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Nutrition Research 22 (2002) 193–220

NUTRITION RESEARCH

www.elsevier.com/locate/nutres

Contribution of animal source foods in improving diet quality and function in children in the developing world

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Received 23 October 2001; accepted 23 October 2001

Abstract

Mild to moderate protein-energy malnutrition (PEM) is prevalent throughout the developing world. Children are particularly susceptible to malnutrition, which contributes to poor growth, diminished mental development, and illness. The recognition that micronutrient deficiencies frequently co-exist with PEM is receiving increasing attention. In this regard, diet quality, or the ability of a given diet to provide the entire complement of high-quality protein, energy, minerals, trace metals, and vitamins necessary to meet requirements, is as significant as diet quantity alone. Animal source foods supply not only high-quality and readily digested protein and energy, but are also a compact and efficient source of readily available micronutrients. This review covers information derived from field studies, both observational and interventions, regarding intake of animal products, such as meat and milk, and also the major constituent micronutrients, iron, zinc, vitamins B_{12} and A and their role on child growth, cognitive development and health.

Keywords: Animal source foods; Micronutrients; Children; Diet quality

1. Introduction

Malnutrition affects one in three children worldwide. Because the pervasive nature of malnutrition has stirred little public alarm, it has been termed "The Silent Emergency" in the 1998 report on the "State of the World's Children" from UNICEF [1]. Only a small

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PII: S0271-5317(01)00374-8

proportion of the global toll of malnutrition is related to famines, wars, and other catastrophes and these disasters usually result in the most severe forms of malnutrition. However, three-quarters of the children who die worldwide of causes related to poor nutrition are considered to be mildly to moderately malnourished. Over half of South Asia's children are malnourished. In Africa, one of every three children is underweight [1]. Stunting still remains a formidable problem in up to 40% to 60% of children in some Asian, African, and Latin American countries, or about 226 million children under age five [1,2]. In general, food insecurity is a widespread and daunting problem, particularly for subsistence farm families or the landless.

Malnutrition usually encompasses a combination of an inadequate intake of total energy and micronutrients and to a lesser extent, protein. Moreover, the high burden of infection and parasites has a negative impact on nutritional status [1]. In children, the most readily measured outcome of malnutrition is poor growth. Growth failure is due not only to low energy or food intake overall, but also to inadequate intake of high-quality protein and vital vitamins and minerals (micronutrients), and sometimes essential fatty acids. Where the quantity of total food intake is inadequate, so is the intake of many micronutrients; single nutrient deficiencies are relatively rare, except perhaps for iodine. The effects of inadequate intake are most pronounced during periods of rapid physiological change and during stages of accelerated growth, e.g. infancy and early childhood, and adolescence. During pregnancy and lactation, nutrients needed for fetal growth and milk production increase a woman's total nutrient requirements. Therefore, women of reproductive age, the fetus, and young children are groups most vulnerable to malnutrition. Recently, researchers have become increasingly aware that malnutrition not only has deleterious effects on physical growth, resistance to infection, and work capacity but also on cognitive development, school performance, and physical activity in adults and children [3,4]. Decreased cognitive function and diminished learning ability affect the productivity, not only of individuals, but collectively, of societies and whole nations, particularly in the developing world and among disadvantaged communities in the affluent nations.

Increasing the availability and utilization of nutrients in the usual diet is one approach to improve nutritional status. However, increases only in the quantity of poor-quality foods will not address diet quality, which encompasses adding adequate amounts of specific micronutrients. Animal source foods of a wide variety provide rich sources of complete protein, energy, and an array of micronutrients that are often limiting in the diet. This review will cover the benefits of animal source foods and their main constituent micronutrients in improving the quality of the human diet to ameliorate micronutrient deficiencies, the constraints to their use, and the adverse functional consequences when micronutrients are deficient in the diet. The micronutrients to be covered are iron, zinc, and vitamin B_{12}. Limited mention of vitamin A is made as this micronutrient has received the most coverage to date. Iodine will not be included as iodine deficiency has received worldwide attention and is supplied mainly by ocean products. The impact of introducing or increasing consumption of animal source foods on women's pregnancy outcome, and on a number of functional areas in young children will be examined. Pregnant women are included in this review as fetal nutrition is a continuum of infant and child nutrition and health. Potential policy implications and issues, and possible approaches to enhance availability, access and utilization of animal source foods by households are also discussed.

2. Animal source foods in the human diet

Overcoming deficiencies in diet quantity and quality are major nutritional challenges globally, particularly in developing countries. *Diet quantity* is concerned with the availability and consumption of total food energy (kcal) and *diet quality* with the ability of the diet to supply protein of high biologic value (presence of all essential amino acids) and adequate supplies of micronutrients (i.e., vitamins, minerals, and trace metals) to meet biologic requirements under a wide range of physiologic and environmental conditions. From earlier emphasis on the protein gap, and then on the energy gap since the late 1980's to the present time, there has been an increasing awareness of "hidden" malnutrition or multiple micronutrient deficiencies, and an appreciation that diet quality is as important as diet quantity [3]. For human nutrition, the micronutrients of major concern in the growth and development and health of children are iron, zinc, iodine, calcium, and vitamins B_{12} and A, and of late, folate. Although marked deficiencies of many of these carry great societal burdens economically and socially, only those most relevant to animal source foods will be discussed.

Animal source foods are energy-dense and an excellent source of high-quality and readily digested protein [4,5]. The proteins in these foods are considered the highest quality available, as they contain a full complement of essential amino acids and most resemble the proteins of the human body in their amino acid composition. Animal source foods are also an efficient source of micronutrients. The main micronutrients offered in abundant and bioavailable form by animal source foods are iron, zinc, and vitamin A from meat, and vitamin B_{12}, riboflavin and calcium from milk [5,6]. To illustrate the utility of adding micronutrient-dense meat to a child's diet, one can look at a sample diet including maize and beans compared to one including meat. To meet the average daily requirements for energy, iron, or zinc, a child would need to consume 1.7–2.0 kg of maize and beans in one day. This is far more than a child can tolerate, while the same requirement could be met with 60 g (2 oz) of meat per day. Similarly, milk products are an important source of calcium and it is difficult for a child to even approach the average calcium requirements (estimated at 345 mg/d) on a cereal-based diet [6]. Additional nutrients that are supplied by meat, poultry, and fish in abundant amounts are riboflavin, taurine, selenium, and the long-chain polyunsaturated fatty acids, pentaenoic and hexaenoic acids, all of which are increasingly being recognized as important for optimal human health.

The main advantage of animal source foods, particularly meat, is the high content and bioavailability of micronutrients; that is, there is a high level of absorption and utilization by the body because of the presence of heme protein found only in meat, fish and fowl. Although some plant foods are relatively high in iron, zinc, or calcium, e.g. spinach and legumes, the micronutrients are poorly absorbed (**Table 1**). Leafy plants are high in oxalate which form insoluble compounds that reduce the amount of minerals absorbed through the intestine. High fiber content and phytates found mainly in uncooked or unfermented cereal

Table 1
Nutritional benefits and risks of animal source foods

Benefits	Risks
High energy density and low dietary bulk	Bacterial food contamination
Dietary diversity	Zoonotic infections (animal parasites infecting people)
Quality protein	Milk substitutes before 6 months of age increases risk of disease and may displace breast-feeding
Micronutrients in bioavailable form	
Better maternal nutrition (in pregnancy and lactation)	

grains, nuts, and seeds, can also form insoluble complexes with iron, zinc, or calcium; thus diminishing the availability of these nutrients. Tannins found in high levels in tea leaves, coffee, red wine, spinach and rhubarb, also inhibit absorption of iron, zinc, and calcium [6–8]. In contrast, meat contains iron and zinc bound to heme protein, which is readily incorporated into blood cells of the body. The presence of heme protein in a meal enhances the absorption of zinc and iron from cereal and other plant sources [8,9] (**Figures 1 and 2**). It must be noted that the levels and bioavailability of micronutrients are not equivalent in both meat and milk. Milk, if consumed with meat, reduces the bioavailability of iron and zinc because of the high calcium and casein content that form insoluble complexes with iron and zinc [8,9]. **Table 2** lists common foods and the levels of important nutrients in these foods, both plant-based and derived from animals.

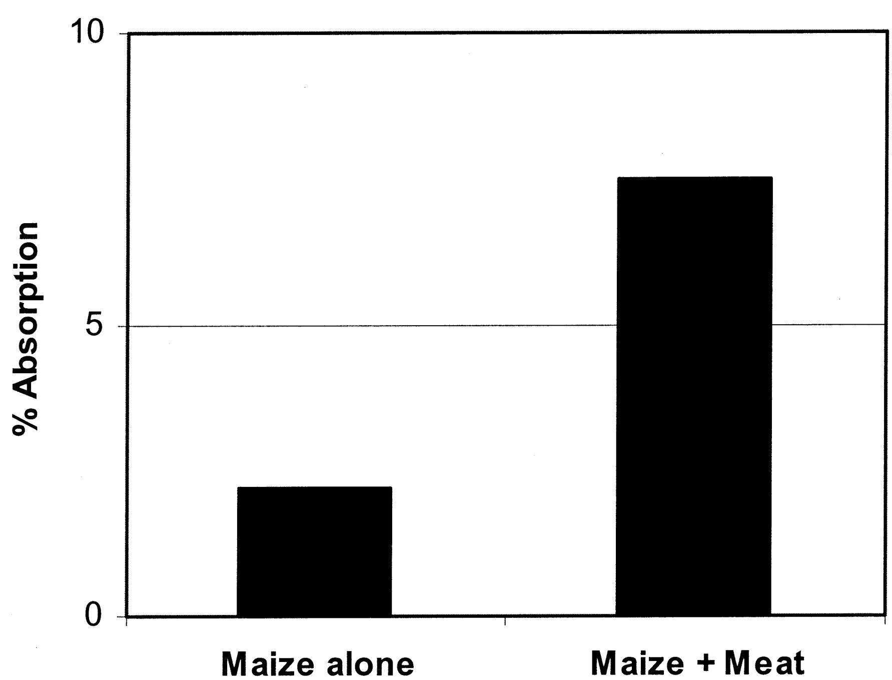

Fig. 1. Absorption of non-heme iron from maize meal in the absence and presence of meat [4].

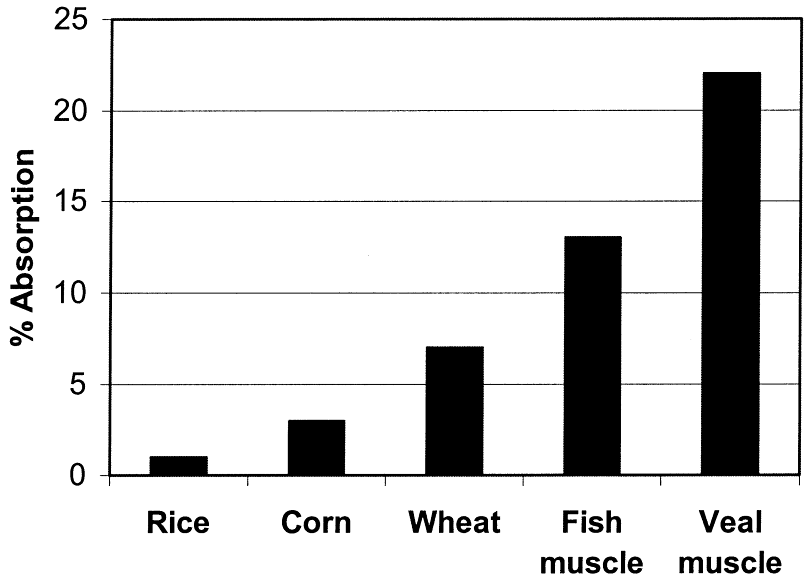

Fig. 2. Mean iron absorption from various foods in Venezuelan peasants [4].

2.1. Specific micronutrients in animal source foods

Many of the apparent beneficial effects of animal source foods on human health and function are mediated in part through the micronutrients they contain, in addition to their high-quality protein and energy density. Iron, zinc, vitamin B_{12}, and preformed vitamin A are

Table 2
Approximate nutrient compositions of some animal source and plant foods per 100g (28,124)[1]

Food	Energy (kcal)	Protein (g)	Fat (g)	Calcium (mg)	Iron	Zinc	Vit. A (RE)	Vit. B_{12} (μg)
Cow's milk	72	3.3	4.0	76	0.04	0.31	28	0.29
Goat's milk	69	2.9	3.0	90	0.04	0.22	46	0.05
Beef	263	18.5	20	7	3.2	6.0	0	2.4
Chicken	161	31.0	6.0	13	1.3	1.8	42	0.23
Goat	269	13.4	3.4	17	3.7	0	0	1.2
Rabbit	173	30.4	8.4	20	2.4	2.4	0	6.5
Fish	85	17.0	5.6	37	8.4	0.6	14	0.6
Offal	143	11.2	10.6	0	2.1	0	0	0
Liver	140	19.9	3.8	7	6.5	0	0	0
Eggs	150	12.1	10	50	1.54	1.1	192	1.0
Termites	414	28.8	32.3	0	2.5	0	0	0
Maize	207	5.9	3.1	47	2.9	0.33	0	0
Wheat	364	10.5	1.0	0	0.8	0	0	0
Beans	127	9.0	0	35	2.0	0.3	2	0
Soy	403	34.1	17.1	0	0	0	0	0
Spinach	50	3.3	0.7	122	1.7	0.7	737	0

[1] Raw or boiled foods.

the principal micronutrients found in animal products in bioavailable forms [6]. Below is a brief description of specific micronutrients that are covered in this review.

2.1.1. Iron

Iron deficiency is one of the most prevalent nutritional deficiencies worldwide; both in developing and developed nations. It has been estimated that at least 50% of women and children and 25% of men are iron deficient in poor countries. Most of the body's iron is found as a component of a number of proteins, including enzymes, hemoglobin circulating in erythrocytes, and myoglobin in muscle [10,11]. Iron compounds can be classified as either functional, serving metabolic or enzymatic functions, or as storage or transport iron. The primary regulatory mechanism of iron is its adjustable absorption from the gastrointestinal tract depending on the iron content of ingested food and its bioavailability, the amount of storage iron, and the rate of erythrocyte production. Those who are not iron deficient absorb 5–10% of dietary iron while those who are iron deficient absorb 10–20% [10]. The Recommended Dietary Allowance (RDA) for adults is 8 mg for men, 18 mg for women, 27 mg for pregnant women and 10 mg for children 4–8 years of age [12].

There are many well-established hematologic and biochemical parameters for assessing iron status [11]. Serum ferritin is the key indicator of body iron stores and is considered to be the most important measure of iron deficiency. However, it is of limited value in populations where infection prevalence and liver disease are widespread, as these conditions produce elevated levels. Hemoglobin and hematocrit levels, although non-specific, are the most commonly used tests to screen for iron deficiency anemia using relatively inexpensive apparatus that can be used by health workers in the field. Mild iron deficiency involves only depleted iron stores and no anemia, as indicated by a low serum ferritin concentration, unless infection is present. Severe iron deficiency is characterized by a low hemoglobin concentration. It is estimated that for every case of iron deficiency anemia found in a population, there is at least one case of iron deficiency without anemia [11]. Severe iron deficiency anemia is often accompanied by increased maternal and childhood mortality [13]. Symptoms of mild and moderate iron deficiency, often so insidious that they go undetected, can impair work capacity and productivity, immune function, infant/child behavior, and cognitive development.

2.1.2. Zinc

Increasing attention is being paid to the global prevalence of mild to moderate zinc deficiency in both developing countries and in disadvantaged groups in industrialized countries. Zinc is involved with gene expression, cell division and differentiation, and DNA and RNA synthesis. Zinc, on a molecular level, plays a major role in a variety of biochemical enzymatic processes relevant to maternal, fetal, infant and child health and survival. Women of reproductive age, the fetus, and young children are particularly at risk for deficiencies because of their high requirements for zinc. Although there is still a dearth of specific indicators and functional markers of non-severe zinc deficiency, plasma and hair zinc can be useful parameters to suspect the presence of zinc deficiency [14].

The main reason for zinc deficiency, particularly in the poor nations of the world, is the low intake of animal source foods. These populations tend to rely on staples, particularly starchy roots and tubers, that have low zinc content. Although cereals grains and legumes have reasonable zinc levels, the high fiber and phytate content decrease the zinc bioavailability, which contributes to the widespread prevalence of zinc deficiency. Bioavailable zinc is most efficiently supplied by meat, fish and seafood. Zinc absorption from plant foods can be considerably increased when their phytate content has been reduced through germination, etc., and they are mixed with heme protein from meat [8]. An excellent review of the impact of zinc deficiency was summarized in a recent supplement of the American Journal of Clinical Nutrition entitled *Zinc in Child Health* [14].

Because of the widespread effects of zinc deficiency on morbidity, mortality, growth and development, policy makers must pay much more attention to improving diet quality through food-based approaches or supplementation where needed in severe deficiency. Increasing the availability of animal source food to families can greatly improve zinc nutrition.

2.1.3. Vitamin B_{12}

The risk of vitamin B_{12} deficiency is high in vegetarians, particularly in extreme forms such as macrobiotic diets, which contain no foods of animal origin [15]. All naturally occurring vitamin B_{12} in the diet is ultimately derived from bacterial synthesis. Intestinal bacteria synthesize the B_{12}, which is absorbed by animals, mainly ruminants, that incorporate it into their tissues and eggs and secrete it in their milk. Plants other than some types of algae are not a source of B_{12} unless they have been exposed to bacteria that can produce the vitamin or are contaminated with substances that contain the vitamin. Rich sources of food vitamin B_{12} include: organ meats (liver, kidney), other meats (beef, chicken, pork), dairy products, fish, eggs, and shellfish. Much of the B_{12} found in fermented foods is an inactive form that is not bioavailable to humans [16].

Plasma vitamin B_{12} levels in vegetarians are generally far below those of non-vegetarians [15]. In addition to low dietary intake, vitamin B_{12} deficiency can be caused by poor intestinal absorption secondary to gastric atrophy (as in the elderly), the absence of intrinsic factor (pernicious anemia), or a wide variety of infections and intestinal parasites common in developing countries [17]. Vitamin B_{12} is essential for normal blood formation and neurological development and function [18,19]. The vitamin plays an indirect but essential role in the synthesis of purines and pyrimidines, transfer of methyl groups, syntheses of proteins from amino acids, and carbohydrate and fat metabolism.

A high prevalence of vitamin B_{12} deficiency has been described recently in some less developed countries. Studies in Mexico [18], Venezuela [20], Guatemala [21], and Kenya [22] found 31–52% of children to have low plasma cobalamin concentrations. In the NCRSP-Mexico sample, 42% of preschoolers, 22% of school-age children, 19% of non-pregnant non-lactating women, 15% of pregnant women, and 30% of lactating women had low plasma B_{12} concentrations [23]. Casterline and colleagues [19] also found a high prevalence of cobalamin deficiency in lactating Guatemalan women and their infants.

Infants are entirely reliant on their mother's intake of B_{12} during pregnancy. Infants who are born to mothers with low vitamin B_{12} status and themselves are left with poor stores of the vitamin are particularly prone to deficiency, especially when being exclusively breast fed as they receive only very low amounts of B_{12} in the breastmilk [24,25].

Table 3
Major micronutrients contained in animal source foods

	Iron	Zinc	Vitamin B_{12}	Vitamin A
Animal source foods				
Meat	+++	+++	+++	++
Milk	0	0	+++	++
Functional areas affected				
Anemia	+++	0	+++	+
Immunodeficiency	++	+++	+	+
Intra-uterine malnutrition	+	++	+	0
Cognition	+++	0	++	0
Activity	+++	++	0	0
Work capacity	+++	0	0	0

3. Functional benefits of the consumption of animal source foods

The following section reviews the literature examining the relationship of diet quality, particularly inclusion of animal source foods, and functional outcomes in women and children. The bulk of evidence comes from observational studies that statistically control for a number of confounding and intervening variables. Because of expense and complexity, controlled intervention studies, which can show a causative effect, are few. The majority of controlled intervention studies that have been conducted have used single or multiple micronutrients (tablets, capsules, etc), rather than using animal source foods. The administration of micronutrient supplements is far less complicated than preparing, delivering, and feeding large groups of children. The functional areas of interest in such studies include pregnancy outcome, growth, cognitive development, and other aspects of health, particularly immune function and morbidity. **Table 3** shows an overview of the relationship between animal source foods, micronutrients, and human function.

The beneficial role of animal source foods in the diets of pregnant women and young children are highlighted by findings from the Human Nutrition Collaborative Research Support Program (NCRSP) which studied the functional outcomes of mild to moderate malnutrition [26]. The NCRSP was a non-intervention longitudinal observational study conducted from 1983 through 1987 in rural areas in Kenya (Embu District) and Mexico (Solis Valley) and in a semi-rural area in Egypt (Kalama). Approximately 250 households were followed in each study area for one to two years. Food intake, pregnancy outcome, growth, cognitive development, school and work performance, morbidity, and immune function were studied. Women were observed before, during, and after pregnancy, and their newborns were observed for at least the first six months of life [27].

Animal source food intake was found to be generally very low (8–12% of kcal of energy). The Kenyan and Mexican diets were similar, relying on maize, legumes, and vegetables as staples with occasional sorghum and millet eaten by the Kenyans. The diet was extremely low in fat, zinc, iron, calcium, and vitamins B_{12} and A [28]. Phytate and fiber intakes of both

Kenyans and Mexicans were very high, thus reducing the bioavailability of iron and zinc in the diet. Tea and coffee taken with meals further lowered the availability of iron, and zinc. Low milk intake, leading to low calcium intake, was found in Kenyan children but not for Mexican children because of the consumption of lime-treated tortillas which supplied additional calcium. In contrast, the energy intake of the Egyptian women and children was generally higher with the main staples being wheat, bread, rice, and legumes. Cheese, milk, eggs, and vegetables were part of the diet with 40% of dietary energy from animal products. However, the high diarrhea prevalence canceled out the advantages of a higher quality diet [26]. Across all sites, intake of animal products correlated highly with levels of zinc, B_{12}, iron, and fat in the diet and B_{12} levels in breast milk in Kenya [24] and Mexico [17]. Poorer households depended almost completely on staples such as maize and tortillas, and the more affluent families generally consumed more animal products, milk, fat, fruits, and sugar.

An additional interesting cohort of children have been followed for the last approximate 15 years [29–34]. In 1985, 243 Dutch children reared on a macrobiotic diet, consisting mainly of cereals, pulses and vegetables, with small additions of seaweed, fermented foods, nuts, seeds, and seasonal fruits were recruited to participate in a mixed-longitudinal study investigating various health and nutrition outcomes, including growth and psychomotor function. Several negative consequences of the diet were noted and nutritional modifications to the macrobiotic diet (addition of dairy and/or meat) were recommended for all macrobiotic families in the Netherlands in 1986, which was later found to be implemented at a mean age of ~6 years. Reports regarding these children provide valuable information about the risks of excluding animal source foods from the diets of young children as well some of the potential benefits to the addition of these foods later in childhood.

3.1. Pregnancy, lactation, and postnatal growth

3.1.1. Animal source foods

Findings from the NCRSP showed that maternal intake of animal source foods during pregnancy is positively associated with infant growth beginning *in utero*. In Kenya, overall maternal energy intake and intake of animal protein during pregnancy were major factors that predicted pregnancy weight gain, birth weight, and birth length [27,35]. In the Egyptian sample, maternal intake of animal products in the second trimester during pregnancy predicted gestational age as well [36].

Postnatal growth failure was observed as early as the third month of life, and was seen in all three NCRSP projects, with both length and weight affected. In Kenya, rate of infant growth (0 to 6 months of age for both weight and length) was related to maternal diet quality or the amount of animal products in her diet during pregnancy and lactation. Maternal intake of vitamin B_{12} and iodized salt, and breast milk levels of B_{12} (measured directly) predicted infant growth. Thus growth failure in infants was at least in part related to inadequate maternal diet during pregnancy and lactation [27,35]. In Egypt, the sole dietary variables predicting infant growth from 0 to 6 months was maternal consumption of animal foods [36]. A number of studies of micronutrient deficiencies and pregnancy outcome and lactation and postnatal growth are presented here.

3.1.2. Micronutrient components of animal source foods

The extent to which maternal iron deficiency affects maternal and neonatal health is unclear [13,37]. There is fairly recent evidence that iron deficiency in pregnancy is associated with prematurity, low birth weight and perinatal mortality. There is also suggestive evidence that maternal iron deficiency, with or without anemia, is associated with increased maternal mortality, lower pregnancy weight gain, poorer maternal immune status and changes in infant behavior [37]. The above conditions could also be associated with other confounding factors such as general protein-energy malnutrition (PEM). To evaluate the validity of the above relationships, intervention studies, with control for possible confounders, are still needed to establish causality.

Maternal zinc deficiency, based on plasma and hair zinc concentrations and dietary assessment, is strongly associated with poor fetal growth and intrauterine growth retardation (IUGR), and an increased risk for amniotic infection, sepsis, and maternal mortality. Over 30 observational studies and ~10 supplementation studies have been carried out in pregnant women [38]. Studies in a number of African countries and in the UK and USA, have shown maternal intake of bioavailable zinc to be positively associated with birth length and weight when controlling for gestational age [38–40]. The linkages of maternal zinc deficiency during pregnancy with problems in their newborn and young infant may be attributed to an impaired ability to mobilize vitamin A in the newborn [40] and/or a faster decline in the concentration of zinc in breast milk that fails to meet the infants requirement for optimal postnatal growth. More controlled intervention studies with zinc containing foods or supplements are needed.

It is well-documented that the vitamin B_{12} concentration of breast milk from B_{12} deficient mothers is substantially lower than in those with adequate B_{12} status [41]. Low plasma vitamin B_{12} levels were common in the nonpregnant, nonlactating, pregnant, and lactating women in the Mexico and Kenya NCRSP. Breast milk vitamin B_{12} was also lower in anemic lactating women than in non-anemic lactating women, and was classified as deficient in 62% of breast milk samples [18]. Positive and statistically significant correlations were found between maternal meat intake and a level of vitamin B_{12} in breast milk in Mexico and Kenya [24,25]. Maternal vitamin B_{12} intake during pregnancy correlated positively with infant birth weight and length in the Kenya sample [24].

3.2. Child growth

3.2.1. Animal source foods

Children in developing countries frequently suffer infections that lead to a decrease in total intake, impaired absorption, and increased nutrient losses, which can result in impaired linear growth. Additionally, their typical weaning diets contain little or no animal source foods except for varying, but usually small, amounts of non-human milk with very low available iron and zinc. The diets are also very low in energy density and in order to obtain an adequate intake the child would have to greatly exceed its gastric capacity volumetrically. The growth and nutritional status of the Dutch children fed a macrobiotic diet early in life (0–8 y) revealed stagnation in growth after the first 6–8 months of life [30]. These children were revisited 6 months to 2 years later and it was found that children from families which, since the initial study, had increased the consumption of fatty fish, dairy products, or both, had grown in height more rapidly than the remaining children [33]. In addition to micronutrient deficiencies, factors related to macrobiotic diets that may lead to impaired growth are low energy density, fat, biologically incomplete protein, and anorexia. Even modest amounts of animal source foods (2 oz/day) incorporated into weaning diets can increase the energy density through its fat content, and can supply vitamin B_{12}, preformed vitamin A, available iron and zinc from non-heme protein, and protein of high biologic value. Appetite and overall intake may then be improved as zinc and iron intake increase [35].

In toddlers and school-age children, diet quality and quantity predict growth rates. In the NCRSP-Kenyan children, where total food intake was low, all food variables positively predicted growth. Animal products in particular, and the intake of available iron, zinc, and iodized salt, were statistically significant predictors of growth [23,35,42]. Diet quality or inclusion of meat in the diet was also an important predictor of growth in Mexico, where in children with a higher consumption of animal source foods it was a major predictor of length at 30 months of age.

Similar findings on the positive association of intake of animal source foods and linear growth were obtained in a study of Peruvian toddlers 12–15 months of age [43]. Complementary foods, consisting of animal source foods and breast milk, were all found to promote toddlers' linear growth. When animal source food intake was low, continued breast-feeding was positively associated with linear growth, as was the case in the Egypt NCRSP [42]. Growth was also positively associated with intake of animal source foods in children with low intakes of complementary foods. Intake of animal protein (meat, fish) showed a positive and statistically significant relationship to height in studies in New Guinea [44] and in South and Central America [14,23].

3.2.1a. Animal milk consumption. In addition to human milk, both cow and goat milk consumption have been linked to improvement in the physical growth of children. Non-governmental organizations (NGO's) working with dairy cattle and goats (i.e. Heifer Project International, Farm Africa, and an ILRI study in Ethiopia [45]) have presented data that show increased milk consumption and child growth in households raising livestock. Increased income generation may also be a factor in improved growth, mediated through improved health care and purchase of animal products, although this was not documented.

A number of studies with varying designs (case control, correlational, and several controlled intervention studies) in various disparate locations (China, Jamaica, Mexico, Nicaragua, and Brazil) all show that cow's milk consumption by infants and young children promotes physical growth, particularly in length or height [46–49]. In school-age children in Malaysia and Japan, where milk and other dairy product intake is low, the addition of milk to the diet in school feeding programs was found to increase linear growth and reduce stunting [50,51]. In the NCRSP studies, factor analyses were carried out to identify combinations or food patterns related to linear growth or height in 6 to 9 year-old children. Both in Mexico and Kenya, statistically significant positive associations were observed with a food pattern that included milk, fat, and animal protein. The food pattern consisting of maize and millet (Kenya) or maize tortillas (Mexico) was negatively associated with growth in height [23,35]. The main micronutrients contained in milk and dairy products relevant to growth are calcium, phosphorus, and vitamin B_{12}. Additionally, the milk contains protein which is of high biological value.

3.1.2b. Animal ownership. A number of correlational studies from Nepal, Mexico, and Kenya have found that dairy livestock ownership of cows and water buffalo is positively related to children's nutritional status. Improvement was seen only if milk was actually consumed by the children and not all sold commercially [52,53]. Additional studies from Brazil, Ecuador, Uganda, and Ethiopia, which controlled for family income and wealth in the analyses, support these findings [54–57]. However, it is important to note that the promotion of animal milk consumption for children under 18 months of age should not lead to a replacement of human milk consumption, especially in exclusively breast fed infants 4–6 months of age. In areas of poverty with poor sanitation and water quality, the risk of death from marasmas and diarrhea are high. The introduction of more animals into the household of small-holder families may compromise sanitation and increase the risk of diarrheal disease and zoonotic infections [5]. It is further important to note that recommendations for use of non-human milk for mothers infected with HIV are being refined by WHO [58]. The current recommendation is to consider the use of animal milk, if readily available, for infants 6 months and over because the risk of transmitting the virus through breast milk rises steeply at this age [59].

3.2.2. Micronutrients components of animal source foods

Iron supplementation studies with anemic children have shown significant benefits in linear growth following supplementation [60–63]. This benefit on linear growth appears only in anemic children [64].

Zinc deficiency has been implicated in both animal and human studies in poor physical growth, even with mild deficiency. A zinc supplementation trial in infants have found increased weight gain and/or increased growth velocity [65]. Numerous recent supplementation trials in preschool and school-age children of developing countries have shown increased linear growth [66,67]. A longitudinal zinc supplementation trial of periurban Guatemalan children found increased measures of body composition, such as mid-arm circumference, but there were no changes in growth [68]. Confounding factors are the marked anorexia and increased infection that are associated with zinc deficiency and can lead to poor nutritional status. Infection per se, decreases zinc stores in the body and further aggravates the situation [14]. The predominant evidence from human studies, as well as many animal studies, support an association between zinc deficiency and decreased linear growth velocity in children [14,58,65]. The mechanisms through which zinc affects growth is postulated to be via its role in DNA synthesis, RNA synthesis, and the effects on cell division [9,68,69].

Because infants have limited hepatic stores of vitamin B_{12}, they are at greater risk of quickly developing symptoms of deficiency, especially if being exclusively breast-fed by mothers who are B_{12} deficient. Vitamin B_{12} deficiency in children consuming strict vegetarian diets, such as a macrobiotic diet, have exhibited growth failure [15,46]. In Dutch macrobiotic children, 8–14 months of age and school-age, some catch-up growth was observed with vitamin B_{12} intervention [70]. Studies of older children have shown that short children compared to taller ones had high vitamin B_{12} intake. A very apt quote by the author states “Macrobiotic diets of children in the study (Dutch) had similar characteristics with the diet of many children in developing countries. The warning of the study for workers in such countries is obvious: Our study once again shows the importance of including fat, and if available, small portions of products containing animal protein in the diets of young children and women of child-bearing age” [71].

3.3. Cognitive function, school performance, physical activity and behavior

3.3.1. Animal source foods

A growing literature is being published on how childhood undernutrition may impact cognitive function, activity, attendance, and school performance. Previous studies focused primarily on the effect that PEM and iodine deficiency had on cognition. However, deficiencies in iron, zinc, and vitamin B_{12} have more recently been implicated in impaired cognitive function. The deleterious effects of poor diet quantity and quality can affect the child beginning *in utero.* Intrauterine malnutrition can lead to low birth weight, which has been linked to impaired mental development. After birth, stunting in young children has been associated with poor cognitive performance. Decreased maternal activity and fatigue, due to anemia and/or malnourishment, can result in decreased childcare and maternal-infant stimulation. Complete reversal of these early deficits is unlikely, although nutritional intervention and mental stimulation can help ameliorate the effects [72].

The NCRSP described earlier also included measures of cognitive function, school performance, activity, and behavior. The positive relationships between intake of animal protein and cognitive function were documented at various ages in young children. In infants of the Egyptian study group, infant alertness during the first six months was positively related to mother’s intake of animal energy [73]. Similarly, maternal intake of animal source foods was a significant positive predictor of the newborn’s orientation and habituation behavior on the Brazelton Neonatal Score [36].

In each study site, toddlers who ate little or no animal protein and those who were stunted, did not perform as well on cognitive tests as those who included animal foods in the diet. Energy intake, stunting and low animal protein intake predicted poor cognitive performance, even when controlling for parental and SES factors [74]. In Kenyan children, intake of animal source foods was still significantly and positively associated with cognitive performance in follow-up testing when the children reached five years of age [74]. The best set of predictors of cognitive function at this age was previous intake of animal protein, even when controlling for household and SES factors, and duration of schooling. Also in the Kenyan toddlers, intake of animal protein was further associated with a higher level of verbalization and more symbolic play, which are felt to be predictive of future cognitive performance [68].

Among school-age children studied, children who were taller and heavier performed better on cognitive tests, particularly verbal and performance tests, than their shorter peers. In Kenya, where both diet quantity and quality were deficient, all dietary variables and anthropometric indicators were positively associated with cognitive test scores and school performance to some degree. In these children, intake of animal protein was positively associated with attentiveness to classroom work and the teacher, and to scores of school performance [76]. The children who had greater intakes of total energy, animal protein, and fat in their diet, were more active and showed more leadership behavior in a free-play setting such as school recess [77]. In the Mexican sample, boys who consumed poor quality diets were apathetic in the classroom [23]. In all cohorts, animal source products positively predicted developmental outcomes, behavior, verbal ability and involvement in classroom activities. These remained significant even when controlling for SES factors [43,72]. In the Dutch study, macrobiotic infants (4–18 months) were found to have slower gross motor and language development compared to omnivorous control infants [34].

3.3.2. Micronutrient components of animal source foods

A variety of studies of specific micronutrient deficiencies in relation to various aspects of cognitive function have been carried out. Iron deficiency has received the most attention with well-designed controlled intervention studies. Several intervention studies have involved supplementation with zinc and observational studies involving vitamin B_{12} and mental function have been carried out.

3.3.2a. Iron. Results of research in the past decade have demonstrated the significant and potentially permanent sequelae of iron deficiency on development of infants, toddlers, and school-age children; although the true long-term impact of childhood iron deficiency on cognitive function is not fully understood [78]. An in-depth review of studies on the effect of iron deficiency on cognitive development in children has recently been published by Grantham-McGregor and Ani [79].

There is clear and consistent evidence from a variety of studies that reveal a strong association between iron deficiency anemia and reduced mental and motor developmental indicators, in both infants and school-age children [78]. Such associations can be seen in mild cases of iron deficiency anemia. Abnormalities are most profound in older infants (18 to 24 months) with the highest prevalence of iron deficiency anemia and a time of rapid brain growth. In addition to lower mental test scores, studies with infants have shown behavioral disturbances including short attention span, increased fretfulness and fearfulness, and failure to respond to test stimuli [80]. These behaviors may, in part, account for the poor test performances in these infants [78]. Iron is an essential component in several general cellular functions in the brain as well as in the synthesis of a number of neurotransmitters and possibly myelin formation. This multiple role of iron could render the brain vulnerable to the effects of iron deficiency during the time of rapid cerebral growth in infancy [81].

As to the reversibility of the developmental deficits in children with iron therapy, the study results have been variable. In two unrelated double-blind randomized controlled studies in Chile [80] and Costa Rica [82], infants with iron deficiency anemia treated with iron for three months improved on their motor and mental developmental scores, but continued to score significantly lower than the non-anemic infants. More disturbing were findings during a follow-up study by Lozoff [82] in these same treated infants. When tested at five years of age, they continued to score lower on tests of mental and motor function when compared to their non-anemic peers, even though the latter group was no longer anemic [83]. This suggests that infants with iron deficiency anemia are at risk for long-term impaired development. On the other hand, in a randomized double-blind study of iron deficient anemic and non-anemic infants (12–18 months) that were treated with iron for four months, significant improvement in both mental and motor developmental scores were observed [84], thus indicating the reversibility of these motor and mental deficits with iron treatment.

Intervention studies of iron deficient anemic school-age children have also had mixed results. In a double-blind controlled study in which 9–12 year-old Indonesian children were treated with either iron therapy or placebo, there were no longer significant differences in concentration tasks or school achievement tasks between the those who were anemic and those who were not [85]. However, in a similar study in Thailand, iron deficient anemic children who were treated with iron supplements continued to score significantly lower on psychoeducational tests [86]. Different findings may reflect differences in ecological settings, school quality, and other unidentified risk factors that also impair educational achievement. The possibility of impaired cognitive performance at all stages of childhood, with long-lasting sequelae and diminished attention and school performance, present strong arguments for the prevention of iron deficiency in infants and children through addition of animal source foods to the diet and the control of parasites.

3.3.2b. Zinc. Zinc is prevalent in the brain, where it binds with proteins and thereby contributes to the structure and function of the brain [87]. There is recent but limited evidence that zinc deficiency plays a role in neuropsychologic function with decreased motor development and activity in the neonate as well as in the older infant [83]. In two controlled supplementation trials in infants and toddlers, one in India [88] and one in Guatemala [89], subjects were randomly assigned to zinc supplementation and placebo groups. Zinc supplemented Indian children exhibited higher physical activity such as running, and crawling. In the Guatemalan study, infants supplemented with zinc were more apt to sit, lie down and play than the control infants. Chinese school-age children (6–9 y) supplemented with zinc were found to function better on a group of neuropsychological tests than children not receiving zinc [90]. These relatively few recent studies in several age groups point to the need for research into the long-term developmental implications of the effects of mild to moderate zinc deficiency on activity and cognition in children. Nonetheless, zinc deficiency may be a serious public health problem adversely affecting the development, as well as the physical growth and health, of millions of children in both the developing and developed nations of the world [91].

3.3.2c. Vitamin B_{12}. Vitamin B_{12} intake and status in the development of infants and young children are of great concern, as a primary role of vitamin B_{12} in the body is in neurological function. A number of case reports and studies of strict vegetarian nursing mothers have been carried out in the U.S. and UK. All studies found low vitamin B_{12} levels in the breast milk and deficient vitamin B_{12} status in the infants who also exhibited neurobehavioral abnormalities, anemia and failure to thrive [70,92,93]. Infants are entirely dependent upon their mother's intake of B_{12} during pregnancy and postnatally they depend on B_{12} from mother's intake to be delivered via breastmilk to the infant. For this reason, infants of vegetarian mothers are particularly prone to deficiency. Early deficiency of vitamin B_{12} places a young infant at risk for future brain damage and retardation. Infants receiving breast milk deficient in vitamin B_{12} develop lethargy, irritability, failure to thrive, and poor brain growth leading to the loss of acquired motor milestones in infancy [94,95]. Children with chronic vitamin B_{12} deficiency develop decreased ability to concentrate, depression, problems with abstract thought, memory impairment, and confusion [96]. A subset of the Dutch cohort of children, now as adolescents, were evaluated to investigate the association between prolonged low vitamin B_{12} status and cognitive and psychomotor development [97]. It was shown that even moderate consumption of animal products, as recommended later in childhood, was not sufficient in restoring normal B_{12} status [98]. A significant association was observed between vitamin B_{12} status and performance on tests measuring fluid intelligence (i.e. reasoning, capacity to solve complex problems, and ability to learning), spatial ability, and short-term memory [97]. Furthermore, a study in Guatemala found that children with low plasma vitamin B_{12} had poorer short-term memory, reasoning, and perception compared to children with adequate B_{12} status [99]. The reversibility of neurological complications after treatment is dependent upon their duration and the type of neurological abnormality [100]. Vitamin B_{12} deficiency is a global problem, particularly in poor nations where little animal source food find their way into the diet, placing millions of infants at risk for adverse developmental outcomes [18]

3.4. Aspects of health

Animal source foods, particularly meat, contain key nutrients essential for red blood cell formation and for the maintenance and integrity of the body's defenses against infection, including the immune system.

3.4.1. Anemia

Nutritional anemias, with inadequate formation of red blood cells due to nutrient deficiencies, are very common throughout the world [101]. The most prevalent type of anemia is due to iron deficiency; however deficiencies in vitamin B_{12}, folate, pyroxidine, copper, vitamin A, and protein also contribute to anemia. Only anemia due to deficiencies in iron and vitamin B_{12} will be covered here. In industrialized nations, anemia is more prevalent among vegetarians than people consuming omnivorous diets [11,70,101]. Among Asian vegetarians living in England, a much higher incidence of iron deficiency anemia was observed compared to the general population. Infants and women of child-bearing age were at the highest risk, reaching 40% for iron deficiency among infants in their second year of life [102]. In the study of Dutch infants and children on macrobiotic diets cited earlier, both iron deficiency anemia and macrocytic anemia due to vitamin B_{12} deficiency was of much higher prevalence than in a group whose diets included meat and fish [29]. In developing countries, where animal source foods are consumed in modest amounts, or if at all, anemia associated with vitamin B_{12} deficiency appears to be fairly widespread [17–19].

3.4.1a. Iron. Iron deficiency anemia is among the most common nutritional disorder in the world, affecting between 40 and 50% of children under five years of age and over 50% of pregnant women in developing countries [1,11,101]. A primary function of iron, as a component of hemoglobin in red blood cells, is to carry oxygen. Importantly, iron is a component of myoglobin, which is a major striated muscle protein that is involved in physical work. Iron deficiency anemia is characterized by too few red blood cells (as measured by hematocrit or hemoglobin) which are poorly hemoglobinized and of small size (microcytosis) [11,13,81].

Iron deficiency anemia is associated with diminished cognitive function in children, extreme fatigue, anorexia, and decreased work and physical activity. Decreased work performance as a result of iron deficiency anemia deserves mention here because of the economic consequences. In a classic study by Viteri [103], a linear dose-response relationship was demonstrated between hemoglobin level and the Harvard step test of performance. The adverse effects appear to be mediated through a combination of decreased oxygen carrying capacity and the effect of iron deficiency on muscle function. Studies in the late 1970's on the effects of iron deficiency anemia on worker productivity in women working on a tree plantation in Sri Lanka [104], and men working on a rubber plantation in Indonesia [105], clearly demonstrated reduced work productivity in the anemic workers compared to those without anemia. Upon treatment with iron in both studies, a significant improvement in work productivity in the anemic workers was seen, with nearly a 50% increase in the Indonesian plantation workers. More recently, similar results were obtained in female Chinese cotton workers who were only mildly to moderately anemic [106].

These results have great economic implications for developing countries whose economic output is often based on physical labor. Yip estimates that if the average reduction in productivity is 20% in those who are anemic, the impact of iron deficiency anemia would equal a staggering total loss of 5–7% of the national economic output if 50% of the women and 20% of the mean were affected [11].

3.4.1b. Vitamin B_{12}. Macrocytic anemia associated with vitamin B_{12} deficiency tends to be a severe form of anemia with large immature red cells known as macrocytes. This form of anemia is being increasingly documented globally, among strict vegetarians in the industrialized nations and among poor people in developing countries who have little access to animal source foods on a household level. A high prevalence of low plasma B_{12} concentrations have been documented in women and children from Mexico, Guatemala, Venezuela, and Kenya [17,19–23]. Little or no meat intake was associated with anemia in some of these studies. A common practice in developing countries is to assume that the majority of anemic people have iron deficiency anemia and most anemia is routinely treated with iron. Vitamin B_{12} should be considered where macrocytic anemia is observed and where the diet is devoid of animal source foods. As little as 45–60 g of meat per day or a cup of milk or other related dairy food may be protective [5,15].

3.4.2. Resistance to infection and immune function

The synergistic relationships between PEM and infection and immune function have been extensively studied [105,107,108]. However, in the past two decades micronutrient deficiencies have also been seriously implicated in reducing the body's defenses to combat infection [109]. Micronutrient deficiencies, single or multiple, or in combination with PEM, most often result in a reduction of the body's defenses against infection and of facets of the immune system. Both PEM and micronutrient malnutrition increases the duration, severity, and complication rates of common infectious diseases. Infection per se acutely lowers levels of micronutrients such as iron, zinc, and vitamins A and C, sequestering these off to the formation of non-specific anti-microbial defenses such as acute phase reactants or are secreted and lost to the body [22,108]. Depletion of these nutrients via vomiting, diarrhea, perspiration, and/or anorexia due to infection or iron and zinc deficiencies themselves, contribute to the losses. Intestinal parasitic infections, particularly with *Giardia*, *Amoeba Histolytica, Ascaris,* and Hookworm not only cause blood loss but can cause malabsorption, particularly of the fat soluble micronutrients [105].

The integrity of the skin, mucous membranes, and epithelial coverings of the body form a first line of defense against the invasion of microorganisms. Zinc, vitamins A and C, and protein are critical in maintaining these barriers. The epithelial coverings of the eyes, respiratory system, gastrointestinal tract, and bladder, are comprised of cells with special structure and function. These cells secrete mucous with antibacterial substances or develop ciliated cells as in the respiratory tract which "sweep out" debris and microorganisms.

Immune responses can be divided into humoral and cell-mediated responses. Humoral immunity involves interactions of B cells with antigen and their subsequent proliferation and differentiation into antibody-secreting plasma cells. Antibodies then bind to antigen and neutralize it, facilitating its elimination. In contract, effector T cells (T helper cells and cytotoxic T lymphocytes) generated in response to antigen are responsible for cell-mediated immunity (CMI). Cytokines secreted by T helper cells can activate various phagocytic cells, enabling them to kill microorganisms more effectively. This type of CMI is important in host defense against intracellular bacteria and protozoa. Cytotoxic T lymphocytes participate in CMI reactions by killing altered self-cells, such as virus-infected and tumor cells.

The secretory antibody system, in which antibodies are secreted onto the mucosal surfaces to combat invading microorganisms, is impaired in vitamin A deficiency and PEM. This secretory antibody system plays an important anti-infection role in the respiratory and gastrointestinal tracts. Zinc is involved in walling off infection and wound healing, important to the maintenance of anatomical barriers against microorganism invasion [105,108,109]. Associations between zinc deficiency and increased diarrheal and respiratory morbidity has been observed [110,111]. A reduction in the severity and duration of diarrhea and acute respiratory infections can be achieved through zinc supplementation [67,112–114]. Recently, the role that vitamin B_{12} plays in the immune system was demonstrated in a study involving the administration of a pneumococcal polysaccharide vaccine to patients, although elderly, with vitamin B_{12} deficiency [115]. A significantly lower antibody response to the pneumococcal vaccine was observed in the patients with low plasma vitamin B_{12} concentrations compared to those with normal plasma concentrations of the vitamin.

The CMI system, which derives from the thymus and lymphoid tissue of the body, is sensitive, not only to PEM but iron, zinc and vitamins A and B_{12} deficiencies [105,107,109].

This system (CMI) is the first line of defense against viruses including HIV, tuberculosis and related acid-fast infections and certain bacterial and fungal infections. Recovery of the depressed CMI system occurs readily with nutritional treatment [107].

There is recent evidence that vitamin A and zinc deficiencies increase the chances of being infected with malaria [116]. Also the chances of vertical HIV transmission between mother and infant has been noted to be increased in vitamin A deficiency [117]. In regard to other diseases, supplementation with zinc or vitamin A significantly reduced morbidity, but particularly mortality from diarrheal disease, acute respiratory infection and decreased the complications and mortality from measles in various parts of the world [113,117–119].

Iron deficiency also affects white blood cells that play a role in combating infection. The ability of granulocytic white blood cells to migrate toward invading organisms (chemotaxis), to ingest microorganisms (phagocytosis) and to kill microorganisms (killing function) are impaired in iron deficiency [105,108]. Anemic children in India were found to have impaired neutrophil bactericidal activity and CMI, which was reversible upon treatment [120].

Thus micronutrients such as iron, zinc, vitamins A and B_{12} play a key role in maintaining the integrity of the body's defenses against infection. This synergism between infection and malnutrition is the leading cause of death in young children under five years of age in developing countries worldwide and leaves the survivors stunted and underweight.

4. Issues and policies

Animal source foods, particularly meat and milk, hold great promise for improving diets of poor quality in developing countries. Such foods offer a sustainable food-based approach to micronutrient deficiencies, are energy-dense and offer an excellent source of high-quality protein. While fortification and use of supplements have a role to play in preventing and combating micronutrient deficiencies in some situations, micronutrient deficiencies are often multiple and coupled with macronutrient deficiencies such as inadequate quantities of food, in which supplementation and fortification programs do not address. Thus inclusion of animal source foods, even in modest amounts, in the diet can help prevent multiple deficiencies together with plant-based foods.

Poverty is the reason given most often for the minimal amounts or absence of animal source foods in the diet. Nonetheless, the demand for animal foods is growing in the developing world. Meat for the most part is held in high regard and valued for its prestige, ceremonial and "health value". It is through increased animal production by small-holder farmers that holds the greatest promise, rather than turning to large commercial schemes for meat production, to improve the diet of poor rural populations. In developing countries, most meat production takes place on small farms of 1 to 2.5 acres, with two to five heads of livestock per household. Productivity is low for a number of reasons, such as poor animal feed, little or no animal health care due to limited or no extension services, and small land holdings for grazing or foliage production. Much of the meat and milk are sold for cash rather

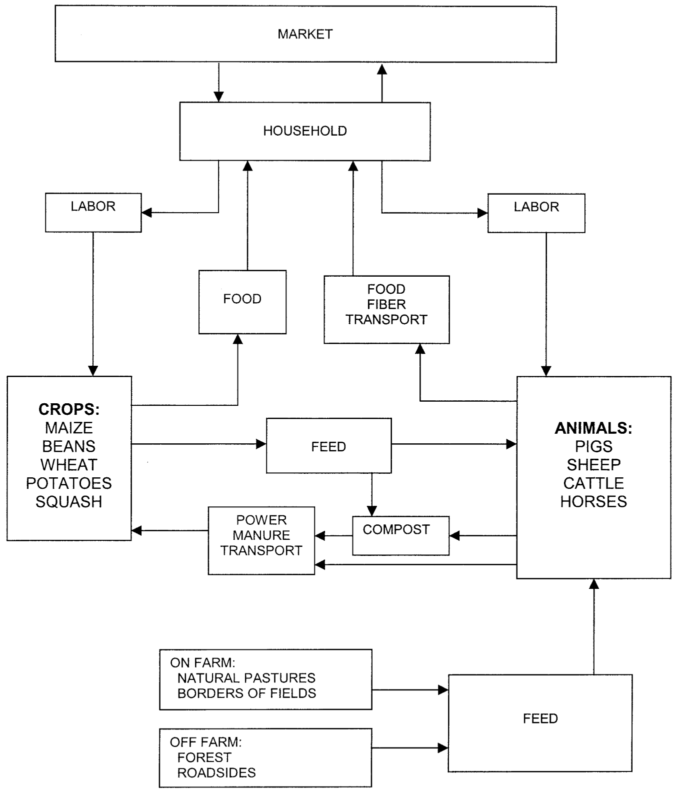

Fig. 3. Example of a farming system in the Central American highlands, including permanent cropping and a high level of integration of crops and animals [102].

than used for household consumption. The main annual output of meat and milk in Africa was estimated to be one tenth of that produced in Europe [5]. Increasing the productivity of each animal to produce more meat, milk or eggs is estimated to be less costly than doubling the number of animals per household [5].

With the conflicting pressures on land use worldwide, many view animal production as a relatively inefficient means of producing food. Animals are often seen as direct competitors with humans for food staples such as corn and grains. However, less than 1% of animals useful to humans subsist on food that is edible to humans. Animals increase the efficiency of the total farming system by consuming plant materials that have no food value to humans such as grasses, tree leaves, household food wastes, and crop residues and byproducts. Animals may also contribute to the farm economy by providing traction for plowing and transporting products to market, and using their wastes in the form of manure to deliver nutrients to plant crops. The opportunities to produce food on land that otherwise is difficult to crop, such as forest, wetland, mountainous, or desert areas is provided by animals. Although livestock production may contribute a variable amount to the total farm income, its contribution to the nutrition of the family can be potentially significant. An example of a small-holder mixed farming scheme is presented in **Figure 3.** Where land is limited, zero grazing can be practiced [121].

4.1. Suggested livestock production based approaches

Livestock and aquaculture enterprises are useful components of a holistic approach to food production and food security. Inclusion of animals in agricultural production systems increases the overall efficiency of production and can be ecologically sound. As outlined above, animal source foods derived from these systems can contribute greatly to alleviating nutrient deficiencies of adults and children. However, development of animal production systems has not received the attention deserved in micronutrient undernutrition. Perhaps this is due to the increasing attention paid to the long-term consequences of overnutrition, often blamed on high consumption of animal products, on human health in industrialized countries, which is now appearing in the media in developing countries. An additional bias exists for some that perceive that livestock compete with humans for human-edible grains. However, as discussed previously, ruminants in particular largely utilize high-fiber plant materials and crop wastes that are not edible to humans. Even the swine and poultry found roaming many rural areas of the developing world are primarily feeding on household food wastes. Many opportunities exist for increasing utilization of animal production as part of the total farm or household economy.

The major challenge is to develop integrated farming systems that optimize the production of animal products in small-scale, low-input, and environmentally sustainable systems that are more likely to enhance the diet of the resource-poor. Models of diversified cropping systems, including integrated crop-livestock and/or aquaculture systems need to be identified and propagated. For example, a common Asian or Latin American integrated system of aquaculture and livestock production may be adapted in other areas of the world. This system utilizes a swine unit built with slatted floors and situated over a carp or duck pond. Feed resources include the undigested grains from the pig fecal matter and grass of the pond banks. In this way, a farmer may have pork, fish, and duck products from a small unit of land, as well as nitrogen-rich pond effluent for fertilization of plant crops. With the increasing popularity of tilapia farming in Africa, perhaps opportunities exist to increase the integration of these operations with other animal and crop production systems.

4.1.1. Alternative "exotic" animal crops

Livestock usually promoted in international livestock development projects are those common in the West, such as cattle, sheep, and swine. However, a variety of other "exotic" or "mini-livestock" animal species, many of which are already domesticated, can be utilized for food, fiber, and traction; these alternative species should be considered when building new livestock projects. **Table 4** lists many animals, domesticated and wild, which can provide meat to the diet. Some of these species are considered "micro-livestock" in that they are inherently small species, e.g. rabbits and chickens [122]. Other micro-livestock are breeds of cattle, sheep, goats, and pigs that are half the size of most common breeds. Some have proposed that a few animals of these species/breeds can be exploited near households and managed as a food source even if the feed conversion efficiency of the "micro-breeds" is somewhat lower than the standard breeds and the animals require no special feed [123]. Additional non-mammalian sources of protein and nutrients are also available, including

Table 4
"Exotic" animals and some fowl used for meat in certain areas of the world (122)

Name	Habitat
Agouti	Gulf of West Africa
Alpaca	South America Andes Mountains
Angora goat	U.S., South Africa, Namibia
Anoas[1]	Southeast Asia
Babirusa[2]	Southeast Asia
Bateng	Southeast Asia
Bateng-cattle hybrids	Southeast Asia (Indonesia, Malayasia)
Bearded pig[2]	Southeast Asia
Bison	U.S., Europe
Buffalo	Egypt, Italy, Former Soviet Union, China, Southeast Asia
Camel	Africa, Asia
Cape buffalo	Central, Eastern, and Southern Africa
Carabao (swamp buffalo)	Southeast Asia
Capybara	South America, Upper Amazon basin
Caribou	Arctic region U.S., Europe, Asia
Deer	
White-tailed, black-tailed, and mule deer	Canada, U.S.
Axis	U.S.
Roe and red	Europe, Former Soviet Union
Reindeer	Canada, Scandinavia, Former Soviet Union
Duck (>700 types)	All over
Eland	Central, Eastern, and Southern Africa
Elephant	Central, Eastern, and Southern Africa
Elk	Canada, U.S.
Gaur	Southeast Asia
Giraffe	Central, Eastern, and Southern Africa
Grant's gazelle	Central, Eastern, and Southern Africa
Guinea fowl	South America, Africa
Guinea pig	Ecuador, Peru, Chile, Bolivia
Horse	All over
Impala (antelope)	Central, Eastern, Southern Africa
Kangaroo	Australia
Kongoni	Central, Eastern, and Southern Africa
Kouprey	Indo-China
Llama	South America Andes Mountains
Moose	U.S., Canada
Oryx	Central, Eastern, and Southern Africa
Pigeon	Europe, Africa
Pronghorn antelope	U.S.
Rabbit	All over
Tamaran[1]	Southeast Asia
Thomson's gazelle	Central, Eastern, and Southern Africa
Wildebeest	Central, Eastern, and Southern Africa
Yak	Himalaya Mountains
Yak-cattle hybrids	Himalaya Mountains
Mithan	Southeast Asia
Sulawesiwarty pig	Southeast Asia
Pygmy hog	Southeast Asia

[1] Related to buffalo.
[2] Related to pig.

reptiles and insects; local indigenous knowledge is usually the best resource to identify these foraged food resources to exploit.

5. Conclusions

Most malnutrition takes the form of mild to moderate PEM in combination with multiple micronutrient deficiencies. These result in such adverse outcomes as stunting, sub-optimal cognitive development, immunodeficiency and anemia in children, and poor pregnancy outcome, anemia and poor milk quality during lactation. Review of the literature presented here has shown that animal source foods have a positive impact on the quality and micronutrient enhancement of the diet of women and children, and can prevent or ameliorate many micronutrient deficiencies. These deficiencies can impose a heavy individual and societal burden. The task remains to improve access to and utilization of animal source foods by poor families. An apt quote is "look to the farm and not to the pharmacy" [5].

Probably the most relevant models of appropriate small livestock development utilize grassroots, community-based approaches. Introduced technology needs to be appropriate for the circumstances. Several NGO's already have successful programs that are not only introducing livestock, but appropriate technologies and education on animal husbandry to individuals and communities. These programs would be greatly enhanced with the addition of appropriate education emphasizing nutrition and the value of different foods in dietary improvement.

Investing in diet improvement for children and women of reproductive age would maximize the chances of improving pregnancy outcome, growth, and cognitive development and school performance of children. Such a capital investment would promote social and economic development of a community and a nation. Reduction of infection and parasites most go hand in hand with dietary quality improvement if the benefits are not to be canceled out.

Acknowledgments

The authors wish to thank the World Bank for their support.

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