CONTRIBUTION OF ANIMAL SOURCE FOODS

IN IMPROVING DIET QUALITY FOR CHILDREN

IN THE DEVELOPING WORLD

Charlotte Neumann, M.D., M.P.H.
Diane M. Harris, Ph.D.
University of California, Los Angeles

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Mild to moderate protein-energy malnutrition (PEM) is prevalent throughout the developing world. Children are particularly susceptible with malnutrition contributing significantly to adverse outcomes such as 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 and minerals, trace metals, and vitamins necessary to meet requirements, is as significant as diet quantity alone. The effects of inadequate intake are most pronounced during early childhood, adolescence, and during pregnancy and lactation in women; thus children and women of reproductive age are the most vulnerable groups. 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. The main micronutrients offered in abundant and readily available and absorbable form from animal products are iron, zinc, vitamin B_{12} and retinol. Other nutrients such as thiamin, calcium, vitamin B_6, vitamin A and milk, riboflavin are available from certain types of meat and/or dairy products. A number of studies have investigated the association of intake of animal source foods with growth and development, (physical and mental), morbidity, including nutritional anemia and immune function, and pregnancy outcome and lactating in women. The most comprehensive of these studies to date has been the three-country Human Nutritional Collaborative Research Support Program, which investigated diet and growth and development outcomes in children and pregnancy outcomes in women. These studies show that intake of animal source products positively predicted both physical and developmental outcomes in children, illustrating the potential utility of these foods in the diet. This review covers information derived from field studies, both observational and interventions, not only of animal foods per se such as meat and milk, but also the major constituent micronutrients, iron, zinc, vitamins B_{12} and A and their role on child growth, cognitive development and health. How to increase the availability, accessibility, and utilization of these foods to resource poor people in developing countries is a major challenge. Policy suggestions include enhancing the programs of non-governmental organizations and agricultural extension agencies, promoting the use of alternative animal crops, investigating new technologies to enhance production and processing, and developing the infrastructure for increasing credit and marketing opportunities to smallholders.

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 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 as high as 40% to 60% of children in some Asian, African, and Latin American countries, or about 226 million children under age 5 (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 overall food intake, but also to inadequate intake of high quality protein and vital minerals and vitamins (micronutrients), and sometimes essential fatty acids. Where the quantity of total food intake is deficient, 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, the nutrients needed for fetal growth and milk production increase a woman's nutrient requirements. Therefore, women of reproductive age, the fetus, and young children are the groups most vulnerable for 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 women and children (3,6). Decreased cognitive function and diminished learning ability affects 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 the usual diet is one approach to improve children's diets. 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 consequences when micronutrients are deficient in the diet in developing countries. The micronutrients to be covered will be iron, zinc, vitamin B_{12} and limited mention of vitamin A 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 such as physical growth, cognitive development, and health will be examined. Pregnant women are included as fetal nutrition is a continuum with infant and child nutrition and health. Potential policy implications and issues, and possible approaches are raised to enhance the access to, and utilization of animal-source foods by households are discussed.

OVERVIEW - CONTRIBUTION OF 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 such as minerals, trace metals and vitamins 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 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, iodine, zinc, calcium, and vitamins A and B_{12} and of late, selenium. Although, marked deficiencies of these, particularly iodine, iron, and vitamin A carry the greatest societal burdens, economically and socially, only those most relevant to animal source foods will be discussed.

Animal-source foods are an excellent source of high quality and readily digested protein and are rich in energy (6,8). In fact, 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 a calorically compact and an efficient source of micronutrients. The main micronutrients offered in abundant and bio-available form by animal products are calcium and B_{12} from milk, and iron, zinc, and vitamin A from meat and offal (8,9). Animal products are the almost exclusive sources of dietary vitamin B_{12}, and a good source of preformed vitamin A, particularly in milk. The zinc content of 100 grams of beef is more than twice that of maize and beans, and it is up to 10 times as absorbable. 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 over 1.7-2.0 kilograms 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 grams or 2 ounces of meat per day. Similarly , milk products are an important source of calcium; it is difficult for a child to even approach the average calcium requirements (estimated at 345 mg/d) on a cereal-based diet (9). Additional nutrients that are supplied by meat, poultry, and fish in abundant amounts are taurine, selenium, and particular 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. Although some plant foods are relatively high in iron, zinc, or calcium, e.g. spinach and legumes, the micronutrients are poorly absorbed. (See Table 1). These minerals in leafy plants are of low bioavailability due to the high oxalate content which form insoluble compounds and reduces the mineral absorbability through the intestine. High fiber content and phytates found mainly in uncooked or unfermented cereal grains, nuts, and seeds, can also form insoluble complexes with iron, zinc, or calcium; thus diminishing the availability of these nutrients. Tannins, which are polycyclic amines, found in high levels in tea leaves, coffee, red wine, spinach and rhubarb, also inhibit absorption of iron, zinc, and calcium (9-11). For this reason, milk added to traditional tea beverages does not deliver substantial additional calcium to the consumer. Tea and coffee taken with meals can impede iron and zinc absorption. In contrast, meat contains iron and zinc bound to heme protein. This form of iron is readily incorporated into blood cells of the body, and its presence in a recipe enhances the absorption of zinc and iron from cereal and other plant sources (11,12). [See Figures 1 and 2 (6)]

It must be noted, however, that the levels and bioavailability of micronutrients are not equivalent in both meat and milk. Table 2 lists common foods and the levels of important nutrients in these foods, both plant-based and derived from animals. Note that meat is particularly high in protein, iron, zinc, and vitamins of the B group, particularly vitamin B_{12}, while milk is mainly high in calcium and vitamin B_{12} and moderately high in vitamin A. Milk, if taken with a meat, reduces the bioavailability of iron and zinc because of the high calcium and casein content which form insoluble complexes with iron and zinc (11,12).

Despite the high nutritional value of animal-source foods, the majority of people in developing countries eat little or none of these foods. Poverty, coupled with poor availability and accessibility to animals, can preclude inclusion of these in the household diet. When animal products are priced out of reach of poor households, people are forced to rely more heavily on less expensive staple cereal grains, legumes or starchy roots. The limitations of these food stuffs, such as low levels of individual micronutrients and/or the presence of inhibitory compounds, become important determinants of a person's nutritional status.

Socio-cultural or religious prohibitions may forbid intake of some or all animal foods, particularly by women and/or young children. Nonetheless, a widely held perception in poor nations is that animal source foods are nutritious and prestigious, but often prohibitively expensive. Moreover, livestock ownership is viewed as a source of wealth and security but not necessarily for household consumption. Utilization may be limited because of lack of knowledge about preparation and preservation of these animal source foods.

Specific Micronutrients Contained in Animal Source Foods

3

Many of the apparent beneficial effects of animal source foods on human health and function are mediated through the micronutrients contained in these foods, particularly meat and milk from a variety of animals. These are in addition to high quality protein and the high energy density. Iron, zinc, vitamin B_{12}, and preformed vitamin A are the principal micronutrients found in animal products in bioavailable form (9). These micronutrients are associated with the positive effects of animal source foods in the diet on pregnancy outcome and lactation, fetal growth, child growth, cognitive function and learning and aspects of health, specifically anemia and resistance to infection. A brief description of specific micronutrients covered in this review, follows below.

Iron Deficiency

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 children and women and 25% of men are iron deficient in poor countries. Most of the body's iron is found in circulating hemoglobin and in muscle as myoglobin (13,14). Iron compounds can be classified as either functional, serving metabolic or enzymatic functions or as storage iron or transport iron. Iron is part of multiple metallo-enzymes and neurotransmitters. 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. Non iron-deficient persons absorb 5-10% of dietary iron while those who are iron deficient absorb 10-20% (13). The recommended daily intake for adults is approximately 10 mg for men, 15 mg for women, 30 mg for pregnant women and 16 mg for children (14).

There are many well established biochemical tests for assessing iron status, the optimal combination differs for clinical and epidemiological assessment, which is also constrained by cost in developing countries (14). Serum ferritin is the key indicator of iron stores and is considered to be the most important measure of iron deficiency, but is of limited value in populations where infection prevalence and liver disease are widespread. Hemoglobin and hematocrit levels, although non-specific, may be used to screen for iron deficiency anemia using relatively inexpensive apparatus that can be used by health workers in the field. Iron deficiency can be classified as mild, or moderate degrees of depleted iron stores, without anemia, and severe, with marked depletion of iron stores with anemia. 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 (14).

The functional outcomes of iron deficiency encompass a broad spectrum of conditions. These include anemia and if severe, are accompanied by increased childhood mortality and maternal mortality (15). Symtoms of mild and moderate iron deficiency, often so insidious that they go undetected, can impair work capacity and productivity, infant/child behavior and cognitive development.

Zinc Deficiency

Increasing attention is being paid to the global prevalence of mild moderate zinc deficiency in developing countries as well as in the disadvantaged groups in industrialized countries. Although not universally recognized as a major global micronutrient deficiency compared to iron, iodine, and vitamin A, zinc deficiency is being increasingly recognized as a health problem even in mild moderate forms (16). 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. The distribution of zinc in the body is ubiquitous and participates in many basic functions. 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, there are sufficient parameters to suspect the presence of zinc deficiency; plasma zinc levels and hair zinc are useful in this regard (16).

Bioavailable zinc is most efficiently supplied by meat, fish and seafood. Plant foods, where the phytate content has been reduced through germination, etc., and mixed with heme protein from meat can furnish some zinc in the diet. 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 (16).

The main reason for zinc deficiency, particularly in the poor nations of the world, is the low intake of animal source foods, particularly meat, fowl, and fish. Reliance on staples, particularly starchy roots and tubers, 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. Adding animal products with heme protein to cereals would enhance the zinc absorption (11). Chronic and severe infections erode zinc status. Because of the widespread effects of zinc deficiency on morbidity and mortality and growth and development, policy makers must pay much more attention to improvement in diet quality through food-based or supplement approaches where needed and feasible. Increasing the availability of animal source food to families can greatly improve zinc nutrition.

Vitamin A

It is estimated that some 40 million children suffer from vitamin A deficiency and about 35,000 infants and young children are blinded annually due to vitamin A deficiency (17). Furthermore, it has been noted that 70% of such children die within one year due to mainly to infection such as pneumonia, diarrhea, and sepsis. The societal cost of vitamin A deficiency is high with blindness and high infant and child mortality and comprises a major public health problem (1,17,18).

Vitamin A plays a critical role in maintaining the structure and function of the cornea and lens and conjunctivae and produces the necessary components for night vision. Vitamin A plays a major role in resistance to infection through multiple functions; mechanical barriers against invasion of pathogens and maintaining a role in immunity. A number of recent studies have reported dramatic

decreases in child mortality in a variety of developing countries and in a number of continents with the administration of high-dose vitamin A capsules to young children, child mortality has decreased from 30 to 54% in various field trials (18).

Animal source foods, especially milk and organ meats are excellent sources of pre-formed vitamin A (retinol). Although dark green leafy vegetables and yellow-orange fruits and vegetables are rich source of beta-carotene, a precursor of retinol. However, the conversion of these carotenoids to retinol can be impeded by poor liver function and other conditions (3,20).

Vitamin B$_{12}$

The risk of vitamin B$_{12}$ deficiency is high in vegetarians, particularly in extreme forms such as macrobiotic diets, which contain little or no foods of animal origin (21). Some fermented foods may contain vitamin B$_{12}$ but animal source foods are nearly the sole source of vitamin B$_{12}$ for humans. Vitamin B$_{12}$ plasma levels in vegetarians are generally far below those of non-vegetarians (21). In addition to low dietary intake, vitamin B$_{12}$ can be caused by poor intestinal absorption secondary to gastric atrophy as in the elderly or absence of intrinsic factor seen in pernicious anemia. In developing countries, due to a wide variety of infections and intestinal parasites in all ages, malabsorption is an important contributing factor (22). The hematologic system, the nervous system, immune function, and pregnancy outcome are all adversely affected by vitamin B$_{12}$ deficiency (25,27). Vitamin B$_{12}$ is found in eggs, dairy products, meats (especially liver), fish, poultry, and seafoods, especially bivalves. The prevalence of B$_{12}$ deficiencies in developing countries is not well documented, but is probably widespread where consumption of animal products is low or absent.

Infants are entirely reliant on their mother's intake of B$_{12}$ during pregnancy. After birth they depend on B$_{12}$ from mother's intake to be delivered via breastmilk to the infant. Vitamin B$_{12}$ in breast milk of B$_{12}$ deficient mothers is very low and cannot supply her infants B$_{12}$ requirements. For this reason, infants of vegetarian mothers are particularly prone to deficiency (23,24). Children born with low vitamin B$_{12}$ stores show developmental problems within the first four to eight months of life (26) and are at risk for damage to the brain and spinal cord.

There is a need to study the global prevalence of vitamin B$_{12}$ deficiency in developing countries particularly on child-bearing women and young children because of the serious health and neurologic consequences for both women and infants (27).

FUNCTIONAL OUTCOMES RELATED TO INTAKE OF ANIMAL SOURCE FOODS AND CONSTITUENT MICRONUTRIENTS

The following section reviews the literature examining the relationship of diet quality, particularly inclusion of animal-source foods in women and children in relation to a number of functional areas in women and children. The bulk of evidence comes from naturalistic observational studies which statistically control for a number of confounding and intervening variables. The relationships are statistically significant but not necessarily causative. Because of expense and complexity, controlled intervention studies which can show a causative effect, are much fewer. Many more controlled intervention studies have been performed using single or multiple micronutrients (tablets, capsules, etc..), rather than using animal source foods. Administering micronutrient supplements is far less complicated than having to prepare, deliver, and feed large groups of children.

Evidence is presented where animal protein or food are the independent variable or where several key constituent micro-nutrients of animal products, iron, zinc, vitamin B_{12} and A are the independent variables considered. The functional areas of interest are pregnancy outcome, growth, and cognitive development, aspects of health, particularly immune function and morbidity. Although the outcomes are artificially categorized, these functions are interactive and even synergistic; for example, children exhibiting inadequate growth may have impaired cognitive function and acquired immunodeficiency with increased infectious diseases all of which further impairs learning. For an overview of the relationship between animal source foods, micronutrients, and human function, please see table 3.

Evidence from Observational Field Studies

The beneficial role of animal source foods in the diets of pregnant women and young children was highlighted by the findings of the Human Nutrition Collaborative Research Support Program (NCRSP) which studied the functional outcomes of mild-moderate malnutrition (28). 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, growth, cognitive development school performance, and pregnancy outcome, morbidity and immune function were studied. Also a number of household and environmental characteristics were followed longitudinally for one to two years with some longer-term follow-ups. This design allowed observation of growth and developmental patterns over time, and a range of childhood stages, as cohorts of children of different age groups were followed concurrently. Women were observed before, during, and after a pregnancy, and their newborns for at least the first 6 months of life (29).

Detailed quantitative dietary intake information collected monthly, in each of the three locations, revealed intakes to be generally very low in animal source products (8-12% of kilocalories of energy from animal products), with the lowest intakes in Kenya. 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, vitamins B_{12} and A (30). 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 zinc, iron, and calcium. Low milk intake leading to low calcium intake was found in Kenyan children but not for Mexican children because 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 in kilocalories was from animal products. However, the high diarrhea prevalence canceled out the advantages of a higher quality diet (28).

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 (23) and Mexico (22). (31). 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. Because socioeconomic status (SES) correlated so highly with intake of animal products, SES was controlled for in all the analyses as well as the functional outcome, particularly cognitive outcomes.

Pregnancy and Lactation and Postnatal Growth

Maternal intake of animal source foods during pregnancy was positively associated with infant growth beginning *in utero*. In Kenya, overall maternal energy intake and intake of animal protein during pregnancy were major factors and predicted pregnancy weight gain, birth weight and birth length (29,33). In the Egyptian sample, maternal intake of animal products in the second trimester during pregnancy predicted gestational age as well (34). A number of studies of micronutrient deficiencies and pregnancy outcome and lactation and postnatal growth are presented here.

Iron: The extent to which maternal iron deficiency affects maternal and neonatal health in unclear (15,35). There is fairly recent evidence that iron deficiency in pregnancy is associated with prematurity and 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. Severe iron deficiency is associated with increased maternal mortality especially when associated with hemorrhage and sepsis at child birth. Hemorrhage superimposed on severe anemia can precipitate heart failure. Indeed, 20% of all maternal deaths may be attributed to iron deficiency anemia in the pregnant mother (35).

All of the above conditions could also be associated with other confounding factors such as general protein-energy malnutrition. To evaluate the validity of the above relationships, intervention studies with control for possible confounders, are still needed to establish causality.

Zinc: Observational studies in humans show strong associations between maternal zinc deficiency and

fetal growth and development, delivery, and the post natal periods.

Maternal zinc deficiency based on plasma, zinc, and hair levels and dietary assessment is strongly associated with poor fetal growth and Intrauterine growth retardation (IUGR) and increased risk for amniotic infection, sepsis, and maternal mortality. Over thirty observation studies and about ten supplementation studies have been carried out in pregnant women (36). Studies of pregnant women in a number of African countries and in the UK and USA, have shown that better intake of bioavailable zinc is positively associated with birth length and weight when controlling for gestational age (36-38). The evidence comes from observational studies such as NCRSP, Egypt, Kenya and from intervention studies (28,29). Also longer gestational age, by as much as two weeks was seen and a 32% reduction in the birth of pre-term infants. High ratio of labor and delivery complications with desultory labor has been noted in zinc deficient women.

The linkages of maternal zinc deficiency during pregnancy to problems of the newborn and young infant born to a zinc depleted or deficient mother have been examined. The ability to mobilize vitamin A in the newborn has been shown to be decreased (38). Zinc content of breast milk, although initially high, even in zinc deficient mothers, may decline more rapidly and not meet the requirements for optimal post-natal growth. Complementary feedings are often zinc deficient. More controlled intervention studies with zinc containing food based approaches of supplement studies are needed.

Vitamin B_{12}: Low intakes of animal protein and vitamin B_{12} in women and children were documented in the NCRSP studies with strong correlations between these. Low plasma vitamin B_{12} levels were common in the Mexican nonpregnant, nonlactating, pregnant, and lactating women. Vitamin B_{12} was lower in the plasma and milk of anemic lactating women than in plasma and milk of non-anemic lactating women, and was classified as deficient in 62% of breast milk samples (25). Similarly, breast milk from women of the Kenyan cohort contained very low levels of vitamin B_{12} comparable to those of poor Indian women on strict vegetarian diets (24). Positive and statistically significant correlations were found between maternal meat intake and a level of vitamin B_{12} in breast milk (23,24). Maternal vitamin B_{12} intake during pregnancy correlated positively with infant birth weight and length in the Kenya sample (23).

A number of case reports and studies of strict vegetarian nursing mothers have been carried out in the USA 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 (39-41). 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 (39-41). Early deficiency of vitamin B_{12} places a young infant at risk for future brain damage and retardation - devastating consequences.

Early growth faltering: Growth failure was observed as early as the third month of life, and was seen in all three NCRSP projects, earlier than generally recognized. Both length and weight were affected, but length to a greater extent, particularly in Kenya. In Kenya, rate of growth of infants, 0 to 6 months of age for both weight and length were 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 (29,33). In Egypt, the sole dietary variables predicting infant growth from 0 to 6 months was maternal consumption of animal foods (34).

Child Growth

Typical weaning diets in children in developing countries 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. Also the diets are very low in caloric density. To obtain adequate intake, a child would have to greatly exceed its gastric capacity volume-wise. Deficiencies of both iron and zinc can cause profound anorexia, as does the presence of infection. Even modest amounts of animal source foods (2 oz/day) incorporated into weaning diets can increase the energy density through its fat content and supplies 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 be improved as zinc and iron intake increase (33).

In toddlers 18 to 30 months of age as well as school-age children, diet quality and quantity predict growth rates. For the 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, both height and weight (33,42,43). Diet quality or inclusion of meat in the diet was also an important predictor of growth in Mexico where children with a higher consumption of animal source foods was a major predictor of length at 30 months of age.

Similar findings on the positive association of intake of animal-product foods and linear growth were obtained in a study of Peruvian toddlers 12 to 15 months of age (44). Complementary foods, consisting of animal-product foods, and breast milk were all found to promote toddlers' linear growth. When animal-product food intake was low, then 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-product foods in children with low intakes of complementary foods. A number of studies of the relationship of height to intake of animal protein (meat, fish) showed positive and statistically significant relationships to height in New Guinea (45) and in South and Central America (16,43).

Animal Milk Consumption and Growth

In addition to human milk, the role of milk consumption, both goat and cow, have been linked to improvement in physical growth of children. Non-governmental organizations (NGO's) working with the dairy cattle and goats such as Heifer Project International, Farm Africa, and an ILRI study in Ethiopia (46) have presented data that all show that increased milk consumption and child growth in households raising livestock. The 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) all document that cow's milk consumption by infants and young children promotes physical growth, particularly in length or height. The main micronutrients contained in milk and dairy products relevant to growth are calcium phosphorus, vitamin B_{12} plus the milk protein which is of excellent biologic value.

Studies in such disparate locations as China, Jamaica, Mexico, Nicaragua, and Brazil found that children who consumed cow's milk or other dairy products obtained significantly greater lengths or heights (48-51). In the Brazil study, the above findings remained so after controlling for parental education, income and other factors (51).

In school-age children, where milk and other dairy product is low, the addition of milk to the diet was found to increase linear growth and reduce stunting. These results were observed in Malaysia and in Japan using school feeding programs. In both studies, rapid growth in height was noted (52,53). Only one study, unpublished, reported improved child growth in children supplemented with goat's milk. This was part of and evaluation of a Heifer Project International program.

In the NCRSP studies, factor analyses were carried out to identify combinations or food patterns which were related to linear growth or height in 6 to 9 year-old children. Both in Mexico and Kenya, statistically significant positive associations were seen with the food pattern which included milk, fat, and animal protein. The food pattern negatively associated with growth in height were maize and millet in Kenya and maize tortillas in Mexico (33,43).

Animal Ownership and Child Growth

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 (47,55).

An additional group of recent studies, which controlled for family income and wealth in the analyses, present even more convincing evidence. These studies were reported from a variety of countries - Brazil, Ecuador, Uganda, and Ethiopia (56-59). Two important caveats or warnings must be included here. Promoting the use of animal milk for children under 18 months of age, it must not replace human milk and especially exclusive breast-feeding for infants 4 to 6 months of age. In areas of poverty and poor sanitation and water quality, the risk of death from marasmas and diarrhea are high. The recommendations for use of non-human milk for poor mothers infected with HIV are being refined by WHO (61); but the current recommendation is to consider the use of animal milk, if readily available, for infants 6 months and over as the risk of breast milk transmission rises steeply at this age (60). Another important caveat is the improvement of water safety, household and compound sanitation with the introduction of more animals into household of small-holder farmers. The risk of increase diarrheal disease and zoozoses have been seen (8).

Specific Micronutrients and Child Growth

Zinc: Zinc deficiency has been implicated in both animal and human studies in poor physical growth, linear, weight, and body fat. Numerous supplement trials in pre-school and school age children support this, particularly in the above relationship in zinc deficient populations. Confounding factors are the marked anorexia, and the increased infection associated with zinc deficiency which can erode nutritional status. Infection per se, decreases zinc stores in the body further aggravates the situation (16).

Zinc supplementation trials in infants resulted in increased weight gain and/or and increased growth velocity (63). Even mild zinc deficiency is also associated with decreased linear growth velocity in children. While some researchers feel there is a strong association between zinc deficiency and impaired gain in height, the effects on weight gain are less clear. The same researchers demonstrated that in a longitudinal zinc supplementation trial of periurban Guatemalan children increases in measures of body composition such as mid upper arm circumference were seen but no changes in growth (64). 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 (16,61,63). 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 (12,62,64). More controlled intervention studies are needed to better define the true public health dimension and impact, particularly of mild/moderate zinc deficiency on the growth and development of children.

Vitamin B$_{12}$: Children on alternate diets deviate from growth norms. Vitamin B$_{12}$ deficiency in children on strict vegetarian diets such as macrobiotics diet, have exhibited growth failure (21,48). Confounders present in the macrobiotic diets in regard to growth are low energy density, fat, and protein which may not be biologically complete. The associated anorexia and listlessness interfere with infant feeding (21).

Exclusively breast-fed infants by mothers who are strict vegetarians are at risk for deficiency. A

study of a Dutch group of macrobiotic children, 8-14 months and school-age children included measure of growth velocity for weight and length, mid-arm circumference, triceps fat fold, and arm muscle area. With vitamin B_{12} intervention, some catch up growth was seen (40). 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 (66).

COGNITIVE FUNCTION, SCHOOL PERFORMANCE, AND PHYSICAL ACTIVITY

A growing literature is being published on the impact of childhood undernutrition on cognitive function, activity, attendance, and school performance. Previously, studies were focused primarily on the effect of protein-energy malnutrition and of iodine deficiency on cognition. However, deficiencies of iron, B_{12}, and recently zinc have been implicated in impaired cognitive function. The deleterious effects of poor diet quantity and quality can begin to affect the child before it is born. Intrauterine malnutrition can lead to low birth weight which has been linked to impaired mental development. Decreased maternal activity and fatigue can result in decreased infant stimulation by an anemic and/or malnourished mother. After birth, stunting in young children has been associated with poor cognitive performance. Complete reversal of these early deficits are unlikely to be reversible, although nutritional intervention and mental stimulation can help ameliorate the effects (65).

Animal Source Foods and Cognitive Function

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 (67). 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 (34).

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. Even when controlling for parental and SES factors, energy intake, stunting and low animal protein intake predicted poor cognitive performance (68). Intake by Kenyan children when they were 18 to 30 months of age. Intake of animal-source products was significantly and positively associated with cognitive performance in follow-up testing when the children reached five years of age (69). The best set of predictors of cognitive function at age five years was previous intake of animal protein, even when controlling for household, SES factors, and duration of schooling (69). Also, intake of animal protein was associated in the Kenyan toddlers 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 to the teacher and to scores of school performance (70). These schoolchildren with greater intake 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 (71). In the Mexican sample, boys who consumed poor quality diets were apathetic in the classroom (43). As in the Kenya cohort of children, and in the Mexican and Egyptian children, animal source products positively predicted developmental outcomes, behavior, verbal ability and involvement in classroom activities. These remained significant even when controlling for socio-economic factors (43,72).

Specific Micronutrients and Cognitive and Related Functions

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 zinc deficiency and observational studies in regard to vitamin B_{12} and mental function were carried out.

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 (73).

There is clear and consistent evidence from a variety of studies that reveal a strong association between iron deficiency anemia, in both infants and school-age children, and reduced mental and motor developmental indicators (73). Such associations can be seen in mild cases of iron deficiency anemia. Abnormalities are most profound in older infants ages 18 to 24 months age group with the highest prevalence of iron deficiency anemia and a time of rapid brain growth.

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 (74).

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 (75). These behaviors may, in part, account for the poor test performances in these infants (73).

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 and in Costa Rica (75,76), 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 the findings on follow-up by Lozoff of these same treated infants (76). 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 were no longer anemic, and after controlling for numerous background factors (79). 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 12 to 18 months old infants treated with iron for four months, significant improvement in both mental and motor developmental scores were observed (80), 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 to 12 year old Indonesian children, anemic and non-anemic, were treated with either iron therapy or placebo, there were no longer significant differences in concentration tasks or school achievement tasks between the anemic and non-anemic children (77). However, in a similar study in Thailand, the iron treated iron deficient anemic children continued to score significantly lower on psycho-educational tests (78). Different findings may reflect that they are due to differences in the 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 prevention of iron deficiency in infants and children through addition of animal source foods to the diet and control of parasites, particularly hookworm.

Zinc: 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 (79).

In two controlled supplementation trials in infant and toddlers (81,82), one in India and one in Guatemala, subjects were randomly assigned to zinc supplementation and placebo groups. The Indian children in the zinc supplemented groups exhibit high physical activity such as running, and crawling. In the Guatemala study of infants, those zinc-supplemented were more apt to sit, lie down and play than the control infants. Zinc has a role to play in motor development in infants and young children. As for school-aged children, an intervention study of 6 to 9 year old Chinese children supplemented with zinc, functioned better on a group of neuropsychologic test than children not receiving zinc (83). 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/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 (84).

Vitamin B_{12}: Vitamin B_{12} intake and status in the development of infants and young children are of great concern as vitamin B_{12} is intimately involved in the development and integrity of the central nervous system. In vitamin B_{12} deficiency brain damage and spinal cord deterioration can occur. Neuro-behavioral disorders are seen such as apathy, lethargy, irritability, and loss of acquired motor milestones in infancy and impaired memory and decreased concentration in older children (85). Although some of the abnormalities can be reversed fairly rapidly with B_{12}, a certain percent never regain normal neurologic function. Children may have poor brain growth with some cortical atrophy (86). Infants born to and then exclusively breast fed by mothers who are strict or extreme vegetarians are at great risk for vitamin B_{12} deficiency and neurobehavioral problems. If the mother will not modify her diet with even a small amount of animal source foods, or vitamin B_{12} supplements, then the infant must be protected through supplementation. Vitamin B_{12} deficiency is a global problem, particularly in poor nations where little animal source food find their way onto the diet, placing millions of infants at risk for adverse developmental outcomes (25).

ASPECTS OF HEALTH

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

Anemia

Nutritional anemias, with inadequate formation of red blood cells due to nutrient deficiencies, are very common throughout the world (87). The most prevalent type of anemia is due to iron deficiency; however vitamin B_{12} deficiencies, folate, pyroxidine, copper, vitamin A, and protein also contribute to anemia. Anemia due to iron deficiency and vitamin B_{12} only will be covered here.

Anemia is more prevalent among vegetarians than people consuming omnivorous diets. In industrialized nations, those on vegetarian diets are known to have a greater prevalence of iron deficiency and macrocytic anemia due to vitamin B_{12} deficiency (14,40,87). 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 (88).

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 (89). 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 (22,25,27).

Iron: Iron-deficiency anemia is among the most common nutritional disorder in the world; and as stated

earlier between 40 and 50% of children under five, and over 50% of pregnant women, in developing countries are affected (1,14,87).

A primary function of iron, as a component of hemoglobin, in red blood cells, is to carry oxygen and for oxygen-carbon dioxide exchange at a cellular level. Importantly, iron is a component of myoglobin, which is a major striated muscle protein and thus 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) (14,15,74).

In addition to diminished cognitive function in children, extreme fatigue, anorexia, decreased work capacity and physical activity are associated with iron deficiency anemia. Iron deficiency anemia can cause in decreased work performance deserves mention here because of the economic consequences. In a classic study by Viteri, a linear dose-response relationship was demonstrated between hemoglobin level and the Harvard step test of performance (90). The adverse effects appears to be mediated through a combination of decreased oxygen carrying capacity and the effect of iron deficiency on muscle function with iron depleted in the myoglobin of voluntary or striated muscle protein. 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 (91), and men working on a rubber plantation in Indonesia (92), 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 mild to moderately anemic (7). Iron therapy led to a significant increase in "production efficiency" and paralleled the change in hemoglobin in the women.

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% of the men are affected, the impact of iron deficiency anemia would equal a staggering total loss of 5-7% of the national economic output (14).

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 on a household level, to animal source foods. Using newer improved techniques, which measures recent absorption of vitamin B$_{12}$, remarkably high prevalences of B$_{12}$ deficiency and anemia were found in Guatemala and Mexico, particularly among pregnant and among lactating women and infants and young children (22,25,27). Little or no meat intake was associated with anemia in these studies. Even among men, a greater prevalence of anemia due to vitamin B$_{12}$ deficiency was seen compared to anemia due to iron deficiency. 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 gm of meat per day or a cup of milk or other related dairy food may be protective (8,21).

Resistance to Infection and Immune Function

The interaction of nutrition and infection is a synergistic one: the worse the malnutrition, the greater is the impairment of the body's defenses against infection and the greater the frequency and severity of infections. The heavier is the infection burden, the more severe is the resulting malnutrition. Protein-energy malnutrition (PEM) (92,93,94), has been extensively studied in this regard, but it is in the past two decades that micronutrient deficiencies have also been seriously implicated in reducing the body's defenses to combat infection (95). Both PEM and micronutrient malnutrition increases the duration, severity, and complication rates of common infectious diseases.

Micronutrient deficiencies, single or multiple, or in combination with PEM most often result in suppression of the body's defenses against infection and of facets of the immune system. Infection per se acutely lowers levels of micronutrients such as iron, zinc, and vitamin 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 (94). 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 such as vitamin A (92).

The integrity of the skin and mucous membranes and epithelial coverings of the body form a first line of defense against the invasion of micro-organisms. Zinc, vitamins A and C, and protein are critical in maintaining these barriers. The epithelial coverings of the eyes, the respiratory system, the gastro-intestinal 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 micro-organisms.

The secretory antibody system whereby antibodies are secreted onto the mucosal surfaces to combat invading micro-organisms and is also impaired in vitamin A deficiency and PEM. The secretory antibody system plays an important anti-infection role in the respiratory and gastro-intestinal tracts. Zinc is involved in walling off infection and wound healing, important to the maintenance of anatomical barriers against micro-organism invasion (92,94,95).

Iron deficiency 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 micro-organisms (phagocytosis) and to kill micro-organisms (killing function) are impaired in iron deficiency (92,94).

Lastly and of great importance, the cell-mediated immune (CMI) system which derives from the thymus and lymphoid tissue of the body is exquisitely sensitive, not only to PEM but iron, zinc and vitamins A and B_{12} deficiencies (92,93,95). 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 (93).

There is recent evidence that vitamin A and zinc deficiencies increase the chances of being infected with malaria (96). Also the chances of vertical HIV transmission between mother and infant has been noted to be increased in vitamin A deficiency (98). In regard to other diseases, supplementation with zinc or with 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 (97,98,100,101).

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 5 years of age in developing countries world-wide and leaves the survivors stunted and underweight.

ISSUES AND POLICIES

Animal source products, 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 which supplements or fortifications will not address. Thus inclusion of animal source foods, even in modest amounts in the diet can handle multiple deficiencies, together with plant-based foods.

Poverty is the reason most often given for the minimal amounts or absence of meat and other animal 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 smallholder farmers that holds the greatest promise rather than turning to large commercial schemes for meat production, to improve the diet of the poor rural populations. Most of the families in the developing world live on small farms of 1 to 2.5 acres with two to five heads of livestock per household where most of the meat production takes place. Productivity is low for a number of reasons such as poor animal feed, meager 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 than used for adequate household consumption. The main annual output of meat and milk in Africa was estimated to be one tenth of that produced in Europe (8). 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 (8).

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 human-edible foods. 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 the wastes in the form of manure 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 (102).

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 children and adults. 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-derived products on human health in industrialized countries, and 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 human-edible. 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.

Intensive vs. non-intensive production systems

Animal production systems are often characterized as "intensive" vs. "non-intensive" systems. Intensive livestock units are defined as mainly monoculture, involving large numbers of animals per unit of land, technology-intensive, and located in peri-urban areas. The products derived from these units are often only accessible to markets for more affluent middle and upper classes, particularly in the urban areas. Owners of these units in developing countries are often relatively wealthy themselves, and have ready access to many of the technology innovations available to producers in the industrialized countries. Although opportunities may exist to enhance availability of animal products to poor households through

assistance to the more intensive-types of production systems, 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 pond. The carp pond may have several species of carp which are stratified in the water column and utilize different feed resources, from the undigested grains from the pig fecal matter to grass of the banks of the pond. Ducks are also commonly associated with these ponds, consuming excess grains from the pig unit as well as plant material growing near and in the ponds. 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.

A Role for Non-Governmental Organizations

Many non-governmental organizations (NGO's), notably Heifer Project International, FARM Africa, and VEDCO-Uganda, have taken a lead in propagating local livestock projects to aid farm families in Africa, Latin America, and Asia. Donation of such animals as cows, goats, rabbits, or water buffalo to a family not only provides milk and meat, but also a source of income when excess milk is sold. Each family passes on one or more female offspring to other needy families; thus, the projects are self-sustaining and self-propagating. These NGO's have excellent education programs to train recipients of animals on animal care and breeding and maintain breeding stock for the recipients. However, they lack strong practical nutrition education components for the family, and usually these programs do not promote use of animal-source foods other than milk. These programs would be strengthened if the efforts in livestock development were also paired with efforts to improve human nutrition and health through practical, participatory educational programs. For example, if parents understand the importance of milk and meat to the health of their children, then perhaps they will be less likely to sell off all of the increased household production and hold back the sufficient amount for the consumption of the children. Work of NGO's in Africa has mainly focused on increasing milk production; less attention has been paid to meat production for household use on inclusion of meat in the diet of children.

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" 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. 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 (104) 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. Additional non-mammalian sources of protein and nutrients are also available, including reptiles and insects; local indigenous knowledge is usually the best resource to identify these foraged food resources to exploit.

Applications of Biotechnology

The first products resulting from biotechnology applications in plant crops are now reaching markets of the industrialized world. However, the real challenge of biotechnology will be to tackle the limitations to productivity found in the developing world, especially among resource-poor farmers. These limitations include inhospitable climates, soils of low fertility, and high levels of pests and diseases. Additionally, the technologies developed must still be accessible to the low-income producer, a market not attractive to the multi-national corporations that are investing heavily in biotechnology.

Examples of relevant biotechnologies are already available, however. One of the most immediate applications for livestock is in the areas of disease diagnosis and prevention and in manipulation of reproduction. Test kits based on such technologies as enzyme-linked immunosorbant assay (ELISA's) and polymerase chain reaction (PCR) are now developed to detect common tropical diseases, such as rinderpest, brucellosis, and trypanosomiasis; ELISA kits are also available to detect hormone levels for monitoring stages of the reproductive cycle in females. Additionally, vaccines that are more stable, effective, cheaper, and safer are being devised based on genetic engineering. Traditional breeding schemes to enhance traits important in the tropics, such as disease resistance, are being enhanced through *in vitro* fertilization, embryo transfer, and genetic mapping.

Development of Infrastructure

Programs need to be enhanced to benefit not only the production of animal-source foods, but also the infrastructure that allows procurement of animals, health care and breeding. Extension services are needed to educate about processing, preservation, and marketing of animals and their products on a small scale commercial level or on a household level.

Credit is often inaccessible to the smallholder or landless. "Micro-credit" programs, which enhance availability of credit to small enterprises, need to be replicated. An outstanding example of such a program is Freedom From Hunger Foundation's "Credit with Education" program which operates in Latin America, Asia, and Africa (104).

For large livestock, access to slaughterhouses and dairy processing facilities for smallholders

need to be enhanced, potentially through cooperatives. Alternatively, appropriate technologies to process meats and milk at home need to be developed and propagated where none exist. An example of the above is the USAID Nutribusiness project in Kenya, which is a community-based solar drying project that produces meat powder and snacks for ruse in weaning foods or finger snacks for home use and for income generation (105).

CONCLUSIONS

Most malnutrition takes the form of mild moderate PEM in combination with multiple micronutrient deficiencies. These result in such adverse outcomes as stunting, sub-optimal cognitive development, immuno deficiency and anemia in children, and poor pregnancy outcome, anemia and poor milk quality during lactation. The analysis 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 children and women, and can prevent or ameliorate many micronutrient deficiencies. These deficiencies exact a heavy societal and individual toll. The task remains to improve access to and utilization of animal source foods by poor families. An apt quote is to "look to the farm and not to the pharmacy" (8).

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. The World Bank has a history of helping to alleviate micronutrient malnutrition (106). A role for the World Bank would be to support NGO's that work primarily with small holder subsistence farmers to improve and expand small animal production using mixed agriculture in an ecologically sound manner. Infrastructure for extension services is in need of support as well.

Investing in diet improvement for children and women of reproductive age would maximize the chances of improvement of pregnancy outcome, and 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 parisites most go hand in hand with dietary quality improvement if the benefits are not to be canceled out.

TABLE 1

Nutritional Benefits from Animal-origin Foods
- High energy density and low dietary bulk
- Dietary diversity
- Quality protein
- Micronutrients in bioavailable form
- Better maternal nutrition (in pregnancy and lactation)

Nutritional Risks
- Milk substitutes before age 6 months increase risk of disease and may displace breast-feeding.
- Risk of bacterial food contamination.
- Risk of zoonotic infections (animal parasites infecting people).

TABLE 2

Approximate Nutrient Compositions of Some Animal Source Foods per 100gm*

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
Ofal	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

(30,107)

* raw or boiled foods are used

TABLE 3
Major Micronutrients Contained in Animal Source Foods

Animal Source Foods	Iron	Zinc	Vitamin B$_{12}$	Vitamin A
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

Table 4

"Exotic" animals and some fowl used for meat in certain areas of the world (McDowell, 1991).

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, Malaysia)
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	Canada, U.S.
Black-tailed	Canada, U.S.
Mule deer	Canada, U.S.
Axis	U.S.
Roe	Europe, Former Soviet Union
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

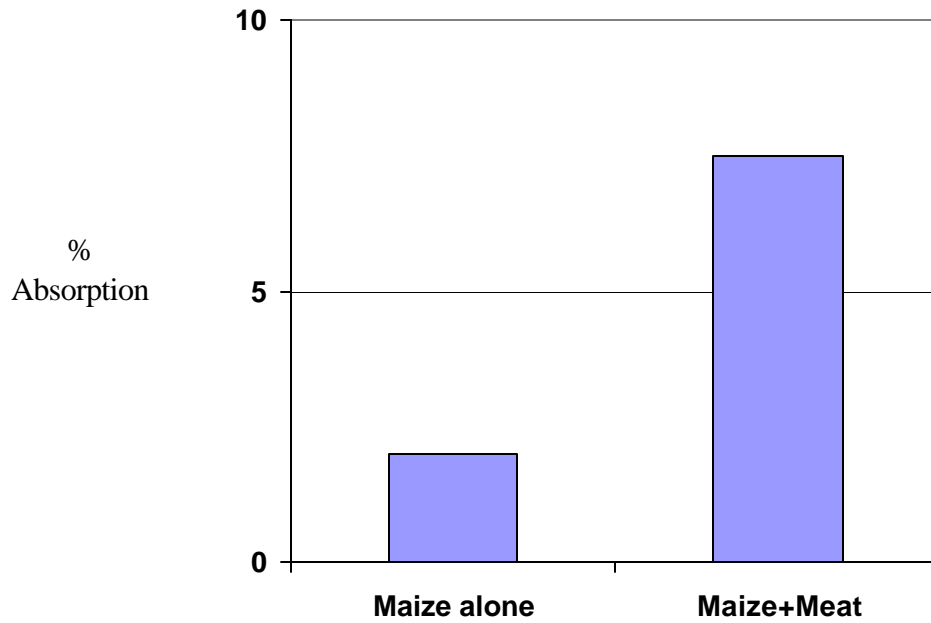1 Related to buffalo.
2 Related to pig.

Impala (antelope)	Central, Eastern, and Southern Africa
Kangaroo	Australia
Kongoni	Central, Eastern, and Southern Africa
Kouprey	Indo-China
Llama	South America Andes Mountains
Moose	Canada, U.S.
Oryx	Central, Eastern, and Southern Africa
Pigeon	Europe, Africa
Pronghorn antelope	U.S.
Rabbit	All over
Tamaran3	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

3 Related to Buffalo

Figure 1

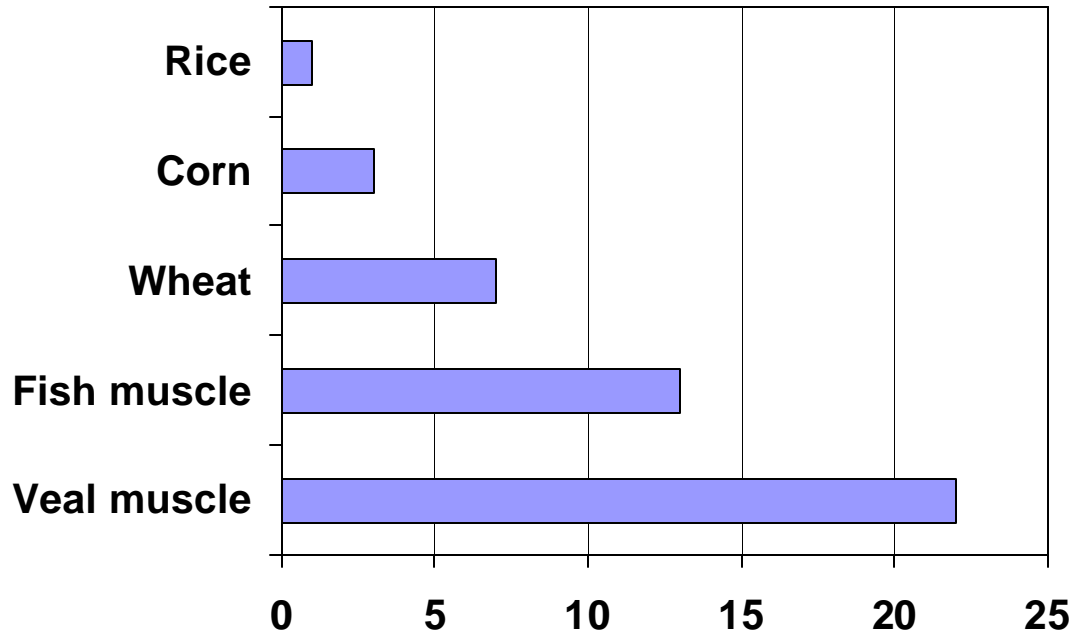## *Absorption of Non-Heme Iron from Maize Meal*

(iron content 5 mg)

Absorption of non-heme iron from a maize meal in the absence and presence of meat. (Data from Layrisse and coworkers)   (6)
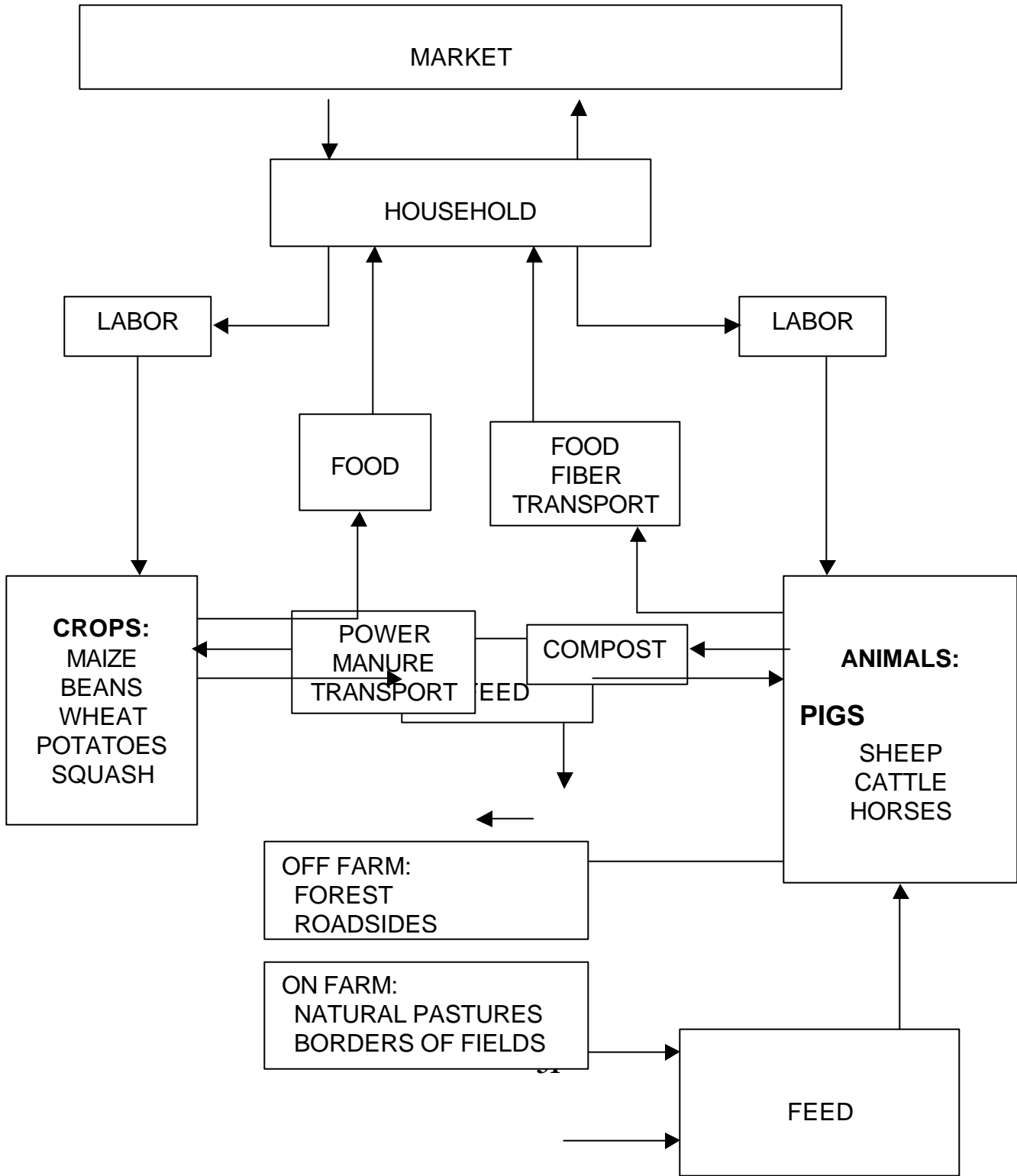
Figure 2

Fe Absorption from Different Foods
% Absorption

The geometric mean absorption of iron from grain products and from fish and meat by Venezuelan peasants. (Data from Martinez-Torres and Layrisse) (6)

Figure 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).

GLOSSARY

Animal source foods - foods derived from animals, including meat, milk, fish, poultry.

Available iron, available zinc - Iron or zinc which is not complexed to compounds, hindering its absorption in the body. For example, oxalates, phytates, tannins, and other phenolic compounds in the diet, provided by plant foods, tend to form insoluble precipitates with iron or zinc which make the minerals unavailable for absorption.

Bioavailability - the fraction of the ingested nutrient that is utilized for normal physiological functions or storage. Factors which may influence bioavailability of a nutrient from a given food include: the efficiency of digestion of the food, the previous intake of the nutrient, the body stores of the nutrient, gut transit time, the presence of gastrointestinal disorders or disease, other products with which the food is consumed, and cooking or processing of the foodstuff.

Cell-mediated immunity - acquired immunity in which the role of T-lymphocytes is predominant (MORE)

Diet quality - the ability of the food consumed to supply protein of high biologic value (presence of all essential amino acids) and adequate supplies of micronutrients such as minerals, trace metals, and vitamins to meet biologic requirements under a wide range of physiologic and environmental conditions.

Diet quantity - the availability and consumption of total food energy.

Energy density - the amount of chemical energy delivered per unit of food.

Ferritin - the complex of iron and the protein apoferritin, one of the chief forms that excess iron is stored in the body. Ferritin is found in all cells of the body, but levels are especially high in liver, spleen, and bone marrow

Heme protein - Protein, derived from blood-containing tissue, which contains a heme group, an iron-containing compound which is responsible for the oxygen-carrying properties of hemoglobin. This chelated iron is kept in solution and is absorbed more readily using an independent mechanism than is the iron found in plants.

High-quality protein - food proteins for which the proportion of essential amino acids most closely match the body's requirement. In general, proteins from animal, poultry, and fish have high-quality protein.

   Microcytic anemia - a reduction in the volume of packed red cells in the blood due to a decrease in the size of individual red blood cells, often due to a deficiency of iron.

Micronutrients - nutrients that cannot be synthesized in the body and are required in trace amounts in the diet for certain essential physiological functions. For human nutrition, the micronutrients of major concern in the growth and development and health of children are iron, iodine, zinc, calcium, vitamins A and B12, and selenium.

NCRSP - The Nutrition Collaborative Research Support Program, initially funded in 1980 by the US Agency for International Development. The purpose of the Nutrition CRSP was to determine whether there were any relationships between energy (food) intake and important physiological functions, including growth, psychological development, pregnancy and lactation outcomes, behavior, and morbidity. The research is a collaborative effort between universities in the United States and institutions in developing countries.

NGO - non-governmental organization -- a privately funded aid group, such as Heifer Project International.

Nutritional anemia - a reduction below normal of the number of red blood cells due to a deficiency of a particular nutrient, such as iron or vitamin B12.

Oxalates - Salts of oxalic acid common in many leafy greens, such as spinach, rhubarb, and chard. Oxalates formed with calcium make this nutrient unavailable, so that the high calcium content in spinach is actually of poor bioavailability.

Phytates - the complex of phytic acid (the hexaphosphate ester of inositol) and di- and trivalent metal ions (such as zinc). Phytates are common in cereal bran, and can inhibit the bioavailability of mineral nutrients, such as zinc.

Preformed vitamin A - Animal sources provide dietary vitamin A as retinoids, which are the most active form of vitamin A. However, plant sources mainly provide carotenoids, principally b-carotene, which must be converted in the body to the active vitamin A compounds.

Protein-energy malnutrition - A negative balance of protein and energy due to the inadequate intake of energy and/or total protein or protein of low quality. Protein-energy malnutrition is a continuum between a primarily protein deficiency (kwashiorkor) to a primarily energy deficiency (marasmus).

Tannins - compounds found in high levels in many types of grains, seeds, leaves and bark (including tea, red wine, apples, cranberries, grapes, spinach, and many legume seeds, such as fava beans). Tannins generally fall under two categories: "hydrolysable" (ester and glycoside derivatives of gallate) and "condensed" (or proanthocyanidins, polymeric flavonoid compounds containing many phenolic groups). Tannins commonly affect food taste and protein availability.

Zero-grazing - a system of livestock management under which all feed is hauled to animals that are confined to a yard or shed (usually applies to ruminants).

References

1.   UNICEF. <u>The State of the World's Children</u>.Oxford University Press, Oxford, U.K., 1998.

2.   <u>World Development Report 1993: Investing in Health</u>. International Bank for Reconstruction and Development, Oxford University Press, New York, N.Y., 1993.

3.   Scrimshaw N. The Consequences of Hidden Hunger for Individuals and Societies. Food and Nutrition 15: 3-23, 1994.

4.   Pollitt E. Iron Deficiency and Educational Deficiency. Nutrition Reviews 55: 133-144, 1997.

5.   Chandra R K. Nutritional Regulation of Immunity and Infection: from Epidemiology to Clinical Practice. J Pediatr Gastroenterol and Nutr 5: 844-852, 1985.

6.   Layrisse M, Martinez-Torres C, Mendez-Costellaro, et al. Relationship between Iron Bioavailability from Diets and the Prevalence of Iron Deficiency. Food and Nutrition Bulletin 12: 301-309, 1990.

7.   Li R, Chen X, Yan H, et al. Functional Consequences of Iron Supplementation in Iron Deficient Female in Beijing China. Amer J Clin Nutri 59: 908-913, 1994.

8.   Bender A. Meat and Meat Products in Human Nutrition in Developing Countries. FAO Food and Nutrition Paper #53, Food Policy and Nutrition Division of FAO 2: 1-88, 1992.

9.   Murphy S P, Beaton G H, Calloway D H. Estimated Mineral Intakes of Toddlers: Predicted Prevalence of Inadequacy in Village Populations in Egypt, Kenya, and Mexico. Amer J Clin Nutri 56: 565-572, 1992a.

10.   Sanders T A B. Vegetarian Diets and Children. Pediatr Clin North Am 42: 955-965, 1995.

11.   Gibson R S. Content and Bioavailability of Trace Elements in Vegetarian Diets. Am J Clin Nutr 59: 1223S-1232S, 1994.

12.   Ferguson E L, Gibson R S, Opare-Obisau C, et al. The Zinc Nutriture of Pre-school

Children Living in Two African Countries. J of Nutr 123: 1487-1496, 1993.

13.   Dallman P R. Behavioral Basis for the Manifestation of Iron Deficiency. Ann Rev Nutr 6: 31-40, 1986.

14.   Yip R. Iron Deficiency: Contemporary Scientific Issues and International Programmatic Approaches. J Nutr 124: 1479S-1490S, 1994.

15.   Dallman P R. Iron Deficiency: Does it Matter?. Journal of Internal Medicine 226: 367-372, 1989.

16.   Black E R ed. Zinc for Child Health. Amer J Clin Nutri 68, 2(S): 409S-516S, 1998.

17.   Underwood B A. From Research to Global Reality: The Micronutrient Story. J Nutr 128(2): 145-151, 1998.

18.   West K P Jr. Dietary Vitamin A Deficiency: Effects on Growth, Infection, and Mortality. Food and Nutrition Bulletin 13: 119-131, 1991.

19.   Rahmathulla L, Underwood B A, Thulasiraj R D, et al. Reduced Mortality Among Children in Southern India Receiving a Small Weekly Dose of Vitamin A. NEJM 323: 329-935, 1990.

20.   Fawzi W W, Herrera M G, Willett W C, et al. Vitamin A Supplementation and Dietary Vitamin A in Relation to Risk of Xeroph Thalmia. Amer J Clin Nutri 38: 385-391, 1993.

21.   Dagnelie P C, Van Staveren, W A, Hautvast J G J A. Stunting and Nutrient Deficiencies in Children on Alternative Diets. Acta Paediatr Scan Suppl 374: 111-118, 1991.

22.   Allen L H, Rosado J L, Casterline J E, Hautvast J G J A, et al. Vitamin B-12 Deficiency and Malabsorption are Highly Prevalent in Rural Mexican Communities. Am J Clin Nutr 62: 1013-1019, 1995.

23.   Neumann C G, Oace S, Murphy S P, Bwibo N, Calloway C, Herman D R. Low B_{12} Content in Breaast Milk of Rural Kenyan Women on Predominantly Maize Diets. FASEB, 1996.

24.   Jathar V S, Inamdar-Desmukh A B, Rege D V, et al. Vitamin B_{12} and Vegetarianism in India. Acta Hematol 53: 90-97, 1975.

25.   Allen L H, King J, Lönnerdal B, eds. <u>Vitamin B$_{12}$ Metabolism and Status During Pregnancy, Lactation and Infancy, Nutrient Regulation During Pregnancy,   Lactation, and Infant Growth</u>. pp.173-186, Plenum Press, New York, 1994.

26.   Hall C A. Function of Vitamin B$_{12}$ in the Central Nervous System as Revealed by Congenital Defects. Amer J Hematology 34: 121-127, 1990.

27.   Casterline J E, Allen L H, and Ruel M T. Vitamin B$_{12}$ Deficiency is Very Prevalent in Lactating Guatemalan Women and their Infants at Three Months Post-Partum. J Nutr 127: 1966-1972, 1997.

28.   Calloway D H, Murphy S, Balderston J, et al. Village Nutrition in Egypt, Kenya, and Mexico: Looking Across the CRSP Projects. Dept. of Nutrition, University of California, Berkeley, CA, 1992. (USAID).

29.   Neumann C G, Bwibo N O, Sigman M. Final Report Phase II: Functional Implications of Malnutrition, Kenya Project. Human Collaborative Research Support Program, USAID, Office of Nutrition, 1989-1992.

30.   Murphy S P, Weinberg S W, Neumann C G, et al. Development of Research Nutrient Data Bases: An Example Using Foods Consumed in Rural Kenya. J Food Composition and Analysis 3: 1-15, 1990.

31.   Murphy S P, Beaton G H, Calloway D H. Estimated Mineral Intakes of Toddlers: Predicted Prevalence of Inadequacy in Village Populations in Egypt, Kenya, and Mexico. Amer J Clin Nutr 56: 565-572, 1992.

32.   Murphy S P, Calloway D H, and Beaton G H. School Children Have Similar Predicted Prevalences of Inadequate Intakes as Toddlers in Village Populations in Egypt,   Kenya, and Mexico. Eur J Clin Nutr 49: 647-657, 1995.

33.   Neumann C G, Harrison G. Onset and Evolution of Stunting in Infants and Children. Examples From the Human Nutrition Collaborative Research Support Program, Kenya and Egypt Studies. Eur J Clin Nutr 48(suppl.1): S90-S02, 1994.

34.   Kirksey A, Rahmanifar A, Wachs T D, et al. Determinants of Pregnancy Outcome and Newborn Behavior of a Semi-Rural Egyptian Population. Amer J Clin Nutr 54: 657-667, 1991.

35.   Allen L H. Pregnancy and Iron Deficiency: Unresolved Issues, Nutrition Reviews 55(4):

91-101, 1997.

36.   Caulfield L E, Zavaleta N, Shaukar A H, and Merialdi M. Potential Contribution of
        Maternal Zinc Supplementation during Pregnancy to Maternal and Child Survival.
        Amer J Clin Nutr 68(suppl): 499-508, 1998.

37.   Negger S Y H, Cutter G R, Avarez J O, and Golderberg R L. The Relationship Between
        Maternal Zinc Levels During Pregnancy and Birthweight. Early Human Development 25: 75-
        85, 1991.

38.   Gibson R S, Hudak J M. Suboptimal Zinc Status in Pregnant Malawian Women: Its
        Association with Low Intakes of Poorly Available Zinc, Frequent Reproductive
        Cycling, and Malaria. Amer J Clin Nutr 61: 702-709, 1998.

39.   Doyle J J, Langerin A M, and Zipursky A. Nutritional B_{12} Deficiency in Infancy. Pediatric
        Hematology and Oncology 6: 161-172, 1989.

40.   Miller D R, Specter B L, Holm, Norman E J. Vitamin B_{12} Status in a Macrobiotic Community.
         Amer J Clin Nutr 53: 524-529, 1991.

41.   Graham S M, Arvela O M, Wise G. Long-term Consequences of Nutritional Vitamin B_{12}
        Deficiency in Infants. J Pediatr 121: 710-714, 1992.

42.   Harrison G, Galal O, Kirksey A, Jerome N. Egypt Project: the Collaborative Research
        Support Program on Food Intake and Human Function. Final Report Washington
        DC., USAID, 1987.

43.   Allen L H, Backstrand J R, Chavez A, and Pelto G H. People Cannot Live by Tortillas Alone:
        The Results of the Mexico Nutrition CRSP. USAID, University of Connecticut, 1992.

44.   Marquis G S, Habicht J P, Lanata C F, et al. Breast Milk or Animal-Product Foods
        Improve Linear Growth of Peruvian Toddlers Consuming Marginal Diets. Amer J
        Clin Nutr 66: 1102-1109, 1997.

45.   Smith T, Earland J, Bhatia K, Heywood P, Singleton N. Linear Growth of Children in Papua
        New Guinea in Relation to Dietary, Environmental and Genetic Factors. Ecology of Food and
        Nutrition 31: 1-25, 1993.

46.   DeWalt K M. Nutritional Strategies and Agricultural Change in a Mexican Community.
        Ann Arbor, MI: UMI Research Press, 1983.

47.   Shapiro B. ILRI, Addis Ababa, Ethiopia, Personnel Communication, Dairy and Draft Cow Project, 1998.

48.   Guldan G S, Zhang M Y, Zhang Y P, et al. Weaning Practices and Growth in Rural Sichuan Infants: A Positive Deviance Study. Journal of Tropical Pediatrics 39: 168-175, 1993.

49.   Walker S P, Powell C A, Grantham-McGregor S M. Dietary Intakes and Activity Levels of Stunted and Non-Stunted Children in Kingston, Jamaica, Part 1, Dietary   Intakes. Euro J Clin Nutr 44: 527-534, 1990.

50.   Seireg M, Zeitlin M F, LaMontagne J, and Morales C M. Field Validation of the Tallstick in Marginal Communities in Nicaragua. J Trop Pediatr 38: 214-223, 1992.

51.   Kassouf A L. Estimation of Health Demand and Health Production Functions for Children in Brazil. Unpublished Ph.D. Dissertation, University of Minnesota,   1993.

52.   Chen S T. Impact of a School Milk Programme onthe Nutritional Status of School Children. Asia-Pacific Journal Public Health 3: 19-25, 1989.

53.   Takahashi E. Secular Trend in Milk Consumption and Growth in Japan. Human Biology 56: 427-437, 1984.

54.   Graves P L. Nutrition and Infant Behavior: A Replication Study in the Kathmandu Valley, Nepal. Amer J Clin Nutri 31: 541-551, 1978.

55.   Hitchings J. Agricultural Determinants of Nutritional Status Among Kenyan Children with Model of Anthropometric and Growth Indicators. Unpublished Ph.D. Dissertation, Stanford University, Palo Alto, CA 1982.

56.   Vosti S A, Witcover J. Income Sources of the Rural Poor: the Case of the Zona de Mata, Minas Gerais, Brazil, Income Source of Malnourished People in Rural Areas: Microlevel Information and Policy Implications. Washington DC: International Food Policy Research Institute, pp. 47-68, 1991.

57.   Leonard W M. DeWalt K M, Uquillas J E, DeWalt B R. Diet and Nutritional Status Among Cassava Producing Agriculturalists of Coastal Ecuador. Ecology of Food and Nutrition 32: 113-127, 1994.

58.   Vella V, Tomkins A, Nviku J, Marshall T. Determinants of Nutritional Status in South-West Uganda. J Trop Pediatr 41: 89-98, 1995.

59.   Eshetu M, Kinfu Y. Correlates of Nutritional Status of Under Five Children in Southern
        Ethiopia. Paper Presented at Annual Meeting of Population Association of
        America, Washington DC, March 26-29, 1997.

60.   Bertolli J, St. Louis M E, Simonds R, et al. Estimating the Timing of Mother-to-Child
        Transmission of Human Immunodeficiency Virus in Breastfeeding Population in
        Kinshasa, Zaire: J Infect Dis 174: 722-726, 1996.

61.   Prasad A S. Zinc Deficiency in Women, Infants, and Children. J Amer College of Nutr
        15: 113-120, 1996.

62.   Cavan K R, Gibson R S, Grazioso C F, et al. Growth and Body Composition of Peri-
        urban Guatamalan Children in Relation to Zinc Status: a Longitudinal Zinc
        Intervention Trial. Amer J of Clin Nutr 57: 341-352, 1993.

63.   Favier A E. Homonal Effects of Zinc on Growth of Children. Biological Trace Elements
        Research 32: 383-398, 1992.

64.   Polysangam A. Effect of Marginal Zinc Deficiency on Human Growth and Development. J
        Trop Pediatr 43: 192-198, 1997.

65.   Pollitt E. Nutrition and Educational Achievement. Series #9, UNESCO, Paris, 1984.

66.   Sigman M. Nutrition and Child Development: More Food for Thought. Current
        Directions in Psychological Sciences 4: 52-55, 1995.

67.   Rahmanifar A, Kirksey A, Wachs T D, et al. Diet During Lactation Associated with
        Infant Behavior and Caregiver-Infant Interaction in a Semirural Egyptian Village.
        J Nutr 123: 164-175, 1993.

68.   Sigman M, Neumann C G, Baksh M, Bwibo N O, McDonald M. Relationship Between
        Nutrition and Development in Kenyan Toddlers. J Pediatr 115: 357-364, 1989.-

69.   Sigman M, McDonald M A, Neumann C, Bwibo N O. Prediction of Cognitive
        Competence in Kenyan Children from Toddler Nutrition, Family Characteristics
        and Abilities. J Child Psychol Psychiatry 32: 307-320, 1991.

70. Sigman M, Neumann C, Jansen A A, Bwibo N. Cognitive Abilities of Kenyan Children in Relation to Nutrition, Family Characteristics, and Education. Child Dev 60: 1463-1474, 1989.

71. Espinosa M P, Sigman M, Neumann C G, Bwibo N O, McDonald M A. Playground Behaviors of School-age Children in Relation to Nutrition, Schooling, and Family Characteristics. Developmental Psychology 28: 1188-1195, 1992.

72. Wachs T D, Bishry Z, Monssa W, et al. Nutritional Intake and Context as Predictors of Cognition and Adaptic Behavior of Egyptian School-age Children. Int. J Behavioral Development 18: 425-458, 1996.

73. Pollitt E. Iron Deficiency and Educational Achievement. Nutri Rev 55: 133-144, 1997.

74. Dallman P R. Biochemical Basis for the Manifestation of Iron Deficiency. Ann Rev Nutri 6: 13-40, 1986.

75. Lozoff B. Behavioral Alterations in Iron Deficiency. Advances in Pediatrics 35: 331-359, 1988.

76. Lozoff B, Jimenez E, Wolf A W. Long-term Developmental Outcome of Infants with Iron Deficiency. N Engl J Med 325: 687-694, 1991.

77. Soemantri A G, Pollitt E, Kim I. Iron Deficiency Anemia and Educational Achievement. Amer J Clin Nutri 42: 1221-1228, 1985.

78. Pollitt E, Hathirat P, Kotchabhakd N J, et al. Iron Deficiency and Educational Achievement in Thailand. J Clin Nutr 50: 587-697, 1989.

79. Black M M. Zinc Deficiency and Child Development. Amer J Clin Nutr (suppl)68: 4645-4695, 1998.

80. Idjradinata P, Pollitt E. Reversal of Developmental Delays in Iron Deficient Anemic Infants Treated with Iron. Lancet 341(8836): 1-4, 1993.

81. Sazawal S, Bentley M, Black R E, et al. Effect of Zinc Supplementation on Observed Activity in Low Socio-economic Indian Pre-school Children. Pediatrics 8: 1132-1137, 1996.

82.   Bentley M E, Caulfield L E, Ram M, et al. Zinc Supplementation Affects the Activity Patterns of Rural Guatamalan Infants. J Nutr 127: 1333-1338, 1997.

83.   Penland J G, Sandstead H H, Alcock N W, et al. A Preliminary Report: Effect of Zinc and Micronutrient Repletion on Growth and Neuropsychological Function of Urban Chinese Children. Journal of American College of Nutrition 16(3): 268-272, 1997.

84.   Sandstead H H. Is Zinc a Public Health Problem?. Nutrition 11(1 suppl): 87-92, 1995.

85.   Graham S M, Arvela O M, and Wise G A. Long-term Neurologic Consequences of Nutritional Vitamin B_{12} Deficiency in Infants. J of Pediatr 121: 710-714, 1992.

86.   Stollhoff K, Schulte F J. Vitamin B_{12} and Brain Development. Eur J Pediatr 146: 201-205, 1987.

87.   DeMaeyer E, Adiels-Tegman M. The Prevalence of Anemia in the World. World Health Statistics Quarterly 38: 302-316, 1985.

88.   Grindulis H, Scott P H, Belton N R, and Wharton B A. Combined Deficiency of Iron and Vitamin D in Asian Toddlers. Arch Dis Child 61: 843-848.

89.   Dagnelie P C, Van Staveren W A, Vergote J V R A, et al. Increased risk of Vitamin B_{12} and Iron Deficiency in Infants on Macrobiotic Diets. Amer J Clin Nutr 50: 818-824, 1989.

90.   Viteri F E, Torun B. Anemia and Physical Work Capacity. Clinics in Hematology, Garby L ed.. Vol.3, pp. 609-626, W B Saunders, London, 1974.

91.   Edgerton V R, Gardner G W, Ohira Y, et al. Iron Deficiency Anemia and its Effect on Worker Productivity and Activity Patterns. British Medical Journal, 2(6204):   1546-1549.

92.   Neumann C G, Stephenson L. Malnutrition and Infection, In: Hunter's Tropical Medicine, ed. Strickland G T, Saunders W B. Phila, 292-295, 1991.

93.   Neumann C G, Lawler G J, Stiehm E R, et al. Immunologic Responses in Malnourished Children. Amer J Clin Nutr 28: 89-104, 1975.

94.   Keusch G T, Farthing M J G. Nutrition and Infection. Ann Rev Nutri 6: 131-154, 1986.

95.   Keusch G T. Micronutrients and Susceptibility to Infection. Ann NY Acad Sci J87: 181-188, 1990.

96.   Galan P, Samba C, Luzeau R, Amedee-Manesmeo. Vitamin A Deficiency in Pre-school Age Congolese Children During Malarial Attacks, Part 2: Impact of Parasitic Diseases on Vitamin A Status. Inter J Vitamin and Nutri Res 60:225-228, 1990.

97.   Semba R D, Miotti P G, Chiphangwi J D, et al. Maternal Vitamin A Deficiency and Mother to Child Transmission of HIV-1. Lancet 343: 1593-1596, 1994.

98.   Sempertegui F, Estrella B, Correa E, et al. Effects of Short Term Zinc Supplementation on Cellular Immunity, Respiratory Symptoms, and Growth of Malnourished Ecuadorian Children. Euro J Clin Nutri 50(1): 42-46, 1996.

99.   Ruel M T, Rivera J A, Santizo M C, Lonnerdal B, Brown K H. Impact of Zinc Supplementation on Morbidity from Diarrhea and Respiratory Infections Among Rural Guatemalan Children. Pediatrics 99(6): 808-813, 1997.

100. Sazawal S, Black R E, Bhan M K, et al. Efficacy of Zinc Supplementation in Reducing the Incidence and Prevalence of Acute Diarrhea - a community based, double-   blind, controlled trial. Amer J Clin Nutri 66(2): 413-418, 1997.

101. Sommer A, Katz J, Tarwotjo I. Increased Risk of Respiratory Disease and Diarrhea in Children with Pre-existing Mild Vitamin A Deficiency. Amer J Clin Nutr 40:   1090-1095, 1984.

102. McDowell R E. The Need to Know About Animals. In: World Food Issues. Center for the Analysis of World Food Issues, Program in International Agriculture. Ithaca, NY: Cornell University, 1984.

103. National Research Council. Microlivestock: Little-Known Small Animals with a Promising Economic Future, National Academy Press, Washington D.C.

104. Vorder Bruegge E, Dunford C, et al. Credit with Education. Convergence XXVIII: 26-35, 1995.

105. Maretzki A, and Maritim, G. University Linkage Program - Pennsylvania State University-USA, and University of Nairobi-Kenya.

106. The World Bank. Enriching Lives: Overcoming Vitamin and Mineral Malnutrition in

Developing Countries. The World Bank, Washington D.C.

107.   Pennington J A T. Bowes and Church's Food Values of Portions Commonly Used. 17th ed. Lippincott, Philadelphia, 1998.