk proteins. Biofactors 2004;21:55–61.
111. Torres-Llanez MD, Vallejo-Cordoba B, Gonzalez-Cordova AF. Bioactive peptides derived from milk proteins. Arch Latinoam Nutr 2005;55:111–7.
112. Severin S, Wenshui X. Milk biologically active components as nutraceuticals: review. Crit Rev Food Sci Nutr 2005;45:645–56.
113. Walzem RL, Dillard CJ, German JB. Whey components: millennia of evolution create functionalities for mammalian nutrition: what we know and what we may be overlooking. Crit Rev Food Sci Nutr 2002;42:353–75.
114. Lien EL, Davis AM, Euler AR. Growth and safety in term infants fed reduced-protein formula with added bovine alpha-lactalbumin. J Pediatr Gastroenterol Nutr 2004;38:170–6.
115. Lonnerdal B, Lien EL. Nutritional and physiologic significance of alpha-lactalbumin in infants. Nutr Rev 2003;61:295–305.
116. Sarker SA, Casswall TH, Mahalanabis D, Alam NH, Albert MJ, Brussow H, Fuchs GJ, Hammerström L. Successful treatment of rotavirus diarrhea in children with immunoglobulin from immunized bovine colostrum. Pediatr Infect Dis J 1998;17:1149–54.
117. Greenberg PD, Cello JP. Treatment of severe diarrhea caused by *Cryptosporidium parvum* with oral bovine immunoglobulin concentrate in patients with AIDS. J Acquir Immune Defic Syndr Hum Retrovirol 1996;13:348–54.
118. Bjornvad CR, Thymann T, Deutz NE, Burrin DG, Jensen SK, Jensen BB, Mølbak L, Boye M, Larsson LI, Schmidt M, Michaelsen KF, Sangild PT. Enteral feeding induces diet-dependent mucosal dysfunction, bacterial proliferation, and necrotizing enterocolitis in preterm pigs on parenteral nutrition. Am J Physiol Gastrointest Liver Physiol 2008;295:G1092–103.
119. Fox PF. General and historical aspects. In: Fox PF, McSweeney PLH, eds. Advanced dairy chemistry. 3rd ed. Vol 1: Proteins, New York: Kluwer Academic/Plenum Publishers, 2003.
120. Berkhout B, Floris R, Recio I, Visser S. The antiviral activity of the milk protein lactoferrin against the human immunodeficiency virus type 1. Biometals 2004;17:291–4.
121. Berkhout B, van Wamel JL, Beljaars L, Meijer DK, Visser S, Floris R. Characterization of the anti-HIV effects of native lactoferrin and other milk proteins and protein-derived peptides. Antiviral Res 2002;55:341–55.
122. Floris R, Recio I, Berkhout B, Visser S. Antibacterial and antiviral effects of milk proteins and derivatives thereof. Curr Pharm Des 2003;9:1257–75.
123. Hallberg L, Bjornrasmussen E, Howard L, Rossander L. Dietary heme iron-absorption—discussion of possible mechanisms for the absorption-promoting effect of meat and for the regulation of iron-absorption. Scand J Gastroenterol 1979;14:769–79.
124. Baech SB, Hansen M, Bukhave K, Jensen M, Sorensen SS, Kristensen L, Purslow PP, Skibsted LH, Sandström B. Nonheme-iron absorption from a phytate-rich meal is increased by the addition of small amounts of pork meat. Am J Clin Nutr 2003;77:173–9.
125. Hurrell RF, Lynch SR, Trinidad TP, Dassenko SA, Cook JD. Iron-absorption in humans as influenced by bovine-milk proteins. Am J Clin Nutr 1989;49:546–52.
126. Vattem DA, Seth A, Mahoney RR. Chelation and reduction of iron by chicken muscle protein digests: the role of sulphhydryl groups. J Sci Food Agric 2001;81:1476–80.
127. Erdman JW Jr, Badger TM, Lampe JW, Setchell KD, Messina M. Not all soy products are created equal: caution needed in interpretation of research results. J Nutr 2004;134:1229S–33S.
128. West MC, Anderson L, McClure N, Lewis SE. Dietary oestrogens and male fertility potential. Hum Fertil (Camb) 2005;8:197–207.
129. Dillingham BL, McVeigh BL, Lampe JW, Duncan AM. Soy protein isolates of varying isoflavone content exert minor effects on serum reproductive hormones in healthy young men. J Nutr 2005;135:584–91.
130. Merritt RJ, Jenks BH. Safety of soy-based infant formulas containing isoflavones: the clinical evidence. J Nutr 2004;134:1220S–4S.
131. Giampietro PG, Bruno G, Furcolo G, Casati A, Brunetti

E, Spadoni GL, Galli E. Soy protein formulas in children: no hormonal effects in long-term feeding. J Pediatr Endocrinol Metab 2004;17:191–6.
132. Zung A, Glaser T, Kerem Z, Zadik Z. Breast development in the first 2 years of life: an association with soy-based infant formulas. J Pediatr Gastroenterol Nutr 2008;46:191–5.
133. ESPGHAN Committee on Nutrition, Agostoni C, Axelsson I, Goulet O, Koletzko B, Michaelsen KF, Puntis J, Rieu D, Rigo J, Shamir R, Szajewska H, Turck D. Soy protein infant formulae and follow-on formulae: a commentary by the ESPGHAN Committee on Nutrition. J Pediatr Gastroenterol Nutr 2006;42:352–61.
134. Bhatia J, Greer F. Use of soy protein-based formulas in infant feeding. Pediatrics 2008;121:1062–8.
135. Bohn L, Meyer AS, Rasmussen SK. Phytate: impact on environment and human nutrition. A challenge for molecular breeding. J Zhejiang Univ Sci B 2008;9:165–91.
136. Michell RH. Inositol derivatives: evolution and functions. Nat Rev Mol Cell Biol 2008;9:151–61.
137. Lonnerdal B, Sandberg AS, Sandstrom B, Kunz C. Inhibitory effects of phytic acid and other inositol phosphates on zinc and calcium absorption in suckling rats. J Nutr 1989;119:211–4.
138. Sandberg AS, Brune M, Carlsson NG, Hallberg L, Skoglund E, Rossander-Hulthen L. Inositol phosphates with different numbers of phosphate groups influence iron absorption in humans. Am J Clin Nutr 1999;70:240–6.
139. Greiner R, Konietzny U. Phytase for food application. Food Technol Biotechnol 2006;44:125–40.
140. Iqbal TH, Lewis KO, Cooper BT. Phytase activity in the human and rat small intestine. Gut 1994;35:1233–6.
141. Hallberg L, Hulthen L. Prediction of dietary iron absorption: an algorithm for calculating absorption and bioavailability of dietary iron. Am J Clin Nutr 2000;71:1147–60.
142. Egli I, Davidsson L, Zeder C, Walczyk T, Hurrell RF. Dephytinization of a complementary foods based on wheat and soy increases zinc, but not copper apparent absorption in adults. J Nutr 2004;134:1077–80.
143. Miller LV, Krebs NF, Hambidge KM. A mathematical model of zinc absorption in humans as a function of dietary zinc and phytate. J Nutr 2007;137:135–41.
144. Hambidge KM, Miller LV, Westcott JE, Krebs NF. Dietary reference intakes for zinc may require adjustment for phytate intake based upon model predictions. J Nutr 2008;138:2363–6.
145. Food and Agriculture Organization/World Health Organization. Human vitamin and mineral requirements. Report of a joint FAO/WHO consultation, Bangkok, Thailand. Rome: FAO/WHO, 2004.
146. Adams CL, Hambidge M, Raboy V, Dorsch JA, Sian L, Westcott JL, Krebs NF. Zinc absorption from a low-phytic acid maize. Am J Clin Nutr 2002;76:556–9.
147. Hotz C, Gibson RS. Assessment of home-based processing methods to reduce the phytate content and phytate/zinc molar ratio of white maize (*Zea mays*). J Agric Food Chem 2001;49:692–8.
148. Bishnoi S, Khetarpaul N, Yadav RK. Effect of domestic processing and cooking methods on phytic acid and polyphenol contents of pea cultivars (*Pisum sativum*). Plant Foods Hum Nutr 1994;45:381–8.
149. Igbedioh SO, Olugbemi KT, Akpapunam MA. Effects of processing methods on phytic acid level and some constituents in bambara groundnut (*Vigna subterranea*) and pigeon pea (*Cajanus cajan*). Food Chem 1994;50:147–51.
150. Egli I, Davidsson L, Juillerat MA, Barclay D, Hurrell R. The influence of soaking and germination on the phytase activity and phytic acid content of grains and seeds potentially useful for complementary feeding. J Food Sci 2002;67:3484–8.
151. Mamiro PS, Kolsteren PW, van Camp JH, Roberfroid DA, Tatala S, Opsomer AS. Processed complementary food does not improve growth or hemoglobin status of rural Tanzanian infants from 6–12 months of age in Kilosa district, Tanzania. J Nutr 2004;134:1084–90.
152. de Pee S, Bloem MW. Current and potential role of specially formulated foods and food supplements for preventing malnutrition among 6- to 23-month-old children and for treating moderate malnutrition among 6- to 59-month-old children. Food Nutr Bull 2009;30:S434–63.
153. Troesch B, Egli I, Zeder C, Hurrell RF, de Pee S, Zimmermann MB. Optimization of a phytase-containing micronutrient powder with low amounts of highly bioavailable iron for in-home fortification of complementary foods. Am J Clin Nutr 2009;89:539–44.
154. O'Dell BL, De Boland AR, Koirtyohann S. Distribution of phytate and nutritionally important elements among morphological components of cereal grains. J Agric Food Chem 1972;20:718–23.
155. Beal L, Mehta T. Zinc and phytate distribution in peas—influence of heat-treatment, germination, pH, substrate, and phosphorus on pea phytate and phytase. J Food Sci 1985;50:96–100.
156. Manach C, Scalbert A, Morand C, Remesy C, Jimenez L. Polyphenols: food sources and bioavailability. Am J Clin Nutr 2004;79:727–47.
157. Chung KT, Wong TY, Wei CI, Huang YW, Lin Y. Tannins and human health: a review. Crit Rev Food Sci Nutr 1998;38:421–64.
158. Reddy NR, Pierson MD, Sathe SK, Salunkhe DK. Dry bean tannins: a review of nutritional implications. J Am Oil Chem Soc 1985;62:541–9.
159. Ramachandra G, Virupaksha TK, Shadaksharaswamy M. Relationship between tannin levels and in vitro protein digestibility in finger millet (*Eleusine coracana*). J Agric Food Chem 1977;25:1101–4.
160. Rao PU, Deosthale YG. Tannin content of pulses—varietal differences and effects of germination and cooking. J Sci Food Agric 1982;33:1013–6.
161. Thankachan P, Walczyk T, Muthayya S, Kurpad AV, Hurrell RF. Iron absorption in young Indian women: the interaction of iron status with the influence of tea and ascorbic acid. Am J Clin Nutr 2008;87:881–6.
162. Grant G, Edwards J, Pusztai A. Alpha amylase inhibitor levels in seeds generally available in Europe. J Sci Food Agric 1995;67:235–8.
163. Pusztai A, Grant G, Duguid T, Brown DS, Peumans WJ, van Damme EJ, Bardocz S. Inhibition of starch digestion by alpha-amylase inhibitor reduces the efficiency of utilization of dietary proteins and lipids and retards the growth of rats. J Nutr 1995;125:1554–62.
164. Tan-Wilson AL, Wilson KA. Relevance of multiple soybean trypsin inhibitor forms to nutritional quality. Adv Exp Med Biol 1986;199:391–411.

165. Liener IE. Implications of antinutritional components in soybean foods. Crit Rev Food Sci Nutr 1994;34:31–67.
166. Pusztai A, Ewen SW, Grant G, Peumans WJ, van Damme EJ, Rubio L, Bardocz S. Relationship between survival and binding of plant lectins during small intestinal passage and their effectiveness as growth factors. Digestion 1990;46(suppl 2):308–16.
167. Pusztai A, Ewen SW, Grant G, Peumans WJ, van Damme EJ, Coates ME, Bardocz S. Lectins and also bacteria modify the glycosylation of gut surface receptors in the rat. Glycoconj J 1995;12:22–35.
168. Banwell JG, Boldt DH, Meyers J, Weber FL Jr. Phytohemagglutinin derived from red kidney bean (*Phaseolus vulgaris*): a cause for intestinal malabsorption associated with bacterial overgrowth in the rat. Gastroenterology 1983;84:506–15.
169. Shiraiwa M, Harada K, Okubo K. Composition and content of saponins in soybean seed according to variety, cultivation year and maturity. Agric Biol Chem 1991;55:323–31.
170. Gee JM, Price KR, Ridout CL, Johnson IT, Fenwick GR. Effects of some purified saponins on transmural potential difference in mammalian small intestine. Toxicol In Vitro 1989;3:85–90.
171. Johnson IT, Gee JM, Price K, Curl C, Fenwick GR. Influence of saponins on gut permeability and active nutrient transport in vitro. J Nutr 1986;116:2270–7.
172. Friedman M. Chemistry, biochemistry, nutrition, and microbiology of lysinoalanine, lanthionine, and histidinoalanine in food and other proteins. J Agric Food Chem 1999;47:1295–319.
173. Friedman M. Lysinoalanine in food and in antimicrobial proteins. Adv Exp Med Biol 1999;459:145–59.
174. Gilani GS, Cockell KA, Sepehr E. Effects of antinutritional factors on protein digestibility and amino acid availability in foods. J AOAC Int 2005;88:967–87.
175. Vetter J. Plant cyanogenic glycosides. Toxicon 2000; 38:11–36.
176. Jones DA. Why are so many food plants cyanogenic? Phytochemistry 1998;47:155–62.
177. Teles FF. Chronic poisoning by hydrogen cyanide in cassava and its prevention in Africa and Latin America. Food Nutr Bull 2002;23:407–12.
178. Ingelfinger JR. Melamine and the global implications of food contamination. N Engl J Med 2008;359:2745–8.
179. Wagacha JM, Muthomi JW. Mycotoxin problem in Africa: current status, implications to food safety and health and possible management strategies. Int J Food Microbiol 2008;124:1–12.
180. World Health Organization. Mycotoxins in African foods: implications to food safety and health. AFRO Food Safety Newsletter 2006;2;1–5. Available at: http://www.afro.who.int/des/fos/afro_codex-fact-sheets/newsletter_0706.pdf. Accessed 27 May 2009.
181. Gong YY, Cardwell K, Hounsa A, Egal S, Turner PC, Hall AJ, Wild CP. Dietary aflatoxin exposure and impaired growth in young children from Benin and Togo: cross sectional study. BMJ 2002;325:20–1.
182. Ramjee G, Berjak P, Adhikari M, Dutton MF. Aflatoxins and kwashiorkor in Durban, South Africa. Ann Trop Paediatr 1992;12:241–7.
183. Turner PC, Collinson AC, Cheung YB, Gong Y, Hall AJ, Prentice AM, Wild CP. Aflatoxin exposure in utero causes growth faltering in Gambian infants. Int J Epidemiol 2007;36:1119–25.
184. Turner PC, Sylla A, Gong YY, Diallo MS, Sutcliffe AE, Hall AJ, Wild CP. Reduction in exposure to carcinogenic aflatoxins by postharvest intervention measures in west Africa: a community-based intervention study. Lancet 2005;365:1950–6.
185. Hotz C, Gibson RS. Assessment of home-based processing methods to reduce the phytate content and phytate/zinc molar ratio of white maize (*Zea mays*). J Agric Food Chem 2001;49:692–8.
186. Mensah P, Tomkins A. Household-level technologies to improve the availability and preparation of adequate and safe complementary foods. Food Nutr Bull 2003;24:104–25.
187. Erdman JW, Pneros-Schneier AG. Factors affecting nutritive value in processed foods. In: Shils ME, Olson JA, Shike M, eds. Modern nutrition in health and disease. Philadelphia, PA, USA: Lea and Febiger, 1994:1569–78.
188. Bjorck I, Asp NG. The effects of extrusion cooking on nutritional value—a literature review. J Food Eng 1983;2:281–308.
189. Hurrell RF, Carpenter KJ. Maillard reactions in foods. In: Høyem T, Kvåle O, eds. Physical, chemical and biological changes in food caused by thermal processing. London: Applied Sciences Publishers, 1977:168–84.
190. Ashworth A, Draper A. The potential of traditional technologies for increasing the energy density of weaning foods (WHO/CDD/EDP/92.4). Geneva: Diarrhoeal Disease Control Programme, 1992.
191. Svanberg U, Lorri W. Fermentation and nutrient availability. Food Control 1997;8:319–27.
192. Adish AA, Esrey SA, Gyorkos TW, Jean-Baptiste J, Rojhani A. Effect of consumption of food cooked in iron pots on iron status and growth of young children: a randomised trial. Lancet 1999;353:712–6.
193. Borigato EV, Martinez FE. Iron nutritional status is improved in Brazilian preterm infants fed food cooked in iron pots. J Nutr 1998;128:855–9.
194. Sharieff W, Dofonsou J, Zlotkin S. Is cooking food in iron pots an appropriate solution for the control of anaemia in developing countries? A randomised clinical trial in Benin. Public Health Nutr 2008;11:971–7.
195. Kröger-Ohlsen MV, Trugvason T, Skibsted LH, Michaelsen KF. Release of iron into foods cooked in an iron pot: effect of pH, salt, and organic acids. J Food Sci 2002;67:3301–3.
196. Latham MC, Food and Agriculture Organization. Human nutrition in the developing world. Rome: FAO, 1997.
197. Cataldo F, Montalto G. Celiac disease in the developing countries: a new and challenging public health problem. World J Gastroenterol 2007;13:2153–9.
198. Abu-Zekry M, Kryszak D, Diab M, Catassi C, Fasano A. Prevalence of celiac disease in Egyptian children disputes the east-west agriculture-dependent spread of the disease. J Pediatr Gastroenterol Nutr 2008;47:136–40.
199. Posner ES. Wheat. In: Kulp K, Ponte JG, eds. Handbook of cereal science and technology. 2nd ed. New York: Marcel Dekker, 2000:1–31.
200. Grundas ST. Wheat. In: Caballero B, Trugo LC, Finglas PM, eds. The encyclopedia of food sciences and nutrition. 2nd ed. Oxford, UK: Elsevier Academic Press, 2003:6130–46.
201. Bienvenido OJ. Rice in human nutrition. Rome: Food

and Agriculture Organization/International Rice Research Institute, 1993.
202. Juliano BO. Rice. In: Caballero B, Trugo LC, Finglas PM, eds. The encyclopedia of food sciences and nutrition. 2nd ed. Oxford, UK: Elsevier Academic Press, 2003: 4995–5001.
203. Platt BS. Tables of representative values of foods commonly used in tropical countries. London: Her Majesty's Stationery Office, 1962.
204. Food and Agriculture Organization. Maize in human nutrition. Rome: FAO, 1992.
205. Williams CD. A nutritional disease of childhood associated with a maize diet. Arch Dis Child 1935;8:423–33.
206. Johnson LA. Corn: the major cereal of the Americans. In: Kulp K, Ponte JG, eds. Handbook of cereal science and technology. 2nd ed. New York: Marcel Dekker, 2000:31–81.
207. Slavin JL, Jacons D, Marquart L. Grain processing and nutrition. Crit Rev Food Sci Nutr 2000;40:309–26.
208. Food and Agriculture Organization. Sorghum and millets in human nutrition. Rome: FAO, 1995.
209. Panasiuk O, Bills DD. Cyanide content of sorghum sprouts. J Food Sci 1984;49:791–3.
210. Pickersgill B. Domestication of plants in the Americas: insights from Mendelian and molecular genetics. Ann Bot (Lond) 2007;100:925–40.
211. Ruales J, Nair BM. Nutritional quality of the protein in quinoa (*Chenopodium quinoa*, Willd) seeds. Plant Foods Hum Nutr 1992;42:1–11.
212. Ogungbenle HN. Nutritional evaluation and functional properties of quinoa (*Chenopodium quinoa*) flour. Int J Food Sci Nutr 2003;54:153–8.
213. Ruales J, de Grijalva Y, Lopez-Jaramillo P, Nair BM. The nutritional quality of an infant food from quinoa and its effect on the plasma level of insulin-like growth factor-1 (IGF-1) in undernourished children. Int J Food Sci Nutr 2002;53:143–54.
214. Valencia S, Svanberg U, Sandberg AS, Ruales J. Processing of quinoa (*Chenopodium quinoa*, Willd): effects on in vitro iron availability and phytate hydrolysis. Int J Food Sci Nutr 1999;50:203–11.
215. Chan SL, Ferguson E, Bailey K, Fahmida U, Harper T, Gibson RS. The concentration of iron, calcium, zinc and phytate in cereals and legumes habitually consumed by infants living in East Lombok, Indonesia. J Food Compos Anal 2007;20:609–17.
216. Suarez FL, Springfield J, Furne JK, Lohrmann TT, Kerr PS, Levitt MD. Gas production in human ingesting a soybean flour derived from beans naturally low in oligosaccharides. Am J Clin Nutr 1999;69:135–9.
217. Steggerda FR, Richards EA, Rackis JJ. Effects of various soybean products on flatulence in the adult man. Proc Soc Exp Biol Med 1966;121:1235–9.
218. Rackis JJ, Honig DH, Sessa DJ, Steggerda FR. Flavor and flatulence factors in soybean protein products. J Agric Food Chem 1970;18:977–82.
219. Savitri A, Desikachar HSR. A comparative study of flatus production in relation to the oligosaccharide content of some legumes. Nutr Rep Int 1985;31:337–44.
220. Olson AC, Gray GM, Gumbmann MR, Sell CR, Wagner JR. Flatus causing factors in legumes. In: Ory RL, ed. Antinutrients and natural toxicants in foods. Westport, CT, USA: Food and Nutrition Press, 1981:275–94.
221. Spencer PS, Schaumburg HH. Lathyrism: a neurotoxic disease. Neurobehav Toxicol Teratol 1983;5:625–9.
222. Sarwar G, Peace RW, Botting HG. Corrected relative net protein ratio (CRNPR) method based on differences in rat and human requirements for sulphur amino acids. J Am Oil Chem Soc 1985;68:689–93.
223. Messina MJ. Legumes and soybeans: overview of their nutritional profiles and health effects. Am J Clin Nutr 1999;70:439S–50S.
224. Havel RJ, Calloway DH, Gussow JD, Mertz W, Nesheim MC. National Research Council. Recommended dietary allowances. 10th ed. Washington, DC: National Academies Press, 1989.
225. Lynch SR, Beard JL, Dassenko SA, Cook JD. Iron absorption from legumes in humans. Am J Clin Nutr 1984;40:42–7.
226. Sandstrom B, Almgren A, Kivisto B, Cederblad A. Effect of protein level and protein source on zinc absorption in humans. J Nutr 1989;119:48–53.
227. Weaver CM, Heaney WR, Hinders SM, Packard PT. Absorbability of calcium from common beans. J Food Sci 1993;58:1401–3.
228. Oberleas D, Harland BF. Phytate content of foods: effect on dietary zinc bioavailability. J Am Diet Assoc 1981;79:433–6.
229. Mage JA. Phytate: its chemistry, occurrence, food interactions, nutritional significance, and methods of analysis. J Agric Food Chem 1982;30:1–9.
230. Nwokolo E. Soybean (*Glycine max*). In: Nwokolo E, Smartt J, eds. Food and feed from legumes and oilseeds. 1st ed. New York: Chapman & Hall, 1996:90–102.
231. Liu K. Soybeans as a powerhouse of nutrients and phytochemicals. In: Liu K, ed. Soybeans as functional foods and ingredients. Urbana: AOCS Press, 2004:1–22.
232. Lusas EW, Riaz MN. Soy protein products: processing and use. J Nutr 1995;125:573S–80S.
233. Davidsson L, Galan P, Kastenmayer P, Cherouvrier F, Juillerat MA, Hercberg S, Hurrell RF. Iron bioavailability studied in infants: the influence of phytic acid and ascorbic acid in infant formulas based on soy isolate. Pediatr Res 1994;36:816–22.
234. Sandstrom B, Kivisto B, Cederblad A. Absorption of zinc from soy protein meals in humans. J Nutr 1987;117:321–7.
235. Nwokolo E. Peanut (*Arachis Hypogaea* L.). In: Nwokolo E, Smartt J, eds. Food and feed from legumes and oilseeds. 1st ed. New York: Chapman & Hall, 1996:49–63.
236. Sanders TH. Peanuts. In: Caballero B, Trugo LC, Finglas PM, eds. The encyclopedia of food sciences and nutrition. 2nd ed. Oxford, UK: Elsevier Academic Press, 2003:4420–7.
237. Sidibe el H. [Thyroid diseases in sub-Saharan Africa]. Sante 2007;17:33–9.
238. Food and Agriculture Organization. Roots tubers plantains and bananas in human nutrition. Rome: FAO, 1990.
239. van Jaarsveld PJ, Faber M, Tanumihardjo SA, Nestel P, Lombard CJ, Benade AJS. β-Carotene-rich orange-fleshed sweet potato improves the vitamin A status of primary school children assessed with the modified-relative-dose-response test. Am J Clin Nutr 2005;81:1080–7.
240. Yanggen D, Nagujja S. The use of orange-fleshed sweet-potato to combat vitamin A deficiency in Uganda. A study of varietal preferences, extension strategies and

post-harvest utilization. Lima, Peru: International Potato Center (CIP), 2006.
241. Ribaya-Mercado JD, Maramag CC, Tengco LW, Dolnikowski GG, Blumberg JB, Solon FS. Carotene-rich plant foods ingested with minimal dietary fat enhance the total-body vitamin A pool size in Filipino schoolchildren as assessed by stable-isotope-dilution methodology. Am J Clin Nutr 2007;85:1041–9.
242. Faber M, Phungula MA, Venter SL, Dhansay MA, Benade AJ. Home gardens focusing on the production of yellow and dark-green leafy vegetables increase the serum retinol concentrations of 2–5-y-old children in South Africa. Am J Clin Nutr 2002;76:1048–54.
243. Kumari M, Gupta S, Lakshmi AJ, Prakash J. Iron bioavailability in green leafy vegetables cooked in different utensils. Food Chem 2004;86:217–22.
244. Fuglie LJ. *Moringa Oleifera*: natural nutrition for the tropics (the miracle tree). Dakar, Senegal: Church World Service, 1999.
245. Makkar HPS, Becker K. Nutrients and antiquality factors in different morphological parts of the *Moringa oleifera* tree. J Agric Sci 1997;128:311–22.
246. Barminas JT, Charles M, Emmanuel D. Mineral composition of non-conventional leafy vegetables. Plant Foods Hum Nutr 1998;53:29–36.
247. Lockett CT, Calvert CC, Grivetti LE. Energy and micronutrient composition of dietary and medicinal wild plants consumed during drought. Study of rural Fulani, northeastern Nigeria. Int J Food Sci Nutr 2000;51:195–208.
248. Nambiar VS, Seshadri S. Bioavailability trials of betacarotene from fresh and dehydrated drumstick leaves (*Moringa oleifera*) in a rat model. Plant Foods Hum Nutr 2001;56:83–95.
249. Watanabe F. Vitamin B_{12} sources and bioavailability. Exp Biol Med (Maywood) 2007;232:1266–74.
250. MacArtain P, Gill CI, Brooks M, Campbell R, Rowland IR. Nutritional value of edible seaweeds. Nutr Rev 2007;65:535–43.
251. Burtin P. Nutritional value of seaweeds. EJEAFChe 2003;2:498–503.
252. Becker EW. Micro-algae as a source of protein. Biotechnol Adv 2007;25:207–10.
253. Ciferri O. Spirulina, the edible microorganism. Microbiol Rev 1983;47:551–78.
254. Johnson PE, Shubert LE. Availability of iron to rats from spirulina, a blue-green alga. Nutr Res 1986;6:85–94.
255. Otles S, Pire R. Fatty acid composition of Chlorella and Spirulina microalgae species. J AOAC Int 2001;84:1708–14.
256. Simpore J, Kabore F, Zongo F, Dansou D, Bere A, Pignatelli S, Biondi DM, Ruberto G, Musumeci S. Nutrition rehabilitation of undernourished children utilizing Spiruline and Misola. Nutr J 2006;5:3.
257. Simpore J, Zongo F, Kabore F, Dansou D, Bere A, Nikiema JB, Pignatelli S, Biondi DM, Ruberto G, Musumeci S. Nutrition rehabilitation of HIV-infected and HIV-negative undernourished children utilizing spirulina. Ann Nutr Metab 2005;49:373–80.
258. Murphy SP, Allen LH. Nutritional importance of animal source foods. J Nutr 2003;133:3932S–5S.
259. Allen LH. Nutritional influences on linear growth: a general review. Eur J Clin Nutr 1994;48(suppl 1):S75–89.
260. Allen LH, Gillespie SR. What works? A review of the efficacy and effectiveness of nutrition interventions. Geneva: Administrative Coordinating Committee/Subcommittee on Nutrition, 2001.
261. Siekmann JH, Allen LH, Bwibo NO, Demment MW, Murphy SP, Neumann CG. Kenyan school children have multiple micronutrient deficiencies, but increased plasma vitamin B-12 is the only detectable micronutrient response to meat or milk supplementation. J Nutr 2003;133:3972S–80S.
262. Bwibo NO, Neumann CG. The need for animal source foods by Kenyan children. J Nutr 2003;133:3936S–40S.
263. Grillenberger M, Neumann CG, Murphy SP, Bwibo NO, Weiss RE, Jiang LH, Hautvast JGAJ, West CE. Intake of micronutrients high in animal-source foods is associated with better growth in rural Kenyan school children. Br J Nutr 2006;95:379–90.
264. Grillenberger M, Neumann CG, Murphy SP, Bwibo NO, van't Veer P, Hautvast JGAJ, West CE. Food supplements have a positive impact on weight gain and the addition of animal source foods increases lean body mass of Kenyan schoolchildren. J Nutr 2003;133:3957S–64S.
265. Murphy SP, Beaton GH, Calloway DH. Estimated mineral intakes of toddlers: predicted prevalence of inadequacy in village populations in Egypt, Kenya, and Mexico. Am J Clin Nutr 1992;56:565–72.
266. Marquis GS, Habicht JP, Lanata CF, Black RE, Rasmussen KM. Breast milk or animal-product foods improve linear growth of Peruvian toddlers consuming marginal diets. Am J Clin Nutr 1997;66:1102–9.
267. Allen LH, Backstrand JR, Stanek EJ, Pelto GH, Chavez A, Molina E, Castillo JB, Mata A. The interactive effects of dietary quality on the growth and attained size of young Mexican children. Am J Clin Nutr 1992;56:353–64.
268. Black ER. Zinc for child health. Am J Clin Nutr 1998;68:S409–516.
269. Murphy SP, Gewa C, Liang LJ, Grillenberger M, Bwibo NO, Neumann CG. School snacks containing animal source foods improve dietary quality for children in rural Kenya. J Nutr 2003;133:3950S–6S.
270. Hoppe C, Molgaard C, Michaelsen KF. Cow's milk and linear growth in industrialized and developing countries. Annu Rev Nutr 2006;26:131–73.
271. Hoppe C, Udam TR, Lauritzen L, Molgaard C, Juul A, Michaelsen KF. Animal protein intake, serum insulin-like growth factor I, and growth in healthy 2.5-y-old Danish children. Am J Clin Nutr 2004;80:447–52.
272. Hoppe C, Molgaard C, Vaag A, Barkholt V, Michaelsen KF. High intakes of milk, but not meat, increase s-insulin and insulin resistance in 8-year-old boys. Eur J Clin Nutr 2005;59:393–8.
273. Sigman M, McDonald MA, Neumann CG, Bwibo N. Prediction of cognitive competence in Kenyan children from toddler nutrition, family characteristics and abilities. J Child Psychol Psychiatry 1991;32:307–20.
274. Sigman M, Neumann CG, Baksh M, Bwibo N, McDonald MA. Relationship between nutrition and development in Kenyan toddlers. J Pediatr 1989;115:357–64.
275. Sigman M, Neumann CG, Jansen AA, Bwibo N. Cognitive abilities of Kenyan children in relation to nutrition, family characteristics, and education. Child Dev 1989;60:1463–74.
276. Espinosa MP, Sigman MD, Bwibo NO, Neumann CG, McDonald MA. Playground behaviors of school-age-

children in relation to nutrition, schooling, and family characteristics. Dev Psychol 1992;28:1188–95.
277. United Nations High Commissioner for Refugees. Policy related to the acceptance, distribution and use of milk products in refugee settings. 2006. Available at: http://www.ennonline.net/pool/files/ife/unhcr.pdf. Accessed 27 May 2009.
278. Mourey A. Nutrition manual for humanitarian action. Geneva: International Committee of the Red Cross, 2008. Available at: http://www.icrc.org/Web/Eng/siteeng0.nsf/htmlall/p0820/$FILE/ICRC_002_0820.pdf. Accessed 9 March 2009.
279. Ziegler EE, Fomon SJ. Potential renal solute load of infant formulas. J Nutr 1989;119:1785–8.
280. Jensen RG. Handbook of milk composition. New York: Academic Press, 1995.
281. Penny ME, Creed-Kanashiro HM, Robert RC, Narro MR, Caulfield LE, Black RE. Effectiveness of an educational intervention delivered through the health services to improve nutrition in young children: a cluster-randomised controlled trial. Lancet 2005;365:1863–72.
282. Hertrampf E, Olivares M, Pizarro F, Walter T, Cayazzo M, Heresi G, Llaguno S, Chadud P, Stekel A. Haemoglobin fortified cereal: a source of available iron to breast-fed infants. Eur J Clin Nutr 1990;44:793–8.
283. Pierce JL, Cromwell GL, Lindemann MD, Russell LE, Weaver EM. Effects of spray-dried animal plasma and immunoglobulins on performance of early weaned pigs. J Anim Sci 2005;83:2876–85.
284. Begin F, Santizo MC, Peerson JM, Torun B, Brown KH. Effects of bovine serum concentrate, with or without supplemental micronutrients, on the growth, morbidity, and micronutrient status of young children in a low-income, peri-urban Guatemalan community. Eur J Clin Nutr 2008;62:39–50.
285. Hurrell RF, Lynch SR, Trinidad TP, Dassenko SA, Cook JD. Iron absorption in humans: bovine serum albumin compared with beef muscle and egg white. Am J Clin Nutr 1988;47:102–7.
286. Roos N, Islam MM, Thilsted SH. Small indigenous fish species in Bangladesh: contribution to vitamin A, calcium and iron intakes. J Nutr 2003;133:4021S–6S.
287. Kent G. Fisheries, food security, and the poor. Food Policy 1997;22:393–404.
288. Garcia-Gallego M, Akharbach H, de la Higuera M. Effects of dietary lipid composition on growth, food utilization and body composition of European eel (*Anguilla anguilla*). Anim Sci 1999;69:157–65.
289. Galdos MEA, Brecht-Ruiz M, Maldonado AS, Minga JP. Fat content of Peruvian anchovy (*Engraulis ringens*), after “El Nino” phenomenon (1998–1999). J Food Compos Anal 2002;15:627–31.
290. Zenebe T, Ahlgren G, Boberg M. Fatty acid content of some freshwater fish of commercial importance from tropical lakes in the Ethiopian Rift Valley. J Fish Biol 1998;53:987–1005.
291. Roos N, Thorseng H, Chamnan C, Larsen T, Gondolf UH, Bukhave K, Thilsted SH. Iron content in common Cambodian fish species: perspectives for dietary iron intake in poor, rural households. Food Chem 2007;104:1226–35.
292. Kongkachuichai R, Napatthalung P, Charoensiri R. Heme and nonheme iron content of animal products commonly consumed in Thailand. J Food Compos Anal 2002;15:389–98.
293. Roos N, Chamnan C, Loeung D, Jakobsen J, Thilsted SH. Freshwater fish as a dietary source of vitamin A in Cambodia. Food Chem 2007;103:1104–11.
294. Puwastien P, Judprasong K, Kettwan E, Vasanachitt K, Nakngamanong Y, Bhattacharjee L. Proximate composition of raw and cooked Thai freshwater and marine fish. J Food Compos Anal 1999;12:9–16.
295. Larsen T, Thilsted SH, Kongsbak K, Hansen M. Whole small fish as a rich calcium source. Br J Nutr 2000;83:191–6.
296. Roos N, Islam M, Thilsted SH. Small fish is an important dietary source of vitamin A and calcium in rural Bangladesh. Int J Food Sci Nutr 2003;54:329–39.
297. Roos N, Leth T, Jakobsen J, Thilsted SH. High vitamin A content in some small indigenous fish species in Bangladesh: perspectives for food-based strategies to reduce vitamin A deficiency. Int J Food Sci Nutr 2002;53:425–37.
298. Lartey A, Manu A, Brown KH, Peerson JM, Dewey KG. A randomized, community-based trial of the effects of improved, centrally processed complementary foods on growth and micronutrient status of Ghanaian infants from 6 to 12 mo of age. Am J Clin Nutr 1999;70:391–404.
299. Chai JY, Murrell KD, Lymbery AJ. Fish-borne parasitic zoonoses: status and issues. Int J Parasitol 2005;35:1233–54.
300. Vimokesant SL, Hilker DM, Nakornchai S, Rungruangsak K, Dhanamitta S. Effects of betel nut and fermented fish on the thiamin status of northeastern Thais. Am J Clin Nutr 1975;28:1458–63.
301. Selmi S, Monser L, Sadok S. The influence of local canning process and storage on pelagic fish from Tunisia: fatty acid profiles and quality indicators. J Food Process Preserv 2008;32:443–57.
302. Siriamornpun S, Yang LF, Kubola J, Li D. Changes of omega-3 fatty acid content and lipid composition in canned tuna during 12-month storage. J Food Lipids 2008;15:164–75.
303. Oyelese OA, Opatokun MO. Exposure time on bacteria flora/count and shelf life of canned sardine (*Sardinella pilchardus*) under ambient and cold storage conditions. J Food Process Preserv 2007;31:517–30.
304. Srikantia SG, Gopalan C. Fish protein concentrates in the treatment of kwashiorkor. Am J Clin Nutr 1966;18:34–7.
305. Brinkman GL, Sharadambal B, Madhave V. A feeding trial of fish protein concentrate with preschool children. Am J Clin Nutr 1970;23:395–9.
306. Ackman RG, McLeod C, Rakshit S, Misra KK. Lipids and fatty acids of five freshwater food fishes of India. J Food Lipids 2002;9(2):127–145.
307. Guler GO, Kitztanir B, Aktumsek A, Citil OB, Ozparlak H. Determination of the seasonal changes on total fatty acid composition and omega 3/omega 6 ratios of carp (*Cyprinus carpio* L.) muscle lipids in Beysehir Lake (Turkey). Food Chem 2007;108:689–94.
308. Petenuci ME, Stevanato FB, Visentainer JE, Matsushita M, Garcia EE, de Souza NE, Visentainer JV. Fatty acid concentration, proximate composition, and mineral composition in fishbone flour of Nile Tilapia. Arch Latinoam Nutr 2008;58:87–90.
309. Morris B. Insects as food among hunter-gatherers. Anthropol Today 2008;24:6–8.
310. DeFoliart GR. Insects as food: why the Western attitude is important. Annu Rev Entomol 1999;44:21–50.
311. Christensen DL, Orech FO, Mungai MN, Larsen T, Friis

H, Aagaard-Hansen J. Entomophagy among the Luo of Kenya: a potential mineral source? Int J Food Sci Nutr 2006;57:198–203.
312. Cunnane SC, Anderson MJ. Pure linoleate deficiency in the rat: influence on growth, accumulation of n-6 polyunsaturates, and [1-14C]linoleate oxidation. J Lipid Res 1997;38:805–12.
313. Innis SM. Trans fatty intakes during pregnancy, infancy and early childhood. Atheroscler Suppl 2006;7:17–20.
314. Codex Alimentarius. Codex standard for processed cereal-based foods for infants and young children 074-1981, revised 1-2006. website. Available at: www.codex-alimentarius.net/download/standards/290/cxs_074e.pdf. Accessed 9 March 2009.
315. NutriSurvey. Food composition. Available at: http://www.nutrisurvey.de/index.html. 2007. Accessed 27 May 2009.
316. Lyhne N, Ovesen L. Added sugars and nutrient density in the diet of Danish children. Scand J Nutr 1999;43:4–7.
317. Gibson SA. Non-milk extrinsic sugars in the diets of pre-school children: association with intakes of micro-nutrients, energy, fat and NSP. Br J Nutr 1997;78:367–78.
318. World Health Organization/Food and Agriculture Organization. Recommendations for preventing dental diseases. Diet, nutrition and the prevention of chronic diseases. Geneva: WHO, 2003:105–28.
319. Di Stefano M, Miceli E, Gotti S, Missanelli A, Mazzocchi S, Corazza GR. The effect of oral alpha-galactosidase on intestinal gas production and gas-related symptoms. Dig Dis Sci 2007;52:78–83.
320. Malik VS, Schulze MB, Hu FB. Intake of sugar-sweetened beverages and weight gain: a systematic review. Am J Clin Nutr 2006;84:274–88.
321. Raben A, Vasilaras TH, Moller AC, Astrup A. Sucrose compared with artificial sweeteners: different effects on ad libitum food intake and body weight after 10 wk of supplementation in overweight subjects. Am J Clin Nutr 2002;76:721–9.
322. Briend A, Ferguson E, Darmon N. Local food price analysis by linear programming: a new approach to assess the economic value of fortified food supplements. Food Nutr Bull 2001;22:184–9.