Nutritional benefits of legume consumption at household level in rural areas of sub-Saharan Africa

A literature study

Ilse de Jager, Wageningen University

July 2013

N2Africa

Putting nitrogen fixation to work for smallholder farmers in Africa

N2Africa is a project funded by The Bill & Melinda Gates Foundation by a grant to Plant Production Systems, Wageningen University who lead the project together with CIAT-TSBF, IITA and many partners in the Democratic Republic of Congo, Ghana, Kenya, Malawi, Mozambique, Nigeria, Rwanda and Zimbabwe.

Email: n2africa.office@wur.nl
Internet: www.N2Africa.org

Authors of this report and contact details

Name: Ilse de Jager, MSc WUR
Address: Wageningen University
P.O. Box 430, 6700AK Wageningen, The Netherlands
E-mail: ilse.dejager@wur.nl

Supervisors:

Name: Dr. Inge D. Brouwer WUR
Address: Wageningen University, Division of Human Nutrition
P.O. Box 8129, 6700 EV Wageningen, The Netherlands
E-mail: inge.brouwer@wur.nl

Name: Prof. Dr. Ken E. Giller WUR
Address: Wageningen University, Division of Plant Production Systems
P.O. Box 430, 6700 AK Wageningen, The Netherlands
E-mail: ken.giller@wur.nl

Name: Esther Ronner, MSc WUR
Address: Wageningen University, Division of Plant Production Systems
P.O. Box 430, 6700 AK Wageningen, The Netherlands
E-mail: esther.ronner@wur.nl

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Ilse de Jager, 2013. Literature study: Nutritional benefits of legume consumption at household level in rural areas of sub-Saharan Africa, www.N2Africa.org, number of pages pp. 95.

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Summary

Background. The N2Africa research project aims to enhance agricultural productivity and food security by cultivating major grain legumes such as common bean, cowpea, groundnut, soyabean, chickpea and pigeonpea. The aim of this literature review is to investigate the nutritional benefits of legume consumption at household level in rural sub-Saharan Africa. Both protein-energy malnutrition and micronutrient deficiencies are highly prevalent in sub-Saharan Africa, especially among children and women of reproductive age. Undernutrition results in substantial increases in overall disease burden and mortality, decreases in intellectual development and reduction in productivity and economic development.

Nutritional values of legumes. Grain legumes are better sources of protein and contain a larger variety and concentrations of micronutrients compared with maize, the most common consumed staple in sub-Saharan Africa. The concentration of protein in grain legumes is at least three times that of maize and grain legumes contain most essential amino acids. Grain legumes are richer in most B vitamins and in iron, better sources of calcium and have larger concentrations of zinc. Some crops (groundnut, soyabean and chickpea) are higher in fat compared with maize therefore providing more energy. The leaves of common bean and cowpea have similar nutrient concentrations as grain legumes but are higher in most micronutrients and also contain pro-vitamin A and vitamin C.

Nutritional requirements for humans. Protein and amino acid requirements for humans depend on many factors: age, energy intake, physical activity, pregnancy, lactation and protein quality. The population average requirement for protein is 0.66 g of protein per kg body weight per day when energy intake from carbohydrates and fat is sufficient. Further, an optimal diet has a least 55 % of total energy from a variety of carbohydrates for all ages except children under the age of 2 years. They require a larger fat intake. For most adults, total dietary fat intake should at least provide 15 % of energy and maximum 30 to 35 % of energy. The international recommended nutrient intakes (RNIs) for the B vitamins, folic acid, vitamin C, vitamin A, iron, calcium and zinc differ depending on age, body weight, sex, for pregnant and/or lactating women and on the bioavailability of the nutrient in a diet.

The sub-Saharan African diet. African diets are usually based on a carbohydrate staple served with soups, relishes and sauces which are prepared from a wide variety of foodstuffs including grain legumes. The carbohydrate staple contributes 40 to 60 % of the total dietary energy supply for an African diet. The relish provides protein, fat, minerals and vitamins. Meat provides on average only 3 % of dietary energy in African diets. Most of the protein intake comes from staple foods and grain legumes. The fat content tends to be small. In some countries people obtain as little as 7 to 15 % of their energy intake from fat. The consumption of grain legumes in the African diet varies with agricultural practices, climate, season and tribal customs. In sub-Saharan Africa the per capita consumption of cowpea is the highest, followed by chickpea and pigeonpea.

Added value of grain legumes in sub-Saharan African rural diet. Grain legumes add energy, proteins, minerals, B vitamins to the African diet and thus are important for diversity of the diet . They are part of two important complementary mixes, with cereals and with roots and fruits. Grain legumes add to these staples proteins, minerals and B vitamins. They supplement cereals for the essential amino acid lysine increasing the quality of protein. When added to root and fruit staples, they only raise the protein content because both have the same limiting amino acids. Where energy and protein are both deficient, leguminous oilseeds can play an important role in improving diets. Legume leaves are significant sources of B-carotene (provitamin A) and vitamin C and compared with grain legumes they add a little more of most B vitamins and more folic acid, calcium and iron to a meal.

Influencing factors on nutritional benefits of legume consumption –(1) bioavailability, (2) household shares, (3) gender. Bioavailability: 1) Grain legumes contain several non-nutritive components, such as phytate, trypsin inhibitors and tannins, that inhibit the uptake of micronutrients and decrease the digestibility of proteins and carbohydrates. Thermal heating, germination, fermentation and soaking reduce the negative effects of non-nutritive components. If grain legumes are consumed with meat and/or vitamin C, this enhances the uptake of micronutrients. If they are consumed in a diet that lacks sufficient carbohydrates or fats to meet energy needs, the protein content of the grain legumes will be converted into energy. Household shares: 2) Some evidence on food allocation within traditional African households suggest a strong pro-leader (contribution rule), pro-male and pro-adult bias with

regard to the quantity of food intake. Further, children often receive the least of the side relishes, including grain legumes, which contain valuable supplementary foods. Gender: 3) A growing body of research highlights the importance of gendered social determinants of child nutrition and health, such as maternal education and women's status, for mediating child survival. However, few published studies consider gendered intra-household bargaining power and processes. Child health and nutrition interventions would be more effective, equitable and sustainable if the interventions were designed to consider gender-sensitive information and if they were continually evaluated from a gender perspective.

Nutritional value of grain legumes in the sub-Saharan African diet. Grain legumes add energy, proteins, minerals and B vitamins to the African diet. They are part of two important complementary mixes, with cereals and with roots, tubers and fruits. They supplement cereals with the essential amino acid lysine increasing the quality of protein. When added to root and fruit staples, legumes raise the protein content but not the quality. Legume leaves are significant sources of B-carotene (provitamin A) and vitamin C. Compared with grain legumes, legume leaves add a little more of most B vitamins and more folic acid, calcium and iron to a meal. Consumption of legume-based foods improves growth in children. Iron and zinc intake are low when consuming legume-based diets. However, methods like dephytinization and fortification seem to be promising in increasing iron and zinc bioavailability in legume-based foods and improving iron and zinc status of infants, children and women of reproductive age. Evidence concerning other micronutrients is inconsistent or poor.

Impact of legume cultivation on nutrition. It is often assumed that agricultural interventions translate into improved nutrition. Recent review studies show no or little effect of agricultural interventions on nutrition and health. Within N2Africa, improved agricultural production of grain legumes could lead to increased consumption of grain legumes in the household and, via improved income from sales of grain legumes, could lead to increased purchasing of foods. Via both ways, this could result in an increase in caloric, protein and micronutrient intake. Other ways through which an agricultural intervention could affect nutrition are related to reduction of consumer food prices, changes in processing, changes in agricultural work patterns, labour devoted to agricultural production and changes in power relations within the household.

List of abbreviations

AA	Ascorbic Acid
BCAA	Branched-chain amino acids (leucine, isoleucine and valine)
BMI	Body Mass Index
DRC	Democratic Republic of the Congo
EAR	Estimated average requirement
FAO	Food and Agriculture Organisation
FeSO4	Ferrous sulfate
g	Gram
HAZ	Height/Length-for-Age Z-score
HFeZnB	High-iron-high-zinc bean variety
IFPRI	International Food Policy Research Institute
IITA	International Institute of Tropical Agriculture
INFOODS	International Network of Food Data Systems
INSTAPA	Improved Nutrition through Staple Foods in Africa
kg	Kilogram
MD	Micronutrient deficiency
MDG	Millennium development goal
mg	Milligram
MUFA	Monounsaturated fatty acids
NaFeEDTA	Ferric sodium ethylenediaminetetraacetate
NPU	Net protein utilization
PEM	Protein-energy malnutrition
PUFA	Polyunsaturated fatty acids
RCT	Randomized Controlled Trial

RE	Retinol Equivalent
RNI	Recommended nutrient intake
SAA	Sulphur amino acids (methionine and cysteine)
SFA	Saturated fatty acids
Stunting	Height-for-age Z score < -2
TAAA	Total aromatic amino acids (phenylalanine and tyrosine)
UL	Upper level
Underweight	Weight-for-age Z score < -2
UNICEF	United Nations Children's Fund
USDA	United States Department of Agriculture
Wasting	Weight-for-height Z score < -2
WAZ	Weight-for-Age Z-score
WHZ	Weight-for-Height/Length Z-score
WHO	World Health Organisation

Scientific names of grain legumes

Arachis hypogaea	Groundnut
Cajanus cajan	Pigeonpea
Cicer arietinum	Chickpea
Glycine max	Soyabean
Phaseolus vulgaris	Common bean
Vigna unguiculata	Cowpea

Glossary of concepts

'Apparently healthy'. The term 'apparently healthy' refers to the absence of disease based on clinical signs and symptoms of micronutrient deficiency or excess, and normal function as assessed by laboratory methods and physical evaluation.

Disability Adjusted Life Years (DALYs). The sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability.

Estimated Average Requirement (EAR). EAR is the average daily nutrient intake level that meets the needs of 50 % of the 'healthy' individuals in a particular age and gender group. It is based on a given criteria of adequacy which will vary depending on the specified nutrient.

Recommended Nutrient Intake (RNI). The RNI is the daily intake, set at the estimated average requirement (EAR) plus 2 standard deviations, which meets the nutrient requirements of almost all apparently healthy individuals (97.5 %) in an age- and sex-specific population group.

Stunting. Stunting reflects shortness-for-age; an indicator of chronic malnutrition and calculated by comparing the height-for-age of a child with a reference population of well-nourished and healthy children.

Underweight. Underweight is measured by comparing the weight-for-age of a child with a reference population of well-nourished and healthy children. It reflects chronic and/or acute malnutrition.

Upper level (UL). ULs have been set for some micronutrients and are defined as the maximum intake from food, water and supplements that is unlikely to pose risk of adverse health effects from excess in almost all (97.5 %) 'apparently healthy' individuals in an age- and sex-specific population group.

Wasting. Wasting reflects a recent and severe process that has led to substantial weight loss, usually associated with starvation and/or disease. Wasting is calculated by comparing weight-for-height of a child with a reference population of well-nourished and healthy children. Often used to assess the severity of emergencies because it is strongly related to mortality.

1 Introduction

Maternal and child undernutrition is highly prevalent in low-income and middle-income countries, resulting in substantial increases in mortality and overall disease burden (Black et al., 2008). Undernutrition refers to a lack of adequate energy, protein and/or micronutrients to meet basic requirements for body maintenance, growth and development. Protein-energy malnutrition is reflected by a) stunting (low height-for-age) which indicates chronic restriction of child's potential growth, b) wasting (low weight-for-height) which indicates acute weight loss and c) underweight (low weight-for-age) which indicates both acute and chronic undernutrition. Protein-energy malnutrition usually manifests early in life, in children between 0 and 2 years of age. FAO estimates that about 870 million people do not receive enough energy from their diets to meet their needs, in the period 2010 to 2012. The vast majority live in developing countries, where about 15 % of the population are estimated to be undernourished (FAO, 2012b) and 32.0 % of children under 5 years are stunted and 3.5 % wasted (Black et al., 2008). Although, on average, children's anthropometric status has improved in developing countries over the past 26 years, more than half of developing countries have less than a 50 % chance of meeting the Millennium Development Goal (MDG) of halving the prevalence of underweight children by 2015 (Stevens et al.). In 2005, Africa had the highest prevalence of stunted (40.1 %) and wasted (3.9 %) children under 5 years compared with Asia and Latin America. Within Africa, the prevalence of stunting is highest in East and Middle Africa (50.0 % and 41.5% respectively), while the prevalence of wasting is highest in Middle and West Africa (5.0 % and 4.3 % respectively) (Black et al., 2008). Twenty-three countries in Africa have a child stunting prevalence of more than 40 %, including Nigeria, Democratic Republic of the Congo (DRC), Ethiopia, Uganda, Tanzania, Malawi and Mozambique. The DRC is the country with the highest child wasting prevalence in the world (11.9 %). The global toll of people affected by micronutrient deficiency is estimated to be even higher than those affected by protein-energy malnutrition and probably exceeds two billion (FAO, 2004). Zinc (2 billion people), iron (1 billion people), iodine (740 million people) and vitamin A (250 million people) deficiency are the micronutrient deficiencies of greatest public health significance in the developing world (Muller & Krawinkel, 2005).

Undernutrition is a major component of illness and death from disease. Maternal and child undernutrition is the underlying cause of 3.5 million deaths, 35 % of the disease burden and 11 % of total global disability-adjusted life years (DALYs). Stunting, severe wasting and intrauterine growth restriction constitutes the largest percentage of any risk factor attributing to the number of global deaths and DALYs in children less than 5 years old (Black et al., 2008). Vitamin A and zinc deficiencies have by far the largest remaining disease burden among the micronutrients. Iodine and iron deficiencies both impair the cognitive development in children. Iron deficiency anaemia and maternal short stature increase the risk of death of the mother at delivery, accounting for at least 20 % of maternal mortality [1]. Vitamin B deficiencies are also prevalent in many developing countries, with many different consequences (Allen, de Benoist, Dary, & Hurrell, 2006). Additionally, undernutrition in the first two years of life leads to irreversible damage, including shorter adult height, reduced educational capacity, decreased offspring birth weight (Cesar G. Victora et al., 2008), reduced physical activity, impaired resistance to infection and impairment of mental development (FAO, 1997). In adults, undernourishment can lead to diminished productivity through reduced physical performance and can hinder community and national development by a vicious circle in which poor workers are unable to generate sufficient income to obtain sufficient calories to be productive. Although it may seem obvious, it is often difficult to demonstrate a direct link between increased agricultural production and enhanced food and nutrition security or health at household level (Masset, Haddad, Cornelius, & Isaza-Castro, 2012; Meinzen-Dick, Behrman, Menon, & Quisumbing, 2011).

A framework developed by UNICEF (UNICEF, 1990) recognises the basic and underlying causes of undernutrition, including the environmental, economic and socio-political contextual factors, with poverty having a central role. Addressing general deprivation and inequity would result in substantial reduction in undernutrition (Haddad, Alderman, Appleton, Song, & Yohannes, 2003) but halving the prevalence of underweight children by 2015 is impossible through income growth alone. To accelerate reductions in undernutrition, the direct causes, inadequate dietary intake and disease, need to be addressed by health and nutrition interventions affecting household food availability and use, maternal and child care and control of infectious diseases (Black et al., 2008).

Primary causes of undernutrition are low food intake combined with poor quality diets. Staple foods provide often ≥ 80 % of total energy intake while consumption of non-staple foods like grain legumes, fruits, vegetables and food of animal origin is low due to lack of affordability for the poor (Broughton et al., 2003). Non-staple foods are often rich micronutrient sources, and therefore low intake of these foods compromises micronutrient status of household members (Boy et al., 2009; FAO & WHO, 2002). In addition, inequity in food shares within the household further affect nutrition status of vulnerable groups like women and young children (Engle & Nieves, 1993; P. L. Engle & I. Nieves, 1993; Luo, Zhai, Jin, & Ge, 2001). Diets of subsistence farmers in Africa often contain sufficient carbohydrates (through cassava, maize, rice, wheat) but are poor in proteins and micronutrients. Grain legumes are often the largest protein source of households (Messina, 1999).

Proteins in food, supply the essential amino acids from which the body makes its own proteins. Whenever the body is growing, repairing, or replacing tissue, proteins are involved. Already in 1933 Cicely Williams diagnosed Kwashiorkor as a nutritional disease attributed to a lack of amino acids and protein. Further awareness of the effects of malnutrition brought about by the events of World War II gave additional stimulus to research on protein deficiency and starvation. In the late 1950s the official position of the WHO and FAO was that the single most important nutrient deficiency was protein. In 1959, Jelliffe created the term “protein-energy malnutrition” recognizing that protein deficiency was not the only cause of malnutrition. It is well-known that in Africa, micronutrient deficiencies and their causes are widespread (Jonsson, 2009; Schönfeldt & Hall, 2012).

Grain legumes are good sources of protein, even these with lowest contents are about three times that of rice (Aykroyd & Doughty, 1982) and they contain most essential amino acids which the human body cannot make or cannot make in sufficient quantity (Rolfes, Pinna, & Whitney, 2009). In addition, grain legumes also contribute to the intake of essential micronutrients, mainly iron, zinc, calcium and folate (Messina, 1999). However, grain legumes are limited in certain amino acids and also contain anti-nutritional factors which bind with many nutrients, including protein, and inhibits complete absorption of the nutrient from the food into the human body (Schönfeldt & Hall, 2012). Grain legumes produced and consumed in Africa include: common bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), groundnut (*Arachis hypogaea*), soyabean (*Glycine max*), chickpea (*Cicer arietinum*) and pigeonpea (*Cajanus cajan*) (Stanton, 1966). Although common bean and cowpea are grown most commonly for their edible grain, the young leaves are also consumed by humans in numerous African countries (Singh, Mohan Raj, Dashiell, & Jackai, 1997).

N2Africa is a large scale, science research project focused on putting nitrogen fixation to work for smallholder farmers growing legume crops in 13 countries in Africa (Ghana, Nigeria, Liberia, Sierra Leone, DRC, Ethiopia, Kenya, Rwanda, Tanzania, Uganda, Malawi, Mozambique and Zimbabwe). N2Africa aims to enhance agricultural productivity and food security through the cultivation of common bean, cowpea, groundnut and soyabean. The relationship between agricultural productivity increase and actual consumption of legumes is unclear. Likewise, the relationship between legume consumption, nutrient intake and diversity of the diet and/or nutritional status is not straightforward. Many factors influence these relationships, such as the actual nutritional content of the grain legumes consumed and the bioavailability of the nutrients in grain legumes within the meal consumed. Therefore, questions are raised regarding the possible impact of N2Africa, via different pathways described by Hoddinott (Hoddinott, 2011) such as household income, new foods in the diet and changes in power within the household, on nutritional benefits at household level. This review aims to contribute to the following research questions:

- *What are the nutritional values of common bean and its leaves, cowpea and its leaves, groundnut, soyabean, chickpea and pigeonpea?*
- *What are the nutritional requirements for humans?*
- *What constitutes ‘the sub-Saharan African diet’?*
- *What are the influencing factors on the potential benefits of legume consumption?*
- *What is the significance of legumes in ‘the sub-Saharan African diet’?*
- *How can legume cultivation translate into improved nutrition?.*

2 Methodology

A review of current literature was conducted. Searches of the PubMed and Scopus database were done with search terms, in different combinations, specific for each research question (see Table 2.1). Further, the United States Department of Agriculture (USDA) National Nutrient Database, the websites of the Food and Agriculture Organisation (FAO), the World Health Organisation (WHO) and the International Network of Food Data Systems (INFOODS) were researched. Articles, books and reports were included which are written in English, which are published after 2000 (with some exceptions for literature which includes knowledge which not have changed) and which are relevant_for one of the specific research questions.

Table 2.1: Search terms per research topic

Research topics	Sources	Search terms
Nutritional values	USDA national nutrient database (2011) & food composition tables (FCT) from INFOODS: West African FCT (2012), South African FCT (2010), Mozambique FCT (2011), Tanzania FCT (2008) and African FCT (1968)	"food composition table*"; USDA; INFOODS; Africa AND "food composition table*"; Legume* OR "grain legume*" OR bean* OR pulse*; "common bean*" OR "phaseolus vulgaris"; leaves AND "common bean*" OR "phaseolus vulgaris"; cowpea* OR "vigna unguiculata''; leaves AND cowpea* OR "vigna unguiculata''; groundnut* OR "arachis hypogaea"; soybean* OR soyabean* OR Soya bean* OR 'glycine max'; chickpea* OR "cicer arietinum"; pigeonpea* OR "cajanus cajan"
Human requirements	WHO and FAO publications	"human nutrient requirement*"; "human nutrient requirement*"; "developing world" OR "developing country" OR developing countries";RNI*; EAR*; UL*; macronutrient*; micronutrient*; energy; water; fat*; protein*; carbohydrate*; calcium OR Ca; iron OR Fe; magnesium OR Mg; phosphorus OR P; zinc OR Zn; copper OR Cu; manganese OR Mn; thiamin OR "Vitamin B1"; riboflavin OR "Vitamin B2"; niacin OR "Vitamin B3"; "pantothenic acid" OR "Vitamin B5"; "Vitamin B6"; folate OR "folic acid" OR "Vitamin B9"; "ascorbic acid" OR "Vitamin C"; "Vitamin A"
The sub-Saharan African diet	Food balance sheets (FAO) & other sources	Legume* OR "grain legume*" OR bean* OR pulse*; consumption; Africa* OR "South Africa*" OR "West Africa*" OR "East Africa*" OR "Central Africa*" OR "East Africa*"; diet* OR meal* OR dish* OR recipe*; macronutrient* OR protein* OR carbohydrate* OR fat*; micronutrient* OR mineral* OR vitamin*; "Food balance sheet*"; FAO
Influencing factors		
Bio-availability	PubMed and Scopus database	Legume* OR "grain legume*" OR bean* OR pulse*; "food legume*"; bio-availability; "nutrient uptake"; "anti-nutritional factor*"; "anti-nutrient*"; "preparation method*"; Phytate*; "Ascorbic acid" OR "Vitamin C"; infection; nutrition; "nutritional status"

Household shares	PubMed and Scopus database	"Intra-household shares" OR "intra-household allocation" OR "intra-household distribution"; food OR resource*; "discrepancy score"; sex OR gender; wom* OR female*; age; child; Africa; Legume* OR "grain legume*" OR bean* OR pulse*;
Gender	PubMed and Scopus database	Gender OR sex; wom* OR female*; nutrition OR "nutrition security"; health; "Intra-household shares" OR "intra-household allocation" OR "intra-household distribution"; control; status; resource*; education; income
Nutritional value of legumes within sub-Saharan African diet	Above sources are combined & intervention studies	1. Legume* OR pulse* OR "grain legume*" OR "pulse grain*" OR bean* OR groundnut* OR "arachis hypogaea" OR cowpea* OR "vigna unguiculata" OR "common bean*" OR "phaseolus vulgaris" OR soybean* OR soyabean* OR Soya bean* OR "glycine max" OR chickpea* OR "cicer arietinum" OR pigeonpea* OR "cajanus cajan" OR "cowpea leaves" OR "vigna unguiculata leaves" OR "common bean leaves" OR "phaseolus vulgaris leaves" 2. "Nutrient status" OR "nutritional status" OR growth OR development OR stunt* OR wast* OR underweight OR deficienc* OR anaemia OR anaemia 3. Intake OR consumption OR eating OR ingestion 4. Nutrient* OR protein* OR micronutrient* OR mineral* OR iron OR zinc OR vitamin C OR ascorbic acid OR ascorbate OR calcium OR "vitamin B" OR thiamin OR "vitamin B-1" OR "vitamin B-6" OR folate OR "vitamin B-9" OR "vitamin A" OR beta-carotene 5. Child* OR schoolchildren OR infant* OR women OR woman OR "female adult*" OR pregnant 6. NOT men, NOT male, NOT rat*, NOT pig*, NOT cancer (1+2+4+5, 1+2+4+5+6, 1+2+4+5 all TITLE-ABS-KEY, 1+3+4+5+6 & 1+3+4+5 TITLE-ABS-KEY)
Impact of legume cultivation on nutrition security	PubMed and Scopus database	Impact OR affect; "agricultur* intervention*" OR "agricultur* project*"; "dietary diversity"; nutrition; health; "micronutrient deficienc*"; "nutritional status"; "intervention study* OR "intervention studies" OR review*

2.1 Nutritional values of legumes

To compare the nutritional values of the nutrient composition of the grain legumes within N2Africa, the USDA, West African and South African food composition tables are used. To compare the nutrient values of grain legumes with that of staple foods, the nutrient composition of maize is also given as maize is one of Africa's dominant food crops and consumed throughout Africa as a staple food (International Institute of Tropical Agriculture (IITA), 2009). Foods, being of biological origin, exhibit variations in composition due to factors such as season, geography, cultivar and husbandry. Therefore a food composition table cannot accurately predict the composition of any given single sample of a food. Hence, the concentrations of nutrients in a food composition table are essentially estimates [21]. The USDA Nutrient Database provides the foundation for most food composition databases in the public and private sectors and includes food composition tables of many different raw grain legumes (U. S. Department of Agriculture, 2011). Foods often vary in their nutrient values depending on the country and climate where they are grown (Latham, 1997). Experiences from Mali have shown that the nutrient value of locally produced foods may vary significantly from region to region within one country (Barikmo, Ouattara, & Oshaug, 2004). Therefore estimates from African national databases are probably better estimates for nutrient composition of grain legumes within the N2Africa project. However, many country specific food composition tables are not up to date, lack information on the initial source of the nutrient values and include uncertainty whether the values were original analytical data or borrowed or imputed from other sources (Barikmo et al., 2004; FAO, INFOODS, ECOWAS/WAHO, & Bioversity International, 2012; Korkalo, Hauta-alus, & Mutanen, 2011). Recently, a report is published by the International Network of Food Data Systems (INFOODS) and FAO with guidelines for checking food composition data prior to the publication of a food composition table to improve the validity of tables (I. FAO, 2012). The West African database (FAO et al., 2012) and the South African database (Medical Research Centre (MRC) of South Africa, 2010) are more or less up to date databases (the South Africa database combines information from the 1991 Food Composition Tables with updated information from two supplements, namely Vegetables and Fruit and Milk & Milk products, Eggs and Meat & Meat products) but both databases are incomplete in regard to data for some grain legumes within the N2Africa project and for some nutrients of interest. Furthermore, some data are borrowed or imputed from other sources, also from the USDA food composition table. Therefore, the USDA, West African and South African food composition tables are all three used to develop ranges of estimates of nutrients to reflect the best possible estimates from literature. Furthermore, as there are large differences among varieties of the common bean, ranges for all nutrients for this crop were developed. The USDA food composition database includes black bean, cranberry bean, French bean, Great Northern bean, kidney bean, navy bean, pink bean, pinto bean, yellow bean, small white bean and white bean. The West African food composition table also includes white bean but no other varieties and the South African food composition table includes only sugar bean. Finally, different sources are used, including country specific food composition tables, from Mozambique and Tanzania, to retrieve nutrient values for cowpea leaves. For the leaves of common beans, no data was found in the USDA, West African, South African and country specific food composition tables but information was available from the outdated (1968) FAO African food composition table.

2.2 Nutrient requirements for humans

A great deal of research has been conducted to determine human needs or requirements for different nutrients. The establishment of dietary requirements is the common foundation for all countries to develop food-based dietary guidelines for their populations. WHO and FAO are used as sources as they provide international references for human nutrient requirements and recommended intakes based on up to date research. Nutrient requirements of course vary in certain groups of people, for example in children because they have added needs for growth and in women during pregnancy and lactation. Therefore recommendations are generally presented per age and sex specific group. Macronutrients recommendations are expressed as percentage of energy and are retrieved from the most up to date WHO and FAO reports available: the WHO (2007) ‘Technical Report on Protein and Amino Acid Requirements in Human Nutrition’ (WHO, FAO, & United Nations University, 2007), the FAO report of an expert consultation (2010) ‘Fats and Fatty Acids in Human Nutrition’ (FAO, 2010) and the report of the joint FAO/WHO Expert Consultation (1998) ‘Carbohydrates in Human Nutrition’ (WHO & FAO, 1998). The dietary requirement for a micronutrient is defined as an intake level which meets a specified criteria for adequacy, thereby minimizing the risk of nutrient deficit or excess. In general, micronutrient recommendations are presented as population recommended nutrient intakes (RNIs) with a corresponding upper limit (UL) where appropriate (see the list of concepts for definitions). They are not intended to define the daily requirements of an individual. However ‘healthy’ individuals consuming within the range of the RNI and the UL can expect to minimize their risk of micronutrient deficit and excess.

2.3 The sub-Saharan African diet

General information about the African diet is retrieved from different sources. Some specific recipes are included from the recipe book by the INSTAPA (Improved Nutrition through Staple Foods in Africa) project (Greffeuille & Mouquet-Rivier, 2010). Data on consumption of individual food grains, including grain legumes, is not readily available. The FAO food security statistics website gives data by country of per capita consumption of food by major categories or groups of food based on the food balance sheets. The FAO food balance sheets are based on production and population statistics and show only average supply for the whole country and not take into account socioeconomic, climate and seasonal differences. But as this data is available for the time periods 1990-1992, 1995-1997, 2000-2002 and 2005-2007, it can be used to analyse the consumption trend of food grain legumes as a group (Akibode & Maredia, 2011). Data on production and trade can be used to estimate a proxy for average consumption of different grain legume crops at country level by estimating the 'net availability of grain legume crop consumption' as gross production (minus exports, plus imports). This can then be divided by the population for a given year to calculate per capita availability of a given grain legume in kg/year. This is only a proxy and not representative of actual level of consumption as changes in stocks in procession of traders, producers and consumers are not taken into account, nor is the seed and feed use and wastage of grain legumes after harvest and before consumption subtracted (Akibode & Maredia, 2011). To obtain more reliable information on actual food consumption patterns and trends, representative consumption surveys (24-hour recalls) need to be done. But they are both costly and time-consuming.

2.4 Influencing factors on nutritional benefits of legume consumption

Literature is retrieved about the bio-availability of micronutrients in grain legumes and the different factors influencing the bio-availability. Further, literature is retrieved on intra-household food allocation, gender and cultural beliefs and its influences on food consumption and nutritional status.

2.5 Nutritional value of grain legumes in the sub-Saharan African diet

The information retrieved for the nutritional values of grain legumes, for the human nutritional requirements, for the 'African diet' and for influencing factors are combined to draw conclusions on the additive value of grain legumes within the African diet. Further, the literature is reviewed to find evidence on the efficacy of the consumption of legume-based foods on nutrient intake and status of most vulnerable groups: reproductive women, children and infants. The focus was on Randomized Control Trials (RCTs) and only literature about human studies was included. Articles published before 2000 were also included if the research did not investigated the iron intake or status as a results of legume-based foods consumption.

2.6 Impact of legume cultivation on nutrition

Literature is retrieved on potential pathways through which agricultural interventions can affect nutrition and reviews of intervention studies are retrieved for evidence on the potential effects

3 Nutritional values of legumes

The estimates of the nutritional values of different grain legumes are reflected in Tables 3.1 to 3.4. They provide a good indication of the nutrient composition of different grain legumes. Grain legumes are good sources of protein, dietary fibre and a variety of micronutrients (Messina, 1999). As Table 3.1 shows, most grain legumes provide about 350 kcal per 100 g edible portion which is similar to the amount of energy provided by most staple foods, such as maize. However, groundnut and soyabean provide more energy per 100 g edible portion because of their higher content of fat compared with other grain legumes. Appendix II shows the nutrient values specific for each variety of the common bean.

3.1 Protein

The amount of protein in grain legumes varies considerably, but even the lowest concentrations (chickpeas with 19.3 g/100 g) are about three times that of maize. Generally, the protein content of grain legumes provides between 20 % and 30 % energy. Soyabeans are particularly high in protein, over 35 % (Messina, 1999). Proteins in food supply the amino acids from which the body makes its own proteins. Proteins are made up of 20 different amino acids, nine essential and eleven non-essential amino acids. Table 3.2 shows the concentrations of the different amino acids in the grain legumes compared with maize. Grain legumes contain most essential amino acids which the human body cannot make or cannot make in sufficient quantity (Rolfes et al., 2009), but generally do not provide the sulphur-containing amino acids, methionine and cysteine. Soyabean is an exception having higher methionine (0.5 g) and cysteine (0.7 g) per 100 g edible portion (see Table 3.2) than that of staple foods. The protein quality of soyabean equals that of animal protein (Mateos-Aparicio, Redondo Cuenca, Villanueva-Suárez, & Zapata-Revilla, 2008). In general, all grain legumes are good sources of lysine (on average grain legumes contain 1.5 g/100 g), and thus provide a useful supplement to most staple foods like maize in which lysine (0.2 g/100 g) is limiting.

3.2 Fat

Groundnut and soyabean oil are important edible oils of vegetable origin. Groundnut contains 45.9 to 49.2 g per 100 g edible portion and soyabean 15.9 to 19.9 g of fat. In contrast to the leguminous oilseeds, most grain legumes contain only small quantities of fat. Chickpea is unusual among the grain legumes in having a relatively high concentration of oil (6.0 g/100 g). The fat content of all grain legumes consists for a major part of polyunsaturated fatty acids (see Table 3.1), mainly the essential linoleic fatty acid.

3.3 Carbohydrates

About 50 % of energy in grain legumes is provided through carbohydrates (see Table 3.1), except for groundnut and soyabean, and this percentage is less compared with maize. Carbohydrates can be divided into water-soluble components, such as sugars (monosaccharides), and insoluble ones such as oligosaccharides (3 to 10 monosaccharides) and starch (polysaccharides). Grain legumes have a larger sugar content than cereals. Sucrose is the major sugar in grain legumes. Unlike cereals, grain legumes contain appreciable quantities of oligosaccharides. These are not digested by human enzymes and therefore are involved in the production of flatus from grain legumes. Some legume seeds, such as leguminous oilseeds, have been reported to lack starch. However, soyabean contains some starch granules. All grain legumes are high in dietary fibre, providing about 10 % of energy. Dietary fibre is defined by Towell (1972) as ‘the skeletal remains of plant cells that are resistant to hydrolysis by the enzymes of man’ (Aykroyd & Doughty, 1982). With regards to the dietary fibre content, groundnut and soyabean are similar to maize while common bean, cowpea, chickpea and pigeonpea contain more.

3.4 Vitamins

In general, grain legumes contain concentrations of different vitamins. Among the fat-soluble vitamins, most grain legumes contain only small amounts of carotenoids (provitamin A), vitamin E and vitamin

K. As regards to water-soluble vitamins, the thiamin (vitamin B-1) content of grain legumes is equivalent to, or slightly exceeds, that of whole cereals. Reported values range from 0.4 and 0.9 mg per 100 g edible portion (see Table 3.1), but much of the variation between and within species is doubtless due to differences in methods of estimating thiamin (Aykroyd & Doughty, 1982). Grain legumes contain little riboflavin (vitamin B-2); representative values range from 0.1 to 0.3 mg per 100 g edible portion. They are, however, a fairly good source of niacin (vitamin B-3), the grain legumes within N2Africa contain on average about 2.3 mg per 100 g edible portion (Table 3.1). Groundnuts are exceptions, containing an average of 14 mg per 100 g. There is considerable variation of vitamin content between different varieties (Ogunmodede & Oyenuga, 1970). Grain legumes contain little more pantothenic acid (vitamin B-5) than maize and in comparison with most common foods are good sources of folic acid (Table 3.1). With the exception of germinated seeds, grain legumes as consumed are almost devoid of ascorbic acid (vitamin C).

3.5 **Minerals**

Besides relevant quantities of some vitamins, grain legumes also contain some important minerals. Grain legumes are considerably richer in calcium than are most cereals. A typical value is about 150 mg per 100 g edible portion, as compared with 6 to 18 mg for maize. Soyabean contains over 200 mg per 100 g edible portion (Table 3.1). Groundnuts have a content well below the average for grain legumes. Calcium content varies widely within species, being dependent on such factors as variety, climate, cultural methods and the mineral content of the soil. Tiwari, Sharma, & Ram (1977) give a range of 155 to 233 mg per 100 g for seven varieties of chickpeas grown under similar conditions. Grain legumes are moderately good sources of iron, containing on average 7 mg per 100 g, with a range of 3 to 16 mg per 100 g edible portion (Table 3.1). Typical legume intakes in many tropical countries provide 2 to 8 mg of iron daily, which represents a considerable fraction of RNI (Aykroyd & Doughty, 1982). Further, legume grains generally contain larger zinc concentrations than maize (see Table 3.1). The contribution of the mineral concentrations to nutrient intake and nutritional status depends strongly on the bioavailability. This is discussed in Chapter 6 and 7.

3.6 **Legume leaves**

Although cowpea is grown most commonly for edible grain, the young leaves are also consumed by humans in numerous African countries (Singh et al., 1997). In Africa, the younger, tender leaves of common beans are also eaten (van Schoonhoven, 1991). At first glance, it would appear that the dry grains are a more important source of calories, proteins, vitamins and minerals than leaves. If corrected for differential moisture contents and considered on a dry weight basis, however, leaves are similar in nutrient values. In practice, dry seeds are consumed in a cooked state at about 70 % moisture content and therefore, on a per-serving basis, have only a slight nutrient advantage over leaves. Table 3.3 shows the concentrations of different nutrients for the fresh weight and dry weight of common bean and cowpea leaves. The protein concentration in common bean leaves, on a dry weight basis, is 27.3 g per 100 g edible portion and for cowpea leaves this is 24.4 g per 100 g. Younger leaves have a higher protein content (Singh et al., 1997; van Schoonhoven, 1991). The amount of protein in leaves is similar to that in seeds. However, a small portion of the nitrogen contained in legume leaves may not be protein nitrogen but nitrate and other non-protein nitrogen. Information on the specific amino acid content on a dry weight basis is missing and therefore a comparison with legume grain is not possible. The total dietary fibre content of common bean leaves increases with leaf age, but fat contents are less affected (Singh et al., 1997; van Schoonhoven, 1991). Compared with the seeds of common bean and cowpea, their leaves contain about ten times more calcium and five times more iron (see Table 3.1 and 3.3). With regards to vitamins, the leaves contain higher concentrations of thiamin, riboflavin and niacin. Like grain legumes, the leaves are good sources of folic acid. Further, the leaves are significant sources of carotenoids (provitamin A) and ascorbic acid (vitamin C), whereas the seeds of common bean and cowpea have negligible amounts (see Table 3.1 and 3.3). The nutritional values of common bean leaves are similar to those of cowpea leaves, except that common bean leaves seem to be higher in calcium, iron and ascorbic acid but contain less riboflavin.

3.7 **Conclusion**

In conclusion, compared with maize, grain legumes are better sources of protein, contain a larger variety and concentrations of micronutrients and some legume crops are higher in fat therefore providing more energy. The amount of protein in grain legumes varies considerably, but even the smallest concentrations are about three times that of maize. Being a good source of lysine, grain legumes are a useful supplement to most staple foods. Grain legumes contain most essential amino acids, but generally are limiting in the sulphur-containing amino acids, except for soyabean. Grain legumes are relatively rich in the B vitamins, especially in thiamin, niacin and folic acid, compared with maize. Grain legumes are also higher in iron, better sources of calcium and have higher concentrations of zinc. The leguminous oilseeds, groundnut and soyabean, contain a much higher fat content compared with maize while most grain legumes contain smaller quantities. The leaves of common bean and cowpea have similar nutrient concentrations as their legume seeds but also contain carotenoids (provitamin A) and ascorbic acid.

Table 3.1: Proximate, mineral and vitamin values of common bean, cowpea, groundnut, soyabean, chickpea, pigeonpea and maize

Nutrient	Unit per 100 g edible portion	Common bean* (mature seeds, raw)	Cowpea (common, mature seeds, raw)	Groundnut (all types, raw)	Soyabean (mature seeds, raw)	Chickpea (mature seeds, raw)	Pigeonpea (mature seeds, raw)	Maize (white, whole grain, raw)
Proximates								
Energy	Kcal kJ	333 – 347 [I] 1393 – 1452 [IV]	316 – 336 [I] 1340 – 1406 [I]	567 – 578 [I] 2374 – 2390 [I]	413 – 446 [I] 1730 – 1866 [I]	364 [II] 1525 [II]	301 – 343 [I] 1260 – 1435 [I]	343 – 362 [I] 1440 – 1515 [I]
Water	g	8.9 - 12.4 [IV]	11.8 - 12.0 [I]	6.3 - 6.5 [I]	7.9 - 8.5 [I]	11.5 [II]	10.6 - 13.4 [I]	10.3 – 13.4 [I]
Total protein	g	16.9 - 23.6 [IV]	21.2 - 23.5 [I]	22.4 - 25.8 [I]	34.7 - 36.5 [I]	19.3 [II]	18.4 - 21.7 [I]	8.1 – 8.5 [I]
Total fat	g	0.8 - 2.6 [IV]	1.3 [I]	45.9 - 49.2 [I]	15.9 - 19.9 [I]	6.0 [II]	1.5 [I]	3.6 – 4.0 [I]
-polyunsaturated FA	g	0.4 - 1.4 [II]	0.9 [II]	50.6 [II]	11.3 [II]	2.7 [II]	0.8 [II]	1.6 [II]
Total carbohydrate	g	53.2 - 65.6 [IV]	47.2 - 60.0 [I]	14.6 - 16.1 [I]	28.3 - 30.2 [I]	60.7 [II]	43.2 - 62.8 [I]	63.3 - 76.9 [I]
-dietary fibre	g	10.3 - 25.2 [IV]	10.6 – 15.3 [I]	8.5 [I]	4.1 - 9.3 [I]	17.4 [II]	15.0 – 20.2 [I]	7.3 – 9.7 [I]
Vitamins								
Thiamin (B-1)	mg	0.4 – 0.9 [IV]	0.7 - 0.9 [I]	0.6 – 0.9 I	0.7 - 0.9 [I]	0.5 [II]	0.6 [I]	0.3 - 0.4 [I]
Riboflavin (B-2)	mg	0.1 – 0.3 [IV]	0.2 [I]	0.1 [I]	0.3 - 0.9 [I]	0.2 [II]	0.2 [I]	0.1 - 0.2 [I]
Niacin (B-3)	mg	0.5 – 2.5 [IV]	2.1 – 3.1 [I]	12.1 – 15.5 [I]	1.6 – 2.0 [I]	1.5 [II]	2.9 - 3.0 [I]	2.0 - 3.6 [I]
Pantothenic acid (B-5)	mg	0.7 – 1.1 [II]	1.5 [II]	1.77 [II]	0.8 [II]	1.6 [II]	1.3 [II]	0.4 [I]
Vitamin B-6	mg	0.3 – 0.5 [IV]	0.36 [I]	0.4 – 0.6 [I]	0.4 – 0.8 [I]	0.5 [II]	0.3 [I]	0.2 - 0.3 [I]
Folic acid (B-9)	µg	364 – 604 [IV]	417 - 633 [I]	110 - 240 [I]	375 – 381 [I]	557 [II]	456 [I]	25 [I]
Ascorbic acid (C)	mg	0.0 – 6.3 [IV]	0.8 - 1.5 [I]	0.0 [I]	6.0 [II]	4.0 [II]	0.0 [II]	0.0 [I]
Vitamin A	mcg RAE**	0 – 15 [I]	3 [I]	0 [I]	1 [I]	3 [II]	1 [I]	0 [II]
Minerals								
Calcium, Ca	mg	74 – 240 [IV]	82 - 110 [I]	47 - 92 [I]	206 - 277 [I]	105 [II]	130 – 257 [I]	6 – 18 [I]
Iron, Fe	mg	3.4 – 10.4 [IV]	7.3 - 8.3 [I]	3.9 - 4.6 [I]	6.5 - 15.7 [I]	6.2 [II]	4.7 - 5.2 [I]	3.0 - 3.5 [I]
Magnesium, Mg	mg	140 – 222 [IV]	184 – 187 [I]	168 – 191 [I]	249 – 280 [I]	115 [II]	183 [I]	80 - 127 [I]
Phosphorus, P	mg	301 – 488 [IV]	387 – 424 [I]	359 – 376 [I]	536 – 704 [I]	366 [II]	269 – 367 [I]	240 - 241 [I]
Zinc, Zn	mg	1.9 – 3.8 [IV]	3.4 – 4.6 [I]	2.5 - 3.3 [I]	4.8 - 4.9 [I]	3.4 [II]	2.0 - 2.8 [I]	1.5 - 1.8 [I]
Copper, Cu	mg	0.4 – 1.0 [IV]	0.7 - 0.9 [I]	0.9 - 1.1 [I]	1.5 - 1.7 [I]	0.9 [II]	1.0 - 1.1 [I]	0.2 [I]
Manganese, Mn	mg	0.9 – 1.8 [II]	1.5 [II]	1.9 [II]	2.5 [II]	2.2 [II]	1.8 [II]	0.5 [II]
Selenium, Se	mg	3.2 – 28.0 [II]	9.0 [II]	7.2 [II]	17.8 [II]	8.2 [II]	8.2 [II]	15.5 [II]

Note. The data is adapted from ‘USDA National Nutrient Database for Standard Reference, Release 24’ by U. S. Department of Agriculture, 2011, available from: http://ndb.nal.usda.gov/ndb/foods/list; from ‘West African Food Composition table’ by FAO, Infoods, ECOWAS/WAHO and Biodiversity International, 2012, available from: http://www.fao.org/docrep/015/i2698b/i2698b00.pdf; & from ‘South African Food Data System’ by South African MRC, 2010, available from http://safoods.mrc.ac.za/. [I]USDA & West African table; [II]USDA; [IV]USDA, West African & South African table; *range of varieties of common bean: black bean (USDA), cranberry bean (USDA), French bean (USDA), Great Northern bean (USDA), kidney bean (USDA), navy bean (USDA), pink bean (USDA), pinto bean (USDA), yellow bean (USDA), small white bean (USDA) and white bean (USDA & West African table) & sugar bean (South African table); **retinol activity equivalents (RAE), accounting for the different bioactivities of retinol and provitamin A carotenoids.

Table 3.2: Amino acid composition of protein in common bean, cowpea, groundnut, soyabean, chickpea, pigeonpea and maize

Nutrient	Unit per 100 g edible portion	**Common bean*** (mature seeds, raw)	**Cowpea** (common, mature seeds, raw)	**Cowpea leaves** (raw)	**Groundnut** (all types, raw)	**Soyabean** (mature seeds, raw)	**Chickpea** (mature seeds, raw)	**Pigeonpea** (mature seeds, raw)	**Maize** (white, whole grain)
Total protein	g	18.8 - 23.6	23.5	4.5	25.8	36.5	19.3	21.7	8.1
Essential amino acids									
Histidine	g	0.5 – 0.7	0.7	0.1	0.7	1.1	0.5	0.8	0.3
Isoleucine	g	0.8 – 1.0	1.0	0.3	0.9	2.0	0.8	0.8	0.3
Leucine	g	1.5 – 1.9	1.8	0.4	1.7	3.3	1.4	1.5	1.0
Lysine	g	1.3 – 1.6	1.6	0.4	0.9	2.7	1.3	1.5	0.2
Methionine	g	0.3 - 0.4	0.3	0.1	0.3	0.5	0.3	0.2	0.3
Phenylalanine	g	1.0 – 1.3	1.4	0.2	1.3	2.1	1.0	1.9	0.4
Threonine	g	0.7 – 1.0	0.9	0.2	0.9	1.8	0.7	0.8	0.3
Tryptophan	g	0.2 – 0.3	0.3	0.0	0.3	0.6	0.2	0.2	0.1
Valine	g	1.0 – 1.2	1.1	0.2	1.1	2.0	0.8	0.9	0.4
Non-essential amino acids									
Alanine	g	0.8 – 1.0	1.1	0.3	1.0	1.9	0.8	1.0	0.6
Arginine	g	1.0 – 1.5	1.6	0.3	3.1	3.2	1.8	1.3	0.4
Aspartic acid	g	2.3 – 2.9	2.8	0.5	3.1	5.1	2.3	2.1	0.6
Cysteine	g	0.2 – 0.3	0.3	0.1	0.3	0.7	0.3	0.3	0.1
Glutamic acid	g	2.9 – 3.6	4.5	0.6	5.4	7.9	3.4	5.0	1.5
Glycine	g	0.7 – 0.9	1.0	0.3	1.6	1.9	0.8	0.8	0.3
Proline	g	0.8 – 1.1	1.1	0.2	1.1	2.4	0.8	1.0	0.7
Serine	g	1.0 -1.3	1.2	0.2	1.3	2.4	1.0	1.0	0.4
Tyrosine	g	0.4 – 0.7	0.8	0.2	1.0	1.5	0.5	0.5	0.3

Note. The data is adapted from 'USDA National Nutrient Database for Standard Reference, Release 24' by U. S. Department of Agriculture, 2011, available from: http://ndb.nal.usda.gov/ndb/foods/list & the data for cowpea leaves is adapted from 'South African Food Data System' by South African MRC, 2010, available from http://safoods.mrc.ac.za/.
*range of varieties of common bean: black bean, cranberry bean, French bean, Great Northern bean, kidney bean, navy bean, pink bean, pinto bean, yellow bean, small white bean and white bean.

Table 3.3: Proximate, mineral and vitamin values of common bean leaves and cowpea leaves

Nutrient	Unit per 100 g edible portion	**Common bean leaves*** (raw, fresh weight)	**Common bean leaves*** (raw, dry weight)	**Cowpea leaves**** (raw, fresh weight)	**Cowpea leaves***** (raw, dry weight)
Proximates					
Energy	Kcal	36	272	37 - 97	282
Water	g	87	-	73.2 – 85.8	10.3
Total protein	g	3.6	27.3	4.5 – 9.3	24.4
Total fat	g	0.4	0.3	0.4 - 0.9	1.9
Total carbohydrate	g	6.6	50.0	3.3 - 12.9	29.8
Minerals					
Calcium, Ca	mg	274	2075	49.7 - 276	1060
Iron, Fe	mg	9.2	69.7	0.8 - 5.8	34
Magnesium, Mg	mg	-	-	58 - 62	401
Phosphorus, P	mg	75	-	72 - 106	364
Zinc, Zn	mg	-	-	0.4 – 1.4	3.35
Copper, Cu	mg	-	-	0.2 – 0.3	1.81
Manganese, Mn	mg	-	-	0.1 – 0.7	-
Vitamins					
Thiamin (Vitamin B-1)	mg	0.2	1.4	0.1 – 0.5	1.15
Riboflavin (Vitamin B-2)	mg	0.1	-	0.2 – 8.3	2.35
Niacin (Vitamin B-3)	mg	1.3	9.8	0.9 - 1.6	10.2
Pantothenic acid (Vitamin B-5)	mg	-	-	0.3	-
Vitamin B-6	mg	-	-	0.2 – 0.5	1.49
Folate (Vitamin B-9)	µg	-	-	104 - 132	673
Ascorbic acid (vitamin C)	mg	110	-	32.4 – 62.5	38
Vitamin A	Mcg RAE	-	-	212 - 519	201

Note. The data is adapted from 'USDA National Nutrient Database for Standard Reference, Release 24' by U. S. Department of Agriculture, 2011, available from: http://ndb.nal.usda.gov/ndb/foods/list, from 'West African Food Composition table' by FAO, Infoods, ECOWAS/WAHO and Biodiversity International, 2012, available from: http://www.fao.org/docrep/015/i2698b/i2698b00.pdf, from 'South African Food Data System' by South African MRC, 2010, available from: http://safoods.mrc.ac.za/, from 'Food Composition Tables for Mozambique' by University of Helsinki, 2011, available from: http://www.helsinki.fi/food-and-environment/research/groups/Food_composition_tables_for_Mozambique.pdf, from 'Tanzania food composition tables' by University and Food and Nutrition centre of Dar es Salaam and Harvard School of Public Health, 2008, available from: https://apps.sph.harvard.edu/publisher/upload/nutritionsource/files/tanzania-food-composition-tables.pdf. & from 'Food composition table for use in Africa' by FAO/HEW, 1968, avaialblle from: http://www.fao.org/docrep/003/X6877E/X6877E10.htm
*FAO African food composition table; **West African, South African, Mozambique & Tanzania food composition table; *** West African;

4 Nutritional requirements for human

The establishment of dietary requirements is the common foundation for all countries to develop food-based dietary guidelines for their populations. Table 4.1 includes a simple classification of the functions in the human body of different nutrients and Appendix III describes in more detail the physiological function of these nutrients. Tables 4.2 to 4.9 provide international recommended intakes of selected macronutrients and micronutrients that will maintain health, prevent deficiency diseases and allow adequate stores of nutrients in normal circumstances, based on the most up to date knowledge on human requirements.

Table 4.1: Simple classification of dietary nutrients

Nutrients	**Function in the human body**
Proteins	For growth and repair
Carbohydrates	As fuel for energy for body heat and work
Fats	As fuel for energy and essential fatty acids
Minerals	For developing body tissues and for metabolic processes and protection
Vitamins	For metabolic processes and protection

Note. Adapted from ‘Agriculture food and nutrition for Africa’ by FAO, 1997, available from: http://www.fao.org/docrep/w0078e/w0078e00.htm.

4.1 Protein

Proteins have a crucial role in virtually all biological processes. The utilization of protein for growth and maintenance depends on the balance of the amino acids content, some have higher quality than others. The amino acids that are not used for protein metabolism will be diverted for use as an energy source. The protein requirement can be defined as: the *lowest level of dietary protein intake that will balance the losses of nitrogen from the body, and thus maintain the body protein mass, in persons at energy balance with modest levels of physical activity, plus, in children or in pregnant or lactating women, the needs associated with the deposition of tissues or the secretion of milk at rates consistent with good health.* The WHO Technical Report on protein and amino acid requirements in human nutrition states that the best estimate for a population average requirement is 0.66g protein/kg body weight per day (WHO et al., 2007). The safe level was reported at 0.83 g protein/kg per day to meet the needs of a healthy adult population. In other words, these recommendations mean that the average requirement for a 90 kg male will be around 75 g of protein per day (WHO et al., 2007). When enough staple food is available to meet peoples’ energy requirements, their protein requirements are also likely to be met. Conversely, protein undernutrition is usually associated with energy deficiency resulting from an insufficient overall intake of food (FAO, 1997). Safe level of protein intake for adult and men and women; for infants, children and adolescent boys and girls; and the extra protein requirements for pregnant and lactating women are shown in Table 1 to 3 in Appendix IV.

To satisfy the metabolic demand, the dietary protein must contain: a) adequate and digestible amounts of nutritionally essential amino acids, b) non-essential amino acids that became essential under specific physiological or pathological conditions and c) sufficient total amino acid nitrogen. The latter can be supplied from any of the above amino acids, from non-essential amino acids or from other sources of non-essential nitrogen. The essential amino acids are leucine, isoleucine, valine, lysine, threonine, tryptophan, methionine, phenylalanine and histidine. The essential amino acid requirement estimates in the 1985 FAO/WHO/UNU report were based on nitrogen balance studies. These nitrogen balance estimates are lower than estimates made using a different method, stable isotope (WHO et al., 2007). Box 4.1 includes a description of the essential amino acid requirements and Table 4.2 shows the (newer) estimates of the requirements for several essential amino acids for infants, children, adolescents and adults determined by the stable isotope method. Table 4 in Appendix IV shows all the adult essential amino acid requirements, both from the stable isotope studies and from the nitrogen balance studies.

Box 4.1: Description of the essential amino acid and their requirements

The requirement for **lysine** has received most attention given its nutritional importance as the likely limiting amino acid in cereals, especially wheat. **Leucine** is the most abundant amino acid in tissue and food proteins but specific demands for non-protein functions have not been identified. Since the three branched-chain amino acids (BCAA: leucine, **isoleucine and valine**) share a common catabolic pathway for their oxidation, and because their maintenance requirements reflect mainly their basal rates of catabolism, isoleucine and valine requirements are estimated from an assumed proportionality with leucine, based on the amino acid composition of body protein. The **threonine** requirement is particularly nutritionally important, since it has been suggested that, after the sulphur amino acids, it is the second rate-limiting amino acid in the maintenance requirement. Of the aromatic amino acids (AAA), **phenylalanine** and tyrosine, the former is nutritionally indispensable while the latter, as a metabolic product of phenylalanine catabolism, is dependent on there being sufficient phenylalanine to supply the needs for both amino acids. Whereas the occurrence of **tryptophan** in proteins is generally less than many other amino acids, it is nutritionally important since it is a precursor for important metabolites such as serotonin and nicotinamide, in the latter case giving it vitamin-like properties through its ability to replace dietary niacin. Its content is low in cereals, especially maize, where it may be the nutritionally limiting amino acid in some varieties. Of the total sulphur amino acids (SAA), **methionine** and cysteine, the former is nutritionally indispensable while the latter, as a metabolic product of methionine catabolism, is dependent on there being sufficient methionine to supply the needs for both amino acids. They are important nutritionally since their concentrations are marginal in legume proteins, although they are equally abundant in cereal and animal proteins. **Histidine** is considered to be an indispensable amino acid because of the detrimental effects on haemoglobin concentrations that have been observed (*10*) when individuals are fed histidine-free diets.

Table 4.2: Several essential amino acid requirements of infants, children, adolescents and adults

	(mg/kg per day)				(mg/g protein)[a]			
Age (years)	Lysine	Methionine & cysteine	Threonine	Tryptophan	Lysine	Methionine & cysteine	Threonine	Tryptophan
0.5	64	31	34	9.5	57	28	31	8.5
1-2	45	22	23	6.4	52	26	27	7.4
3-10	35	18	18	4.8	48	24	25	6.6
11-14	35	17	18	4.8	48	23	25	6.5
15-18	33	16	17	4.5	47	23	24	6.3
>18	30	15	15	4.0	45	22	23	6.0

Note. Adapted from the report of a joint FAO, WHO and UNU expert consultation 'Protein and amino acid requirements in human nutrition' by WHO, 2007.
[a]Calculated as the individual amino acid requirement divided by the total protein requirement (0.66 g protein/kg per day)

4.2 Fat

Fats and oils are concentrated forms of energy. The energy yield from the complete oxidation of fatty acids is about 9 kcal per gram, in comparison with about 4 kcal per gram for carbohydrates and proteins. Therefore intake of fat is important for energy. Especially, in populations with inadequate total energy intake, such as in many developing regions, dietary fats are an important macronutrient that contribute to energy intake. Furthermore, the intake of fat is important for the essential fatty acids. Fatty acids are often grouped into three broad groups, based on the number of double bonds, namely saturated fatty acids (SFA), monounsaturated fatty acids (MUFA) and polyunsaturated fatty acids (PUFA). However, it is recognized that individual fatty acids within each broad classification of fatty acids may have unique biological properties and health effects. The minimal total fat intake for adults is 15 % of energy to ensure adequate consumption of total energy, essential fatty acids, and fat soluble vitamins for most individuals. For women of reproductive age and adults with a body mass index (BMI) of lower than 18.5, especially in developing countries in which dietary fat may be important to achieve adequate energy intake in malnourished populations, a minimal fat intake of 20 %

of energy is recommended. The maximum total fat intake for most individuals is 30 to 35 % of energy (see Table 4.3) (FAO, 2010).

Table 4.3: FAO/WHO recommendations on dietary fat

- Dietary fat should supply at least 15 % of energy for most adults.
- Women of reproductive age should consume at least 20 % of energy from fat.
- Diets of young children should undergo a gradual transition from breast-milk (50–60 % energy from fat) towards the adult recommendations, with care taken to avoid dietary fat intake falling too rapidly or below required levels for growth and development. During weaning and until 2 years a child's diet should contain 30–40 % energy from fat.
- Sedentary individuals should not consume more than 30 % energy from fat.
- Active individuals in energy balance may consume up to 35 % energy from fat.
- Intakes of saturated fat should not exceed 10 % of energy.

Note. Adapted from the FAO report 'Fats and fatty acids in human nutrition', by FAO and WHO, 2010

4.3 Carbohydrate

Carbohydrates have a wide range of physiological effects which may be important to health, such as provision of energy, effects on satiety/gastric emptying, control of blood glucose and insulin metabolism. The minimum amount of carbohydrate in the human diet that is needed to avoid ketosis (a state of elevated levels of ketone bodies in the body, which are formed by the liver when glycogen stores are depleted and used for energy) is of the order of 50 g per day in adults. But an optimum diet consists of at least 55 % of total energy from a variety of carbohydrate sources for all ages except for children under the age of two (WHO & FAO, 1998). Table 4.4 shows the latest international recommendations by FAO and WHO.

Table 4.4: FAO/WHO recommendations on dietary carbohydrate

- Optimal diet has at least 55 % of total energy from a variety of carbohydrates for all ages except children under the age of 2 years.
- Fat should not be specifically restricted in children under 2 years.
- The bulk of carbohydrate-containing foods should be rich in non-starch polysaccharides and with low glycaemic index.

Note. Adapted from the report of the WHO/FAO Expert Consultation 'Carbohydrates in human nutrition', by FAO and WHO, 1998

4.4 Vitamins

Vitamins are a chemically unrelated group of organic molecules needed in small amounts in human diets. Fat-soluble vitamins (vitamin A) can, to some extent, be stored in the body and are not normally excreted in the urine. Water-soluble vitamins (vitamin C and B vitamins), however, are largely excreted, and little is retained by the body for immediate use; a daily dietary intake is therefore desirable.

The B-complex vitamins. The main functions of these water-soluble vitamins are in the metabolism of carbohydrates during energy production and in regulating the body's use of protein (Rolfes et al., 2009). They are listed in Table 4.5 along with the physiological roles of the coenzyme forms and a brief description of clinical deficiency symptoms. Table 4.6 shows recommended nutrient intakes for the B vitamins for different groups (WHO & FAO, 2004). Thiamine, riboflavin and niacin usually occur together in foods, but in different proportions depending on the food source. The richest sources are meats, fish, eggs and milk, and there are good supplies in all grain legumes and whole-grain cereals. Oilseeds have useful quantities, and small amounts are obtained from regular intake of fruits and green leafy vegetables (Rolfes et al., 2009).

Table 4.5: Physiological roles and deficiency signs of B-complex vitamins

Vitamin	Physiological roles	Clinical signs of deficiency
Thiamin (B1)	Coenzyme functions in metabolism of carbohydrates and branched-chain amino acids	Beriberi, polyneuritis, and Wernicke-Korsakoff syndrome
Riboflavin (B2)	Coenzyme functions in numerous oxidation and reduction reactions	Growth, cheilosis, angular stomatitis, and dermatitis
Niacin (B3, nicotinic acid, nicotinamide)	Cosubstrate/coenzyme for hydrogen transfer with numerous dehydrogenases	Pellagra with diarrhoea, dermatitis, and dementia
Vitamin B6 (pyridoxine, pyridoxamine, pyridoxal)	Coenzyme functions in metabolism of amino acids, glycogen, and sphingoid bases	Nasolateral seborrhoea, glossitis, and peripheral neuropathy
Pantothenic acid (B5)	Constituent of coenzyme A and phosphopantetheine involved in fatty acid metabolism	Fatigue, sleep disturbances, impaired coordination, and nausea

Note. Adapted from 'Vitamin and mineral requirements in human nutrition' by WHO and FAO, 2004.

Table 4.6: Recommended nutrient intakes for B-complex vitamins (thiamine, riboflavin, niacin, Vitamin B6 and pantothenic acid), by group

Group	Thiamine (mg/day)	Riboflavin (mg/day)	Niacin (mg NEs/day)*	Vitamin B6 (mg/day)	pantothenic acid (mg/day)
Infants and children					
0-6 months	0.2	0.3	2**	0.1	1.7
7-12 months	0.3	0.4	4	0.3	1.8
1-3 years	0.5	0.5	6	0.5	2.0
4-6 years	0.6	0.6	8	0.6	3.0
7-9 years	0.9	0.9	12	1.0	4.0
Adolescents			16		5.0
Females, 10-18 years	1.1	1.0	-	1.2	-
Males, 10-18 years	1.2	1.3	-	1.3	-
Adults					
Females, 19+ years	1.1	1.1	14	1.3-1.5	5.0
Males, 19+ years	1.2	1.3	16	1.3-1.7	5.0
Pregnant women	1.4	1.4	18	1.9	6.0
Lactating women	1.5	1.6	17	2.0	7.0

Note. Adapted from 'Vitamin and mineral requirements in human nutrition' by WHO and FAO, 2004.
*NEs: niacin equivalents; **Preformed.

Folic acid. Folic acid is essential to numerous bodily functions. The human body needs it to synthesize DNA, repair DNA, and methylate DNA as well as to act as a cofactor in certain biological reactions. Folic acid is especially important in aiding rapid cell division and growth, such as in infancy and pregnancy. Children and adults both require folic acid to produce healthy red blood cells and prevent anaemia. Mild deficiency is relatively common but can usually be corrected by increasing the daily consumption of foods containing folic acid. More severe deficiency may occur during pregnancy and breastfeeding, in premature or low-birth-weight babies (neural tube defects) and in people taking certain drugs, including some antimalarial (Rolfes et al., 2009). Table 4.7 shows RNIs for folic acid for different groups. Although folic acid is found in a wide variety of foods, it is present in a relatively low density except in liver and raw dark-green leafy vegetables. Diets that contain adequate amounts of fresh green vegetables (more than 3 servings per day) will be good folic acid sources (WHO & FAO, 2004).

Vitamin C. Vitamin C is also known by its chemical name, ascorbic acid. Vitamin C acts as an electron donor (reducing agent or antioxidant), and probably all of its biochemical and molecular roles can be accounted for by this function. It is known that vitamin C is important for the growth and maintenance of healthy bones, teeth, gums, ligaments and blood vessels. It is also involved in the production of chemicals responsible for the transmission of nerve impulses between nerve cells (neurotransmitters) and in the production of adrenal gland hormones. Vitamin C is also involved in the response of the immune system to infection and in wound healing. In addition, it assists in the absorption by the body of non-haem iron, the form of dietary iron found in plants, which is not easily absorbed through the gut wall (Rolfes et al., 2009). Table 4.7 shows RNIs for vitamin C for different groups. Prolonged deficiency of vitamin C in the diet causes scurvy, a disease in which the body's immune system is weakened. The epithelial cells lose their binding power, which makes wound healing difficult and bruising easy. The principal dietary sources of vitamin C are fresh fruits and vegetables, fresh animal milk and breast milk (WHO & FAO, 2004).

Table 4.7: Recommended nutrient intakes (RNIs) for folic acid and vitamin C and the recommended safe intake for vitamin A, by group

Group	Folic acid (µg/day)[a]	Vitamin C (mg/day)[b]	Vitamin A (µg RE/day)[d]
Infants and children			
0-6 months	80	25	375
7-12 months	80	30[c]	400
1-3 years	150	30[c]	400
4-6 years	200	30[c]	450
7-9 years	300	35[c]	500
Adolescents, 10-18 years	400	40[c]	600
Adults	400	45	
Females, 19+ years	-	-	500-600
Males, 19+ years	-	-	600
Pregnant women	600	55	800
Lactating women	500	70	850

Note. Adapted from 'Vitamin and mineral requirements in human nutrition' by WHO and FAO, 2004.
[a]expressed as dietary folate equivalents; [b]larger amounts may often be required to ensure adequate absorption of no-haem iron; [c]Arbritary values; [d]RE: retional equivalent.

Vitamin A. Vitamin A is involved in vision, as it helps to keep the front of the eye strong, clear and moist. It is also involved in cell differentiation, reproduction and growth and in the immune response. It helps to keep all the cells on the surface of the body in a healthy condition, including the skin, the surface of the eye, the inside of the mouth, the cells that line the gut and the cells that line the respiratory tract. When there is a deficiency of vitamin A in the body, symptoms show in the eyes and in the surface tissues. Table 4.7 shows the 'safe level of intake' for vitamin A for different groups. The 'safe level of intake' is used because the intake levels do not strictly correspond to the definition of RNI. Vitamin A can occur in two forms in foods: retinol (already formed vitamin A), which is colourless and found only in animal products, and carotene (pro-vitamin A, beta-carotene is the most important form), which is an orange pigment found in many foods including red palm oil, carrots, sweet potato, tomato, oranges, mango, papaya and dark-green leafy vegetables (Rolfes et al., 2009). Carotene is converted to retinol in the walls of the intestine. Each µg of retinol equivalent (RE) corresponds to 1 µg retinol, 2 µg of β-carotene in oil, 12 µg of other dietary beta-carotene or 24 µg of other dietary provitamin-A carotenoids. Fat, protein, zinc and vitamin E all help in absorption and utilization of vitamin A by the body (WHO & FAO, 2004).

4.5 Minerals

Minerals are another group of chemical compounds used by the body that must be provided by the diet. Minerals occur in varying quantities within the food system. Most minerals are required in minute amounts and have very specific functions in the human body.

Iron. Iron has several vital functions in the body. It serves as a carrier of oxygen to the tissues from the lungs by red blood cell haemoglobin, as a transport medium for electrons within cells, and as an integrated part of important enzyme systems in various tissues. Most of the iron in the body is present in the red blood cells as haemoglobin. Iron is also involved in the formation of myoglobin, which is the oxygen-carrying pigment in muscle cells. Red blood cells have a life span of only about four months. The nutrients required to replace red blood cells include iron to make haemoglobin, together with folic acid and protein. The body can store some iron in the tissues and can also recycle some of the iron when red blood cells die. However, a continual supply of iron must be absorbed from the diet to retain health. Daily iron requirements for men, women, children and infants for different diets are shown in Table 4.8. There are two types of iron in food, haem iron and non-haem iron. Haem iron is obtained from meat and relatively good absorbed. The iron in plants, eggs and milk is in a form of non-haem iron. During digestion, this inorganic iron is partly reduced to the more readily absorbed form. However, the human body may actually absorb less than 5 % of the non-haem iron consumed. Therefore dietary iron bioavailability is low in populations consuming monotonous plant-based diets (Zimmermann & Hurrell, 2007). This is discussed in chapter 7.

Table 4.8: Recommended nutrient intakes for iron for different dietary iron bioavailabilities

		RNI (mg/day) for a dietary iron bioavailability of			
Group	Mean body weight (kg)	15 %[a]	12 %[a]	10 %[b]	5 %[c]
Infants and children					
0.5-1 years	9	6.2[d]	7.7[d]	9.3[d]	18.6[d]
1-3 years	13	3.9	4.8	5.8	11.6
4-6 years	19	4.2	5.3	6.3	12.6
7-10 years	28	5.9	7.4	8.9	17.8
Males					
11-14 years	45	9.7	12.2	14.6	29.2
15-17 years	64	12.5	15.7	18.8	37.6
18+ years	75	9.1	11.4	13.7	27.4
Females					
11-14 years (pre-menarche)	46	9.3	11.7	14.0	28.0
11-14 years (menarche)	46	21.8	27.7	32.7	65.4
15-17 years	56	20.7	25.8	31.0	62.0
18+ years	62	19.6	24.5	29.4	58.8
Postmenopausal	62	7.5	9.4	11.3	22.6
Lactating	62	10.0	12.5	15.0	30.0

Note. Adapted from 'Vitamin and mineral requirements in human nutrition' by WHO and FAO, 2004.
[a]A diet rich in vitamin C and animal protein; [b]A diet rich in cereals, low in animal protein but rich in vitamin C; [c]A diet poor in vitamin C and animal protein; [d]Bioavailability of dietary iron during this period varies greatly.

Calcium. Calcium salts provide rigidity to the skeleton and calcium ions play a role in many, if not most, metabolic processes. Many neurotransmitters and other cellular functions depend on the maintenance of the ionized calcium concentration in the extracellular fluid. Growing children and pregnant and breastfeeding women require extra amounts of calcium in the diet, as they absorb and retain more calcium for the formation of new bone. A problem related to a lifelong lack of calcium in the diet is osteoporosis (bone mineral loss) which contributes to fractures in elderly. Adequate calcium intake throughout life and regular physical activity help to prevent osteoporosis (this does not mean that all osteoporosis can be attributed to calcium deficiency, there are many other causes). Table 4.9 shows theoretical calcium allowances based on an animal protein intake of 20 to 40 g and recommended calcium allowances for an intake of 60 to 80 g of animal protein. The calculated RNIs for a diet including 20 to 40 g of animal protein are more relevant for developing countries. Good sources of calcium are milk, cheese, small fish containing bones that can be eaten, grain legumes, millet and dark-green leaves.

Table 4.9: Recommended nutrient intakes for calcium, for a diet low (20 to 40 g) and a diet high (60 to 80 g) in animal protein

Group	Calcium (mg/day)[a]	Calcium (mg/day)[c]
Infants and children		
0-6 months		
Human milk	300	300
Cow milk	400	400
7-12 months	450	400
1-3 years	500	500
4-6 years	550	600
7-9 years	700	700
Adolescents, 10-18 years	1000[b]	1300[b]
Adults		
Females		
19 years to menopause	750	1000
Postmenopause	800	1300
Males		
19-65 years	750	1000
65+ years	800	1300
Pregnant women	800	1200
Lactating women	750	1000

Note. Adapted from 'Vitamin and mineral requirements in human nutrition' by WHO and FAO, 2004.
[a]Theoretical calcium allowances based on an animal protein intake of 20 to 40 g (average for developing countries) instead of 60 to 80 g (typical for developed countries); [b]Particularly during the growth spurt; [c]Recommended calcium allowances based on North American and western European data (an average intake of 60 to 80 g of animal protein.

Zinc. Zinc is an essential component of a large number of enzymes participating in the synthesis and degradation of carbohydrates, lipids and proteins as well as in the metabolism of other micronutrients. Zinc stabilizes the molecular structure of cellular components and membranes and in this way contributes to the maintenance of cell and organ integrity. Its involvement in such fundamental activities probably accounts for the essentiality of zinc for all life forms. Zinc also plays a central role in the immune system, affecting a number of aspects of cellular and humoral immunity. The clinical features of severe zinc deficiency in humans are growth retardation, delayed sexual and bone maturation, skin lesions, diarrhoea, impaired appetite, increased susceptibility to infections and the appearance of behavioural changes. The effects of mild zinc deficiency are less clear. A reduced growth rate and impairments of immune defence are so far the only clearly demonstrated signs of mild zinc deficiency in humans (WHO & FAO, 2004). Daily zinc requirements for men, women, children and infants for different diets are shown in Table 4.10. Flesh foods are the richest sources of bioavailable zinc are.

Table 4.10: Recommended nutrient intakes for dietary zinc (mg/day) to meet the normative storage requirements from diets differing in zinc bioavailability

		RNI (mg/day) for a zinc bioavailability of		
Group	Mean body weight (kg)	50 %	30 %	15 %
Infants and children				
0-6 months	6	1.1	2.8	6.6
7-12 months	9	0.8, 2.5	4.1	8.4
1-3 years	12	2.4	4.1	8.3
4-6 years	17	2.9	4.8	9.6
7-9 years	25	3.3	5.6	11.2
Adolescents				
Females, 10-18 years	47	4.3	7.2	14.2
Males, 10-18 years	49	5.1	8.6	17.1
Adults				
Females 19+ years	55	3.0	4.9	9.8
Males 19+ years	65	4.2	7.0	14.0
Postmenopausal				
First trimester	-	3.4	5.5	11.0
Second trimester	-	4.2	7.0	14.0
Third trimester	-	6.0	10.0	20.0
Lactating				
0-3 months	-	5.8	9.5	19.0
3-6 months	-	5.3	8.8	17.5
6-12 months	-	4.3	7.2	14.4

Note. Adapted from 'Vitamin and mineral requirements in human nutrition' by WHO and FAO, 2004.

Other minerals. Other mineral nutrients include phosphorus, magnesium, selenium, copper and manganese. Together with calcium, phosphorus and magnesium are important components of bone and other supporting tissues. As phosphate is a major constituent of all plant and animal cells, phosphorus is present in all natural foods, and primary dietary deficiency of phosphorus is unlikely to occur in humans. Similarly, magnesium is present in most foods, especially those of plant origin, and dietary deficiency is rare. The precise function of selenium is still not fully known. Selenium deficiency occurs mainly in places where soils are selenium deficient. Selenium is believed to have an important role in the prevention of cancer and other degenerative diseases. Copper serves as a constituent of several enzymes, all of which are involved in some way with oxygen or oxidation. Some act as antioxidants, others are essential to iron metabolism. The richest food sources of copper are grain legumes, whole grains, nuts, shellfish, and seeds. Manganese-dependent enzymes are involved in bone formation and various metabolic processes. Because manganese is widespread in plant foods, deficiencies are rare.

4.6 Conclusion

Human protein and amino acid requirements depend on many factors: age, energy intake, physical activity, pregnancy, lactation and protein quality. The best estimate for a population average requirement is 0.66 g of protein per kg body weight per day (when energy intake from carbohydrates and fat is sufficient). Further, an optimal diet has a least 55 % of total energy from a variety of carbohydrates for all ages except children under the age of 2 years. They require a higher fat intake. For most adults, total dietary fat intake should at least provide 15 % of energy and maximum 30 to 35 % of energy. The international recommended nutrient intakes (RNIs) for the B vitamins, folic acid, vitamin C, vitamin A, iron, calcium and zinc differ depending on age, body weight, sex, for pregnant and/or lactating women and on the bioavailability of the nutrient in a diet.

5 The sub-Saharan African diet

Income, prices, individual preferences and beliefs, cultural traditions, as well as geographical, environmental, social and economic factors all interact in a complex manner to shape dietary consumption patterns. In low income countries, 11 % of dietary energy is derived from roots and tubers, 6 % from grain legumes, 3 % from animal products and the remainder is made up mainly of cereals (Schönfeldt & Hall, 2012). African diets are usually based on one or several carbohydrate-rich staples, generally eaten in the form of a stiff 'porridge', served with soups, relishes and sauces prepared from a wide variety of other foodstuffs (FAO, 1997). In most African countries staple cereals such as maize, sorghum, millet and rice contribute 40 to 60 % of the total dietary energy supply and therefore also makes a considerable contribution to the protein intake. Maize is one of Africa's dominant food crops and consumed throughout Africa as a staple food (International Institute of Tropical Agriculture (IITA), 2009). The relish provides oil, protein, vitamins and minerals and it makes the starchy staple more palatable. The components and the nature of the starchy staple will remain fairly constant within a community, while the relish (usually composed of vegetables, grain legumes and fish or meat if available) will vary in components, flavour and consistency depending on the season, household resources and dietary habits (FAO, 1997). The diets in different African regions, an example of a staple food and a sauce recipe, the macronutrients and micronutrients within the African diet and the consumption of grain legumes in Africa are discussed.

5.1 Diets in different African regions

In the drier areas in the north of West Africa, the staple foods are sorghum or millet which have a fairly good protein value. The rainy season is short, so that there is usually shortage of food before the next harvest. Maize, cassava and sweet potatoes are also common. In the savannah country of East Africa, maize has largely replaced millet and sorghum as the staple food. Meat and milk consumption is higher than in West Africa, because the raising of cattle plays a more prominent role in local agricultural practices. Severe droughts are the chief hazard to food supplies in the area. Plantains and starchy roots and tubers are the main staples in the tropical rainforest areas of West and Central Africa and it is here that disease associated with protein deficiency is most common. One crop is usually dominant, for example cassava in much of the DRC, plantains in parts of Uganda and Ghana, and yams in Nigeria. Meat is rare, the only source of animal protein is small game such as chicken, guinea fowls, rabbits, guinea pigs and bush meat. There are normally no seasonal food shortages in the rain forest areas and no disastrous droughts, but damage is caused by occasional tornadoes. The soil is sometimes too poor to raise sufficient food. Outside of the temperate zones, in the southern part of the continent, a greater variety of fruits and vegetables are available including bananas, pineapples, papaya, mangoes, avocadoes, tomatoes, carrots, onions, potatoes, and cabbage. Nonetheless, the traditional meal in southern Africa is also centred on a staple crop, usually rice or maize, served with a stew. The most common dish made from maize flour is called *mealie meal* or *pap*, *sadza*, and *nshima* or *nsima*. The stew may include a few boiled vegetables, such as cabbage or spinach, or on more special occasions, fish, beans, or chicken. Like other regions of Africa, much of the diet in the countries of North Africa (extending from Morocco to Iran) are based on cereals. However, cooking with olive oil, onions, and garlic is more common and as the countries are largely Muslim no pork is consumed and alcohol is forbidden (Stanton, 1966). Milk is scarcely consumed throughout Africa (except in some countries such as Kenya, Mauritania, and Somalia) because of the very low production of milk per animal and the lack of preservation technology (FAO, 1997). In addition to these broad groups, there are some tribes whose diet was originally almost entirely based on livestock products but they now barter some of these for cereals. There are also groups living near lakes, rivers or the seas who eat fairly large quantities of fish. The West, East and South African diets are described in more detail in Appendix V.

In West Africa cowpeas are mixed with rice, maize or sorghum and with gari (dried fermented cassava flour) or plantain. In these mixes, grain legumes provide a supplementary value to protein requirements (quantity and/or quality), to mineral and vitamin requirements and they also contribute towards variety in taste and texture. Further, grain legumes, particularly groundnuts and chickpeas, are popular as snack foods and contribute towards energy intake. Fried bean-flour cakes are commonly eaten in West Africa.

5.2 Example of a staple food and a sauce recipe of West Africa

Fermented maize porridge is a common staple food in West Africa and groundnut sauce a common sauce. In Benin the fermented maize porridge is known as Koko and is mainly prepared from fermented maize (referred to as Ogi) but sorghum or a mix of these two cereals can also be used. Koko is often eaten by children for breakfast but also as a snack with added roasted groundnuts or cake in Benin. The box below shows the recipe based on 5 observations in households in Cotonou in 2009 for the European project INSTAPA (Greffeuille & Mouquet-Rivier, 2010).

Box 5.1: Koko, Ogi cruel

Ingredients
Maize (1000 g)
Water (pre-cooking: 1510 g, soaking: 1207 g, dough kneading: 879 g & filtration: 3946 g

Recipe description for Ogi (fermented maize dough)

- Grains are first soaked in water to remove the floating impurities.
- Grains are then boiled for about 30min (between 15 and 50 min). Cooking is then stopped and the grains let stand in the water used for boiling for 8 to 43 h (20h on average).
- The grains are washed in water and drained before milling in one unique step.
- Water is added to the milled grains to form a dough.
- Then the resulting dough is sieved by kneading on a metallic sieve or muslin with adding water. This stage allows the separation of starch and envelopes.
- The filtered flour is let in water for at least 24 h. Fermentation occurs during this stage.
- The deposit is called *ogi.* It can be used after 24 h to 48 h of fermentation. To preserve *ogi* for several days, the supernatant is removed and fresh water is added.

Recipe description for Koko

- 3.5 L to 4 L of water or *ogi* supernatant are brought to the boil in a cooking pot.
- Pieces of *ogi* are diluted in supernatant or 500 ml water and poured in the cooking pot containing boiling water.
- The gruel is cooked for 10 min on average.

In Burkina Faso groundnut sauce is often eaten with rice at lunch or dinner. Groundnut can be used as different forms: roasted groundnuts, oil, groundnut ball or paste. The ingredients used in these sauces are very variable. The box below shows the recipe based on 6 observations in province of Boulgou in 2003 for the European project INSTAPA (Greffeuille & Mouquet-Rivier, 2010).

Box 5.2: Groundnut sauce

Ingredients
Groundnut: ball (109 g), paste (112 g), roasted (163 g), oil (89 g)
Other potential ingredients: rocou, tomato powder (16 g); tomato paste (56 g); fresh onions (126 g); spices (5 g); salt (16 g); dried fish (33 g); stock cube (6 g); dried or fresh chilli pepper (5 g); *Cassia tora* leaves (27 g); onion leaves (48 g); eggplant (78 g); glutamate (4 g); red palm oil (89 g); beef (87 g); Soumbala (42 g); garlic (1 g) and/or potash (5 g)

Recipe description

Onions are fried with groundnut oil and slices onion leaves, eggplant, tomato powder and tomato paste. *Cassa tora* leaves are washed, drained, sliced and added to the cooking pot together with water. *Soumbala,* dried fish and salt are crushed together and mixed with the other cooking ingredients. Groundnut paste and/or ball are diluted into water for 25 min. Salt, spices, glutamate and roasted groundnuts are also added. Everything is cooked for around 44 min.

5.3 Macronutrients in the African diet

Analysis show that dietary energy measured per capita per day has been increased from the mid-1990s to 2007 by about 157 kcal per capita per day in developing countries. In developing countries, the contribution of cereal to per capita calorie consumption has declined in all the regions over the past 14 years (Akibode & Maredia, 2011). However, for most African populations carbohydrates from cereals, root crops and highland banana and plantain (Dixon, Gulliver, & Gibbon, 2001) still supply most of the energy needed by the body and have the highest yield of energy per unit of land. Carbohydrates also make an essential contribution to the effective conversion and use of other nutrients, through the energy they supply. In 2005 to 2007, Africa had a daily per capita value of 62g protein per person per day. This has increased slightly since 1990 from 57g per protein per person per day (Schönfeldt & Hall, 2012). In general, African diets tend to be quite low in animal protein as meat and meat products provide an average of only 3 % of dietary energy supply. Most of the protein intake comes from staple foods and grain legumes. The contribution of grain legumes to total per capita protein consumption in developing regions has been mixed, it has increased in Middle East and North Africa region and remained steady in sub-Saharan Africa (Akibode & Maredia, 2011). Proteins in plants often contain much smaller amounts of one or more essential amino acids than animal proteins and therefore are less efficient. Combining complementary protein sources in the right proportions can maximize the protein quality of the diet. For example, when grain legumes and cereals are eaten together, which is the case in many African dishes. Total dietary fat provides on average 18 % of total food energy in sub-Saharan Africa, but populations in some countries obtain as little as 7 to 15 % of food energy from fat (FAO, 1997).

5.4 Micronutrients in the African diet

African diets often contain insufficient micronutrients. A food consumption study conducted in Uganda in 2008 shows that the main inadequacies in all areas studied, as in many developing countries, were those linked to limited consumption of foods from animal sources, such as vitamin A, vitamin B-12, iron, zinc, and calcium. Inadequate intakes were least common for folate, vitamin B-6, and vitamin C for all age groups (Harvey, Rambeloson, & Dary, 2010).

5.5 Legume consumption in the African diet

The consumption of grain legumes varies with agricultural practices, climate, season and also, within quite small areas, according to tribal customs. The average per capita consumption of all grain legumes in the developing world is about 8 kg per year and almost double the consumption per capita in the rest of the world. Since mid-1990s the average per capita consumption has steadily increased in the developing world, representing a growth rate of 0.8 % per year. But when viewed from a long-term perspective, since 1970, declining trends in per capita legume consumption are observed. The declining historical trend in per capita consumption is expected to continue into the future because of several forces in developing countries: reduction in grain legume production (result of increased competition for farmland use from other high-yielding cereal varieties and bio-energy uses), increasing imports (imported grain legumes are not always cheaper and do not always meet the preferences of consumers) and rising incomes (not always a positive impact on demand for traditional foods which may include grain legumes). However, the decline will probably be at a slower rate than in the past few decades due to environmental benefits and the nutritional value of grain legumes. The contribution of grain legumes to total per capita caloric consumption has remained steady in sub-Saharan Africa and increased in Middle East and North Africa. Compared with grain legumes, the trend per capita net availability of cereals has either remained stagnant or declined but for animal source food it has increased in most developing regions from 1990 to 2007. There is a wide disparity in the level of per capita availability of animal source food among developing regions with sub-Saharan Africa, a top grain legume consuming region, at the low end (Akibode & Maredia, 2011; FAO, 2012a).

The per capita consumption of common beans is the largest among all grain legumes, averaging 3 kg/year in 2006 to 2008, with sub-Saharan Africa reporting one of the highest levels per capita consumption (5 kg/year). Chickpea is the next biggest consumed legume crop. In recent years, 1.3 kg of chickpea per year is averagely consumed worldwide. Middle East and North Africa is one of the regions with the most significant consumers of chickpea, averaging 2.11 kg per year in 2006 to 2008.

Cowpea is the third important legume crop on a per capita basis globally (0.8 kg/year). It is also the legume crop that has seen the largest increase in per capita consumption over the last 14 years, up by almost 60 % from the level in 1994 to 1996. In sub-Saharan Africa the per capita consumption of cowpea is the highest (6.5 kg per year). In Africa, the production of groundnuts is highest but most of this is exported for oil extraction. But still considerable amounts are eaten during harvesting, roasted and consumed as snacks and are a common ingredient in soups in West Africa (Akibode & Maredia, 2011). No information is found on consumption of leaves of common bean and cowpea because of the difficulty of documenting their production and consumption (Singh et al., 1997).

From the list of 50 top grain legume producers in the world in 2006 to 2008, Nigeria (297 million tons of grain legumes) is ahead of all other countries within the N2Africa project, followed by Ethiopia (123 million tons of grain legumes) and Tanzania (108 million tons of grain legumes). However, they are not the highest grain legume consuming countries on a per capita basis. Consumption per capita is better correlated with per capita production than volume of production *per se* (Akibode & Maredia, 2011; FAO, 2012a). From the N2Africa counties, Rwanda has the highest per capita consumption with an estimate of per capita availability of grain legumes for consumption of 27 kg per year. Followed by Uganda and Kenya with, respectively, per capita availability for consumption of all grain legumes of 19 kg and 16 kg per year. From the list of 50 top grain legume producers, Mozambique and DR Congo have the smallest production of food grain legumes of the N2Africa countries and also the lowest per capita availability for consumption of all grain legumes.

5.6 **Conclusion**

African diets are usually based on a carbohydrate staple served with soups, relishes and sauces, prepared from a wide variety of foodstuffs including grain legumes. The carbohydrate staple contributes 40 to 60 % of the total dietary energy supply. The relish provides protein, fat, minerals and vitamins. Meat provides an average of only 3 % of dietary energy supply in African diets and most of the protein intake comes from staple foods and grain legumes. The fat content tends to be very small, in some countries people obtain as little as 7 to 15 % of food energy from fat. The consumption of grain legumes varies with agricultural practices, climate, season and tribal customs. In sub-Saharan Africa the per capita consumption of cowpea is the highest (6.5 kg per year), followed by chickpea and pigeonpea.

6 Influencing factors on benefits of consumption of legumes

From the above chapters, in general the conclusion can be drawn that legumes can contribute to meet nutritional requirements for energy, protein, minerals and vitamins, especially in a monotonous diet based on mostly one staple food. However, many different factors influence the bioavailability of the nutrients present in grain legumes and the quantity of grain legumes consumed. Therefore they also determine the nutritional relevance of legume consumption. This chapter generally discusses these different influencing factors which potentially influence the benefits of legume consumption. First, the bioavailability of the nutrients in grain legumes is determined by the presence of anti-nutritional factors in grain legumes, the preparation methods used, the presence of other foods in the same meal and the nutritional status of the consumer. Second, in relation to nutrition, also the distribution of foods within the family is significant and hereby gender roles.

6.1 Bioavailability

Foods, and the nutrients they contain, interact chemically and physiologically and the value of the whole diet is not necessarily the sum of the individual components. The bioavailability of the nutrients in grain legumes depends on different factors: the presence of anti-nutritional factors in grain legumes, the preparation methods, the presence of other foods in the same meal and the nutritional status of an individual and whether infections are present.

6.1.1 Anti-nutritional factors

The contribution of grain legumes to protein, calories and micronutrients is limited due to the presence of anti-nutritional factors which lower protein and starch digestibility, and mineral bioavailability. Anti-nutritional factors have been defined as substances which by themselves, or through their metabolic products arising in living systems, interfere with food utilization and affect the health and production of animals (Mohamed, Gibriel, Rasmy, Abu-Salem, & Abou- Arab, 2011). Some of the most important anti-nutritional substances in grain legumes are phytate, trypsin inhibitors, tannins and saponins (Messina, 1999). The amounts vary with species and variety, but in general grain legumes tend to contain more anti-nutritional factors than cereals. The natural presence of these anti-nutritional factors in grain legumes is related to resistance of the plant in the field, or the seed during storage, to attack by insects or other pathogens (Aykroyd & Doughty, 1982). Phytate is tightly bound in the phosphorus content of grains and grain legumes, especially in the outer layer of grain legumes. Phytate bind with certain metal ions such as calcium, magnesium, zinc, copper and iron, to form insoluble complexes that are not readily broken down and may pass through the digestive tract unchanged. In this way phytate inhibits the taking up of certain minerals from plant foods. It also forms strong complexes with other positively charged food components like proteins (can reduce digestibility up to 10 % (Gilani, Cockell, & Sepehr, 2005)) and carbohydrates, which lead to their reduced digestibility (Kumar, Sinha, Makkar, & Becker, 2010). Phytate bind with certain metal ions such as calcium, magnesium, zinc, copper and iron, to form insoluble complexes that are not readily broken down and may pass through the digestive tract unchanged. In this way phytate inhibits the absorption of certain minerals from plant foods. It also forms strong complexes with other positively charged food components such as proteins (can reduce digestibility up to 10 % (Gilani et al., 2005)) and carbohydrates, which lead to their reduced digestibility (Kumar et al., 2010). The amount of phytate in grain legumes is highly variable as it depends on a lot of factors: growing conditions (phytate level seem to increase with higher temperatures during the growing season and when phosphate-rich fertilizers are used compared with natural compost), harvesting techniques and processing methods. On average, the phytate concentration is between 1 % and 2 % (Messina, 1999). Table 7.1 shows an indication of the phytate content for some grain legumes. Trypsin inhibitors are proteins that reduce the activity of proteolytic enzymes (which break down protein) and thereby cause substantial reductions in protein and amino acid digestibility (up to 50 %) (Gilani et al., 2005) and thus limiting the intake of amino acids needed to construct new proteins. Similarly, the presence of high concentrations of tannins in grain legumes can significantly reduce the digestibility of proteins (in rats, poultry and pigs up to 25 %), carbohydrates and minerals (Gilani et al., 2005). Tannins form complexes with essential amino acids, enzymes and other proteins, thus lessening their protein digestibility and nutritional values (Mohamed et al., 2011). In Table 7.1 it is shown that the tannin content of grain legumes varies among different legume species and also within the individual species. Saponins occur in a wide range of plants, including grain legumes such as groundnut, soyabean and chickpea. Saponins are very poorly absorbed and most form large micelles with bile acids and cholesterol. Whether saponins lower cholesterol in humans is still unclear. In 1970, it was reported that the oligosaccharides (carbohydrates which exist of 3 to 10 simple sugars) in grain legumes were responsible for gas production. The oligosaccharides content of grain legumes is about 25 to 50 mg/g. The oligosaccharides pass into the large intestine where bacteria metabolize them and form large amounts of carbon dioxide, hydrogen and methane which lead to flatulence and diarrhoea. Because of the discomfort and social embarrassment associated with flatulence, some people opt to avoid grain legumes (Messina, 1999).

Table 6.1: Phytate and tannin content of grain legumes (mg/g on dry matter basis)

Food	Phytate (mg/g)	Tannin (g/kg)
Common bean	-	0.3 – 7.5
Cowpea	3.9–13.2 (cooked)	1.4 – 10.2
Groundnuts	9.2–19.7	-
Soyabean	9.2–16.7	-
Chickpea	2.9–11.7 (cooked)	0.8 – 2.7
Pigeonpea	-	3.8 – 17.1
Maize	9.8 – 21.3	-

Note. Phytate data adapted from 'Phytase for food application' by Greiner & Konietzny, 2006 (Greiner & Konietzny, 2006) & Tannin data adapted from 'Effects of anti-nutritional factors on protein digestibility and amino acid availability in foods' by Gilani, 2005 (Gilani et al., 2005).

Phosphorus in cowpea leaves is not present as phytate, a storage form of phosphorus that accumulates in legume seeds. Therefore the minerals of cowpea leaves are more bioavailable than those in seeds. In traditional cowpea dishes consumed with cowpea leaves, the iron and calcium contents are increased (Madodé et al., 2011).

6.1.2 Preparation methods

Over the centuries, traditional methods of processing and cooking grain legumes have evolved to give safe, appetizing and nutritious products. Appropriate processing for grain legumes is probably more important than for any other food group, owing to the high content of anti-nutritional components and the indigestible nature of grain legumes. Grain legumes are commonly soaked and cooked in an open pot of water over a low heat fire. This provides for a long-term slow (up to 8 hours) cooking process and yields a palatable and nutritious product. The requirements for high quality water and sufficient wood fuel for cooking are major constraints. In Africa, germination and fermentation have found wide acceptability. Box 6.1 (on the next page) describes the different methods used for the preparation of grain legumes (Aykroyd & Doughty, 1982). Removals of undesirable components are very essential in improving the nutritional quality and acceptability of grain legumes. Dehulling, soaking, thermal processing, germination and fermentation are traditional household food-processing and preparation methods known to enhance bioavailability of micronutrients in plant-based diets. *Thermal processing* may degrade phytate depending on the plant species, temperature and pH. It generally reduces the trypsin inhibitor content by 80 to 90 % in grain legumes. It can also enhance the bioavailability of thiamine, vitamin B-6, niacin, folate and carotenoids by releasing them from entrapment in the plant matrix (Hotz & Gibson, 2007). Boiling grain legumes generally reduces the trypsin inhibitor content by 80 to 90 %. *Soaking* legume flours (not whole seeds) in water can result in passive diffusion of water-soluble phytate, which can then be removed by decanting the water. The extent of the phytate reduction depends on the species, pH, and length and conditions of soaking (Hotz & Gibson, 2007). *Fermentation* can induce phytate hydrolysis via the action of microbial phytase enzymes, which hydrolyse phytate to lower phosphates. Such hydrolysis is important because these phosphates do not have a negative effect on zinc absorption and do not inhibit non-haem iron (iron present in plants) absorption. The extent of the reduction in phytate concentrations during fermentation varies; sometimes 90 % or more of phytate can be removed by fermentation of cowpeas and soyabeans. In plants with high tannin content phytase activity is inhibited and fermentation is less effective in reducing phytate. Fermentation also improves protein quality and digestibility, vitamin B content and keeping quality. Low-molecular-weight organic acids (citric, malic, lactic acid) are also produced during fermentation may enhance iron and zinc absorption via the formation of soluble ligands and generating a low pH that optimizes endogenous phytase activity (Hotz & Gibson, 2007). *Germination* increases the activity of endogenous phytase activity in grain legumes, oil seeds and cereals. The rate of phytate hydrolysis varies with the species and variety as well as the stage of germination, pH, moisture content, temperature, solubility of phytate, and the presence of certain inhibitors (Hotz & Gibson, 2007). Storing grain legumes is possible in the home and thereby may contribute to family diets in periods of food shortage. In poor storage conditions, however, significant losses can occur. Insects and small animals can severely damage the seeds. Proper storage temperature and moisture content of the seed are important for preventing the growth of moulds and multiplication of insects (Aykroyd & Doughty, 1982). Among the processing methods, germination and fermentation appear to be most effective in decreasing the phytate concentrations, whereas soaking and cooking remove about 50 % to 80 % of the endogenous phytate in grain legumes and cereals (Deshpande, 2002).

Box 6.1: Leguminous preparation methods

Dehulling. Legumes with intact hulls take a long time to cook to a soft consistency. Other legumes such as haricot bean have much softer hulls, which need not necessarily to be removed. However, dehulling and splitting the cotyledon (seed lobe) to form a 'dahl' reduces cooking time considerably. The ease of hull removal depends on the thickness of the seed-coat. Traditional methods of dehulling in West Africa normally involve roasting, sun-drying or soaking. There are two main methods, dry and wet. In the dry method, the seeds are mixed with small amounts of oil and sun-dried to loosen the seed-coat. After 2 to 5 days of sun-drying, the seed-coats are removed by rollers or hand-operated chakkis (horizontal mills). At this stage about half the seeds are dehulled and most are split, and the process of oiling and sun-drying is repeated until all are milled into 'dhal'. In the wet method, the grain is soaked in the water for a few hours, drained, left in heaps and dried in the sun before being milled and winnowed to remove the seed-coat. Although this method requires only about half the labour, dhal produced by the dry method fetches a higher price as it cooks more rapidly.

*Soaking***.** Soaking is a preliminary step to almost all methods of preparing legumes. It is carried out to assist removal of the seed-coat (as described above), to moisten and soften the seed so as to shorten the cooking time and to reduce the toxin content. Many cultivated legumes do not imbibe water as quickly as other seeds, and the toughness of the seed-coat increases with storage, especially in warm conditions. The use of warm water for soaking and cracking seeds with though seed-coats assists moisture penetration. The time needed for soaking varies with variety and species, and with length and conditions of storage. For example, cowpea may need only one to two hours or as long as 10 hours. Many legumes such as haricot bean are soaked overnight. However, soaking pigeonpeas for more than 12 hours tended to harden the seed, which remained tough even after prolonged cooking.

Thermal processing (boiling, steaming). Heat treatment of all kinds inactivates enzymes and improves flavour in addition to improving the nutritional value. Cooking whole legumes, with or without the seed-coat, in boiling water or steam is the most common method used. They may be served whole or crushed to a puree. The shorter the cooking time required to make legumes soft, the higher their acceptability. The required cooking time increases the more seed coats are present and the thicker the seed coats. Seeds of legumes of the same species have different cooking times. Reasons are unknown. Also the longer the storage time, the longer the cooking time required. There is some loss of solids from legumes during cooking; the amount lost depends on species and variety. Heat threatening leads to a decrease in the nitrogen solubility index (the percentage of total nitrogenous constituents (mainly protein) soluble in water under specified conditions). As fuel is scarce and expensive, techniques for reducing cooking time are important. For example, adding salt to the water, use a pressure-cooker and/or an amount is prepared for several days at one time.

Germination (sprouting, malting). Soaking legume seeds to start the process of germination is an ancient and popular practice in many parts of the world. The seed-coat splits during the process and is removed by washing. The seeds may often be eaten whole after roasting, or ground and used in soups or side-dishes.

Fermentation. Fermentation is one of the oldest methods of processing legumes. The naturally-occurring fermenting organism may be bacteria or fungi. This technique overcomes the disadvantage of long cooking time, leads to an easily digested product and reduces some non-nutritive components such as flatulence-producing factors. It is particularly useful for hard seeds. The process may be of short duration, overnight only, or prolonged for months.

Overall, fermentation and germination are the most effective methods in reducing anti-nutritional components but they imply an additional workload and induce particular tastes (Mohamed et al., 2011). The use of only one method may not effectively remove all anti-nutritional factors present and thus a combination of two or more methods may be required to accomplish the desired degree of removal (Hotz & Gibson, 2007).

Besides improvements in bioavailability of micronutrients by different preparation methods, there are also losses in activity of heat-labile and water-soluble vitamins, like vitamin C, folate, thiamine and riboflavin (Hotz & Gibson, 2007). With regard to the small content of vitamin C in some legume varieties, the prolonged cooking which most dry grain legumes need (as described above), and the habit followed in some countries of cooking them in sufficient quantities to last for several meals, would remove or destroy any of the vitamin C they contained. Furthermore, a long storage period will oxidize the vitamin (Aykroyd & Doughty, 1982). In case of folate, losses during harvesting, storage, distribution and cooking can be considerable.

6.1.3 **Combination of foods**

When different foods are eaten at the same time the different nutrients can enhance or inhibit the uptake of other nutrients. For example, the absorption and assimilation of non-haem iron (from grain legumes) is increased by including foods rich in vitamin C, especially fruits which also contain citric acid. As common bean leaves and/or cowpea leaves contain vitamin C they can also enhance the uptake of iron when from a legume dish when consumed together. But as vitamin C is extremely labile and is easily destroyed by heat and air, considerable amounts of vitamin C are lost when the leaves are processed, dried or kept warm after cooking and therefore reduces the potential enhancing effect of iron uptake by combined consumption of legume leaves and grain legumes. Sources of haem iron such as liver, meat, chicken or fish, eaten in the same meal, can also increase the absorption of non-haem iron. Coffee and tea contain tannins which may reduce iron absorption from foods if these beverages are taken together with meals (WHO & FAO, 2004). Another example, is that the amount of fibre in a meal adversely affect the digestibility of the proteins present and hence decrease their biological availability (WHO et al., 2007).

6.1.4 **Nutritional status and infections**

The nutritional status of a person may affect the uptake of nutrients from the digestive tract. For example, the regulation of iron absorption within the body is related to body iron stores of an individual. In individuals with low iron concentrations in the red blood cells, iron transfer through the iron uptake cycle of the body increases to the maximum and a greater fraction of non-haem iron is absorbed from the diet (Zimmermann & Hurrell, 2007).

In the case of infection, the uptake of nutrients may decrease. In particular, hookworm, malaria, HIV/Aids and chronic diarrhoea have been linked with malnutrition through the negative effects on digestion and absorption of nutrients. For example, fat-soluble vitamins may not be absorbed if the digestion of fat is impaired and thus children with diarrhoea will absorb less vitamin A than normal. The relationship between malnutrition and infection is cyclical: infection predisposes one to malnutrition, and malnutrition, which impairs all immune defenses, predisposes one to infection.

6.2 **Other influencing factors**

Besides the availability and accessibility of grain legumes in a household (potential N2Africa outputs), household shares, gender roles and cultural beliefs are important other influencing factors on the consumption of grain legumes.

6.2.1 **Household shares**

Two patterns of intra-household food distribution to various family members differing in age, sex, earning status and family role are recognized in the literature: a *Contributions Rule*, that individuals considered in the culture to have higher economic value would receive a higher percentage of the family's food; and a *Needs Rule*, in which those considered to have greater need (but not contribution) would receive a greater percentage of the family's food (Engle & Nieves, 1993). The Contribution Rule seems to be a better predictor of food distribution patterns and nutrient intake among household members in recent studies using the discrepancy score (reflects average dietary adequacy of each member of the family, see Chapter 8) (Engle & Nieves, 1993; Luo et al., 2001). The household leader usually enjoys better food allocation than other members of the household. They often eat first, obtaining sufficient food to ensure that they maintain their capacity for earning money or working to provide the food supply for the family. Engle and Nieves (1993) found that male heads of households consumed a relatively larger proportion of the family's protein, while female heads of households consumed a relatively larger proportion of the family's calories, given their nutritional requirements. Luo et al. (2001) found that both male and female household leaders received relatively more protein and energy in both urban and rural areas. The allocation of other micronutrients also indicate that leaders are in a much better position than other members. Administrators have a better food allocation than manual workers and farmers and also household members with a higher educational level are more likely to have better food allocation. In both cases, this is associated with their steady and higher income (Luo et al., 2001).

In general intra-household food distribution seems to be in favour of males (Carloni, 1981; Hadley, Lindstrom, Tessema, & Belachew, 2008; Luo et al., 2001). More specifically, it is found that for beans, vegetables and fruits the food share is higher for women but food of animal origin is disproportionally given to males (Luo et al., 2001). Most families in Africa eat together from common pots. The adult males of the family usually have first call on the contents of the pot, the women coming next and then the children (Aykroyd & Doughty, 1982). It is found that calorie intake of pre-school children falls short of estimated energy requirements (according to age-specific requirements) compared with adolescents and adults (Chaudhury, 1988). In times of scarcity children are worse off than other family members; they rarely get much of the soup which may contain valuable supplementary foods such as meat or fish, grain legumes and green leaves. In some cattle-keeping areas milk is consumed by adults and old people but not by children. Foods of animal origin are thought to damage the child's character, so that he is in danger of becoming a greedy and careless adult (these ideas also existed in Europe). In many parts of Africa grain legumes are not given to children under two years old. They are thought to be badly digested by children, which is true for many of the legume preparations eaten by adults (Aykroyd & Doughty, 1982). But by applying specific preparation methods it is found to increase digestibility, improve protein to energy ratio and reduce flatulence from beans (Hoddinott, 2011). Including the effect of snacks seem to diminish the differences between adult and child diets (Engle & Nieves, 1993; Harbert & Scandirzo, 1982). However, Luo et. al. (2001) (Luo et al., 2001) included all foods consumed by household members, also snacks, and found that young children do have an inadequate share of food. Finally, pregnant women seem to have no privileges with respect to food and no attention is paid to their specific dietary needs. A widely held belief is that the diet of pregnant women should be drastically reduced so that the delivery will be easy (Aykroyd & Doughty, 1982). It is important to understand intra-household food distribution in a community (contribution rule versus needs rule, sex and age) in order to understand the impacts of intervention programmes in ultimately decreasing the prevalence of malnutrition and improving the nutritional status of inhabitants.

6.2.2 **Gender roles**

A growing body of recent research findings on gender and food security proofs that reducing gender disparities promotes better food and nutrition security for all (International Food Policy Research Institute, 2005). It highlights the importance of gendered social determinants of child nutrition and health, such as maternal education and women's status. First of all, recent studies show that within rural households, food is inequitably divided among household members in relation to their nutritional requirements, with women and girls being disadvantaged in comparison to men and boys (Carloni, 1981; Hadley et al., 2008; Luo et al., 2001). This gender difference seems to be the largest in severely food insecure households (Hadley et al., 2008). Where food is part of female disadvantage, it appears to be a problem of quality (micronutrient intake) more often than one of quantity (calorie intake). Pregnant and lactating women also have systematically lower calorie intake adequacy than both men and other women. Besides discrimination against women of food allocation within the household, discrimination operates through access to education, to resources (income, agricultural inputs) and to health care. Deprivation with respect to these factors contributes to decreasing women's functional capabilities and women's status (women's power relative to men's in their households, communities and nations) (DeRose, Das, & Millman, 2000). Access to education is associated with a steady and higher income. And it is found that the higher the percentage of the families' income the mother earns, the better nourished the children are, controlling for socioeconomic status (Engle, 1993). With increased income, women are more likely to make joint decisions with their husbands regarding their children's medical care and school attendance as well as food expenditures and home repairs. They also exercised greater control over how the extra income was spent. Research shows that placing assets in the hands of women increases household spending on children's clothing and education and reduces the rate of illness among girls (International Food Policy Research Institute, 2005). Also, a review of gender differences in agricultural productivity found that yield differences actually result from inequalities in agricultural inputs between male and female farmers (Berti, Krasevec, & FitzGerald, 2003). In sub-Saharan Africa, for example, women play a key role in food production and yet they have less access to education, labour, and fertilizer than men do. In Burkina Faso, men have greater access to fertilizer and to both household and non-household labour for their farm plots. Reallocating these resources to women could increase household agricultural output by 10 to 20 percent. In Kenya, if women farmers are given the same degree of education, experience, and farm inputs as their male counterparts, they increase their yields for maize, common beans and cowpeas by 22 percent (Berti et al., 2003). Educating women is a key method for boosting agricultural productivity in sub-Saharan Africa. Simulations using data from women farmers in Kenya suggest that yields could increase by 25 percent if all women attended primary school (International Food Policy Research Institute, 2005). Therefore access to education and resources for women may contribute to food and nutrition security. Smith, Ramakrishnan, Ndiaye, Haddad, and Martorell (2003) explored the relationship between women's status and children's nutrition in sub-Saharan Africa. The study found that women's status (measured by whether the woman works for cash income, the woman's age at first marriage, the percent difference in the woman's and her partner's age and the difference in the woman's and her partner's years of education) significantly affects the nutritional status of children on both the short- and long- term. This is because better-resourced women have better nutritional status themselves, are better cared for, and provide higher quality care for their children. It seems that targeting development programmes to women improves overall household welfare. In the case of linking agricultural programs to improved nutrition and health, gender roles and gender equity seem to be a key dimension (Meinzen-Dick et al., 2011). Evidence shows that increasing women's control over land, physical assets, and financial assets serves to raise agricultural productivity, improve child health and nutrition, and increase expenditures on education, contributing to overall poverty reduction (Quisumbing & Agnes, 2003). Nevertheless, more studies are needed which explicitly consider gendered intra-household bargaining power and processes. Child health and nutrition interventions will be more effective, equitable and sustainable if they are designed based on gender-sensitive information and continually evaluated from a gender perspective (International Food Policy Research Institute, 2005).

6.2.3 Cultural beliefs

Cultural beliefs and habits also influence the consumption of grain legumes. As mentioned above, in many African countries grain legumes are an important part of the adult diet but are not served to young children because of fear of indigestion. Often the reason lies in the method of preparation. For example, in central and eastern Africa, beans are often cooked without dehulling for the family meals and not suitable for young children. However, also in West Africa, where easily-digested products are made from cowpea, mothers are reluctant to feed preparations to young children for fear of indigestion (Aykroyd & Doughty, 1982). Therefore it is important to take into account these cultural beliefs as they may influence the effectiveness of an intervention. Further, grain legumes tend to have a poor image and may carry the title of 'poor man's meat' which gives rise to the question whether or not grain legumes should be invested in. Further, grain legumes have been viewed as labour-intensive, low opportunity crops, with problematic seed systems. These beliefs may contributed to more scientists being involved in crop improvement programs for cereals than for grain legumes (Monitor Group supported by Bill & Melinda Gates Foundation, 2012). These beliefs may also influence the preferences for consumption of grain legumes at the household level.

6.3 Conclusion

Many factors influence the bioavailability and quantity of grain legumes consumed and therefore also determine the nutritional relevance of legume consumption. 1) Grain legumes contain several non-nutritive components such as phytate, trypsin inhibitors and tannins, which inhibit the uptake of micronutrients and decrease the digestibility of proteins and carbohydrates. Thermal heating, germination, fermentation and soaking reduces the negative effects of non-nutritive components. If grain legumes are consumed with meat and/or vitamin C, this enhances the uptake of micronutrients. If they are consumed in a diet which lacks sufficient carbohydrate or fat to meet energy needs, the protein content will be converted into energy. 2) In Africa, most families eat together from common pots. Some evidence on the allocation of foods within households suggest a strong pro-leader (contribution rule), pro-male and pro-adult bias in terms of the quantity in food intake. In many parts of Africa children do not obtain much of the relish, including grain legumes, which contains valuable supplementary micronutrients. The use of grain legumes in the feeding of infants is important as they have special protein requirements. 3) A growing body of research highlights the importance of gendered social determinants of child nutrition and health, such as maternal education and women's status, for mediating child survival. There is a lack of published intervention studies that explicitly consider gendered intra-household bargaining power and processes. Child health and nutrition interventions will be more effective, equitable and sustainable if they are designed based on gender-sensitive information and continually evaluated from a gender perspective. Overall, many factors have to be taken into account to be able to conclude whether the increase of legume production and thus potential increase of legume consumption will in the end be nutritionally meaningful.

7 Nutritional value of grain legumes in the sub-Saharan African diet

The value of the contribution of legumes to good nutrition can be assessed by studying them in the context of human eating patterns. Mankind has survived because he/she has been able to locate, and later cultivate, sufficient nutritious food to fulfil his/her requirements. The instinct for eating mixtures of a wide selection of foods is deep-rooted and is still evident. Legumes play an important part in this diversity. Diets based on starchy staples tend to be monotonous and unappetizing. Therefore they are eaten with sauces and relishes made from a variety of foods, including grain legumes. This does not only give an appetizing taste and texture but also adds nutrients to the staple dish, which ensures a balanced diet, meeting nutrient requirements (Aykroyd & Doughty, 1982). Grain legumes are part of two important complementary mixes: cereals and grain legumes, and starchy roots and fruits and grain legumes. The additive nutritional value of grain legumes within the African diet are discussed: the contribution to protein, energy and micronutrients requirements. Finally, the literature is reviewed to find evidence on the efficacy of the consumption of legume-based foods on nutritional intake and status of most vulnerable groups for nutrient deficiencies: reproductive women, children and infants.

7.1 Legumes and protein requirements

Eating cereals and grain legumes together during the same meal gives a higher value to the quality of protein consumed than if they were eaten separately. As is mentioned earlier, legume protein is generally limited in the sulphur amino acids (methionine and cysteine) and cereal protein is limited in lysine. Table 7.1 shows the amino acid content of major food proteins expressed as percentage of the proposed requirement pattern and Table 7.2 shows several amino acid requirements compared with amino acid composition of grain legumes. Soyabean is included in Table 7.1 as a legume protein source in the table and, as an exception among the grain legumes, it is shown that soyabean is able to supply the sulphur amino acids. It is shown that lysine in cereals is between 57 % and 86 % of requirement levels but for the sulphur amino acids they are greater than the proposed requirement values (WHO et al., 2007). Table 7.2 shows that cowpea, groundnut and pigeonpea are limited in the sulphur amino acids but that maize is higher in the sulphur amino acids compared with the requirements. Therefore, when grain legumes and cereals are eaten together in the same meal, which is the case in many African dishes, the mix of amino acids provided for use in the body is improved. In general, grain legumes provide lysine which is limited in cereals and cereals providing the sulphur amino acids which are limited in most grain legumes. There are certain proportions for cereal/legume mixtures that maximize the value of the combined protein. The size of the proportion is subject of debate and is influenced by many factors: the variability of the protein content, the total protein and energy content of the diet, the digestibility of the protein and the use of accompanying foods. The protein value of a mixture should be considered together with its energy value, since utilization of the protein depends on the satisfaction of energy needs. Cereals are adequate sources of protein and a proportion of 5 to 10 % of grain legumes added to cereals has been found satisfactory (Aykroyd & Doughty, 1982). Most roots and tubers, like potato and yam, are not low in protein (when allowance is made for the water content) and comparable with cereals. Those that contain little protein, like cassava and plantain, are usually eaten as part of a mixed diet, with side-dishes and relishes containing many foods rich in protein such as grain legumes, meat and fish. Millions of people in the world rely on cassava as a major source of energy, it has also spread considerably in Africa, and grain legumes play an important part in improving the nutritional value of cassava-based diets. Grain legumes do not have the same supplementary effect on the proteins of roots, tubers and fruits which contain more lysine than cereals. Table 7.1 shows that lysine in cassava and yam is about 90 % of dietary requirements. Therefore it merely raises the protein content and has little effect on the quality.

Young leaves of common bean and cowpeas are also consumed in numerous African countries. The leaves are often served boiled, but are also consumed fried or fresh in relish. Drying is a common way of preserving leaves. The leaves of common bean and cowpea contain similar amount of protein as the legume seeds on a dry weight basis, with a higher nitrogen content in younger leaves. The amino acid composition of cowpea leaves matches human amino acid requirements (Singh et al., 1997).

Table 7.1: Distribution of amino acids in food proteins and diets

	Percentage of requirement pattern							
	Beef	Soya	Potato	Rice	Maize	Wheat	Cassava	Yam
Lys	203	144	121	**86**	**58**	**57**	**92**	**91**
Tryp	213	217	240	224	117	217	192	213
Threo	202	191	167	153	157	127	115	157
SAA	182	114	131	176	132	203	124	125
BCAA	144	136	120	146	177	122	**79**	116
TAAA	275	281	243	305	314	306	135	265

Note. The data is adapted from the report 'Protein and amino acid requirements in human nutrition' by WHO, 2007
Lys, lysine; Tryp, tryptophan; Threo, threonine; SAA, sulfur amino acids; BCAA, branched-chain amino acids; TAA, total aromatic acids.

Table 7.2: Several essential amino acid requirements compared with amino acid composition of protein in common bean, cowpea, groundnut, soyabean, chickpea, pigeonpea, and maize

	Amino acid requirement (mg/g protein)[a]	Common bean (mg/g protein)[b]	Cowpea (mg/g protein)	Groundnut (mg/g protein)	Soyabean, (mg/g protein)	Chickpea (mg/g protein)	Pigeonpea (mg/g protein)	Maize (mg/g protein)
Lysine	**45 - 57**	68.4	68.1	**34.9**	74.0	67.4	69.1	**24.7**
Methionine & cysteine	**22 - 28**	28.3	**25.6**	**23.2**	32.9	31.0	**23**	49.3
Threonine	**23 - 31**	40.1	38.3	34.9	49.3	36.3	36.9	37.0
Tryptophan	**6.0 - 8.5**	11.8	12.8	11.6	16.4	10.4	9.2	12.3

Note. The data is adapted from the report 'Protein and amino acid requirements in human nutrition' by WHO, 2007; & from 'USDA National Nutrient Database for Standard Reference, Release 24' by U. S. Department of Agriculture, 2011.
[a]The range of requirements from 0.5 years to above 18 years old (see Table 4.2), calculated as the individual amino acid requirement divided by the total protein requirement (0.66 g protein/kg per day); [b]Range of varieties of common bean: black bean, cranberry bean, French bean, Great Northern bean, kidney bean, navy bean, pink bean, pinto bean, yellow bean, small white bean and white bean.

7.2 Legumes and micronutrient requirements

The relish often provides the micronutrients lacking in the main staple dish. Grain legumes supplement cereals for minerals and vitamins of the B complex. Table 7.3 shows several vitamin and mineral requirements in mg/day compared with vitamin and mineral composition of grain legumes. FAO (2012a) an average consumption of 8 kg of grain legumes per capita per year in developing countries which means an average consumption level of 22 g grain legumes per day per capita. Therefore the vitamin and mineral composition values are calculated per 22 g edible portion of each legume. The Table 7.3 shows that the thiamin value of legume grain is about 0.2 mg per 22 g edible portion which equals the requirement for 0 to 2 years old but not that for older children and adults. The riboflavin, pantothenic acid and vitamin B6 content of grain legumes is per portion of 22 g less than the requirement per day but in general a little higher than in maize. Grain legumes also provide additional nicotinic acid. Nicotinic acid is important in the traditional mixture of maize and beans, as maize is relatively deficient in this vitamin and also in tryptophan, which can partly replace nicotinic acid (Aykroyd & Doughty, 1982). For children of 0 to 2 years old, folic acid composition of most grain legumes per 22 g is sufficient. For older children and adults it is not (it can be assumed that they eat more). However, compared to maize the folic acid contribution to the diet is much higher (80 µg versus about 6 µg per 22 g edible portion). Similar, the calcium, iron and zinc content per 22 g is higher for grain legumes than maize but at a consumption level of 22 g the calcium, iron and zinc requirements are not met. Legume seeds and cereals have negligible amounts of vitamin C and vitamin A. However, the leaves of common bean and cowpea are significant sources of B-carotene (provitamin A) and vitamin C. Additionally, they are a little richer in most B vitamins and higher in folic acid, calcium and iron content compared with grain legumes. For example, in traditional dishes made with cowpea that are consumed with cowpea leaves, the iron and calcium contents are increased as they decrease the anti-nutritional factors present in cowpeas (Madodé et al., 2011). This will be discussed in the next chapter.

Table 7.3: Several vitamin and mineral requirements (mg/day) compared with vitamin and mineral values in common bean, cowpea, groundnut, soyabean, chickpea, pigeonpea, and maize per average intake of grain legumes (mg/22 g)

	requirement (mg/day)[a]	Common bean	Cowpea	Ground-nut	Soyabean	Chick pea	Pigeon-pea	Maize
Vitamins								
Thiamine	**0.2 – 1.5**	0.1 – 0.2	0.2	0.1 – 0.2	0.2	0.1	0.1	0.1
Riboflavin	**0.3 – 1.6**	0.02 – 0.06	0.04	0.02	0.06 – 0.20	0.04	0.04	0.02 – 0.04
Pantothenic acid	**2.0 – 7.0**	0.2	0.3	0.4	0.2	0.4	0.3	0.1
Vitamin B6	**0.1 – 2.0**	0.1	0.1	0.1	0.1 – 0.2	0.1	0.1	0.05
Folic acid[b]	**80 – 600**	80 – 133	92 – 139	24 – 53	83 - 84	123	100	6
Vitamin C	**25 – 70**	0 – 1.4	0.2 – 0.3	0	1.3	0.9	0	0
Minerals								
Calcium[d]	**300 - 1000**	16 – 53	18 – 24	10 – 20	45 – 61	23	29 – 57	1 – 4
Iron	**3.9 – 65.4**	0.7 – 2.3	1.6 – 1.8	0.9 – 1.0	1.4 – 3.5	1.4	1.0 – 1.1	0.7 – 0.8
Zinc	**0.8 – 20.0**	0.4 – 0.8	0.8 – 1.0	0.6 – 0.7	1.1	0.7	0.4 – 0.6	0.3 – 0.4

Note. Adapted from 'Vitamin and mineral requirements in human nutrition' by WHO and FAO, 2004 & from Table 3.1.
[a]in mg NEs/day, niacin equivalents; [b]in µg/day; [c]in µg RE/day, retinol equivalent; [d]Theoretical calcium allowances based on an animal protein intake of 20 to 40 g

7.3 Legumes and energy requirements

Carbohydrate rich foods in many developing countries are difficult to consume in large quantities due to their bulkiness, thick viscous texture, poor palatability and low energy density. The addition of a small amount of fat to carbohydrate rich foods not only improves palatability but also reduces its bulkiness and enhances its energy density. Fats play a major role in meeting the energy requirement of infants, children and adults living in the developing world. The fat content of many African diets tends to be very low. Protein malnutrition is mainly caused by a low food intake. If enough food is eaten to satisfy energy requirements, protein requirements are mostly also met. Where energy and protein are both deficient, leguminous oilseeds can play an important role in improving diets. Leguminous oilseeds are concentrated sources of energy and also contain a substantial amount of protein (FAO, 2010). Groundnuts contain about 47 g, soyabean about 17 g and chickpea about 6 g of fat per 100 g edible portion. Therefore grain legumes can play an important part in alleviating protein-energy malnutrition. For example, to raise the energy density of food for young children without lowering the proportion of total energy supplied by proteins, as supplementary feeding when breastfeeding is insufficient and as more frequent feeding than only at family meals through extra meals or snacks (as grain legumes are often major ingredients in snack foods). Furthermore, a diet based on only one staple food has little variety. This monotony may, in itself, restrict intake so that energy requirements are not met (Rolls et al., 1981). Therefore the addition of grain legumes to a meal increases variety in taste and texture and increases the quantity of the meal consumed and contributes to meet the energy requirements.

7.4 Efficacy of legume-based foods consumption on nutrient intake and status of reproductive women, children and infants

The literature is reviewed to evaluate the efficacy of the consumption of legume-based foods on nutrient intake and status of most vulnerable groups for nutrient deficiencies: women of reproductive age, children and infants. The literature search resulted in 23 randomized controlled trials. Eight studies targeted women addressing the iron, zinc and vitamin B-6 intake and status, six studies targeted children addressing iron, calcium, energy – protein intake and status and nine studies targeted infants addressing iron, zinc, calcium, copper, selenium, manganese, vitamin E, vitamin A, protein/amino acid composition, bone mineral content and growth intake or status. The effect of consumption of legume-based foods on nutrient intake and status are discussed for each different nutrient: iron, zinc, calcium, copper, selenium, manganese, vitamin E, vitamin A and protein/amino acid composition. Appendix VI shows a table with details of all studies included for this review.

7.4.1 Iron

Six of the articles investigated the effect of iron fortification of legume-based foods on iron bioavailability and iron status. Three articles clearly showed a positive effect of iron fortification on iron status (Abizari, Moretti, Zimmermann, Armar-Klemesu, & Brouwer, 2012; Lartey, Manu, Brown, Peerson, & Dewey, 1999; Schümann et al., 2005), two articles found a positive effect on iron bioavailability (Abizari, Moretti, Schuth, et al., 2012; Lönnerdal, Bryant, Liu, & Theil, 2006) and one article showed no effect on iron bioavailability (Rudolph, Preis, Bitzos, Reale, & Wong, 1981). Fortifying canned refried beans with haem iron or ferrous sulfate (FeSO4), a cowpea meal with 10 mg ferric sodium ethylenediaminetetraacetate (NaFeEDTA), or a Weanimix with vitamins and minerals improved iron status in iron deficient children, Ghanaian children, or Ghanaian infants. It was shown that haem iron was more effective in improving iron status of iron deficient children than FeSO4 (Schümann et al., 2005). For the other studies no comparison was made with other fortificants.

CDC (Centre of Disease Control and Prevention) and WHO (World Health Organization) recommend to measure at least serum ferritin and haemoglobin concentration to evaluate the response on iron status in an intervention trial. However, if other biomarkers like transferrin receptor or inflammatory biomarkers like acute phase proteins are measured a better classification of iron status in the participating groups is possible. Schümann et al measured serum ferritin and serum haemoglobin concentration, which is according to WHO and CDC recommendations sufficient to establish the iron status of the participants. Lartey et al also measured serum ferritin and haemoglobin concentration, but additionally also haematocrit concentration and serum transferrin saturation, which are not mentioned by WHO and CDC to improve the validity of the outcome. However, C-reactive protein concentration was also measured which when used for adjustment of ferritin levels increased the validity. Abizari et al measured serum haemoglobin, serum ferritin, and serum transferrin receptor concentration, which make a classification of iron deficiency possible. Furthermore, they also measured C-reactive protein, with which adjustment of ferritin concentration was possible. To summarize, the three efficacy studies (Abizari, Moretti, Zimmermann, et al., 2012; Lartey et al., 1999; Schümann et al., 2005) had good measurement methods to indicate the iron status of the participants.

In human studies stable iron isotope (Fe^{54}, Fe^{57}, Fe^{58}) and radioisotope (Fe^{55}, Fe^{59}) measurements are commonly used to investigate iron bioavailability (Hoppe, 2008). Lönnerdal et al measured iron bioavailability by radioisotopes whereas Abizari et al (women) measured iron bioavailability by the erythrocyte incorporation of stable iron isotopes. Iron absorptions of the NaFeEDTA fortified cowpea meals were ~1.5 % and of the FeSO4 cowpea meals ~1.0 % (Abizari, Moretti, Schuth, et al., 2012) which indicated that NaFeEDTA is a better fortificant compared to FeSO4. The further usefulness of NaFeEDTA on iron status of Ghanaian children was indicated by the efficacy study of Abizari et al (Abizari, Moretti, Zimmermann, et al., 2012). However, iron absorption in the NaFeEDTA fortified cowpea meal of the efficacy study was ~7 % (Abizari, Moretti, Zimmermann, et al., 2012) which was much higher than in the stable isotope study. Assuming that iron status of the Ghanaian children in the efficacy study was lower than iron status of the healthy women in the stable isotope study, iron absorption would be higher in the Ghanaian children (Hurrell & Egli, 2010) and consequently would explain the different iron absorptions in the two studies. Iron absorption from either a soyabean ferritin or a FeSO4 fortified meal was similar (~31 and ~35 % respectively) (Lönnerdal et al., 2006). These iron absorption percentages are much higher than the iron absorption percentages found by the study of Abizari (Abizari, Moretti, Schuth, et al., 2012). A difference in iron status of the target groups is unlikely, even though in the study of Lönnerdal et al 1 out of 16 women was slightly anaemic and 4 out 16 women were iron deficient while the study of Abizari et al included healthy women. It is however possible that the amount of fortified iron consumed caused the difference in iron absorption. In the study of Lönnerdal et al it was only 1 mg whereas in the studies of Abizari et al it was 9.3 and 12.8 mg/day and 10 mg/day. This great difference in iron intake could explain the difference in absorption, in case of higher intake relatively less iron is absorbed (Cook et al, 1973). Another explanation might be a difference between cowpea and soyabean in for example levels of iron uptake inhibitors, with iron absorption being higher from soyabeans than from cowpea. The study of Rudolph et al (Rudolph, Preis et al. 1981) showed no effect of fortifying a soy-based formula with 12 mg iron per liter on iron status of low-birth weight infants. However, this study did not investigate directly the effect on nutrient status but rather at the rate of haemolysis.

The isotope and efficacy study of Murray-Kolb et al (Murray-Kolb, Welch, Theil, & Beard, 2003) improved iron status of marginal iron deficient women by consuming soyabean in the form of a muffin or a soup. The geometric mean iron absorption was 24.5 % (range: 9–36 %). However a high-iron-high-zinc bean variety (HFeZnB variety) in the study of Donangelo et al had an iron bioavailability of less than 2 % and had little effect on improving iron status of young women with low iron reserves (Donangelo et al., 2003). In both studies iron was labelled and radio-iron incorporation in red blood cells was measured. Furthermore, both groups of women had indications of iron insufficiency. Therefore, differences in target groups or the method of measuring iron absorption cannot explain the different outcomes. In the study of Murray-Kolb et al no baseline values of the participants are given. The low iron absorption in the HFeZnB variety could be due to the interaction between zinc and iron, which influenced the iron absorption. A study reported that giving iron and zinc supplementation separately was more effective in improving iron and zinc absorption as when they were giving together (Lind et al., 2003). This could be due to the inhibitory effect of zinc intake on intestinal iron absorption (Crofton et al., 1989). Another study confirmed that zinc has an inhibitory effect on iron absorption (Olivares, Pizarro, Gaitán, & Ruz, 2007), but the inhibitory effect lasted only 30 minutes in this study. However, another more recent study showed actually the opposite as seen in the results of Donangelo et al, which was that iron absorption increased with increased zinc intake (Badii, Nekouei, Fazilati, Shahedi, & Badiei, 2012). Furthermore, it could be that iron absorption is low in the HFeZnB variety because during breeding of the HFeZnB also phytic acid and polyphenol content increased and hence iron absorption would have been inhibited (Petry, Egli, Zeder, Walczyk, & Hurrell, 2010). Finally, it could be that phytic acid and polyphenol contents are higher and/or iron content is lower in common beans compared with soyabeans. It should be investigated whether the HFeZnB variety has higher iron bioavailability compared to other common bean varieties.

Iron absorption has more than tripled (~6 %) in generally healthy women in the study of Beiseigel et al (Beiseigel et al., 2007) when ascorbic acid (vitamin C) was added to two different bean varieties. However, consuming a diet based on fermented soyabean (tempeh) with additional vitamin C-rich fruits had no effect on improving iron status (5.1 % absorption) in Indonesian pregnant women nor on preventing it (Wijaya-Erhardt, Muslimatun, & Erhardt, 2011). Both studies used appropriate measurement methods to either measure iron absorption (radioisotope) or iron status (haemoglobin, plasma ferritin, transferrin receptor, C-reactive protein). Consequently, it seems that an increased iron absorption by ascorbic acid does not translate into improved iron status. On the other hand, it could be that the study period was too short to indicate a positive effect of adding ascorbic acid to legume-based foods on iron status, or matrixes of beans and soyabeans could be different and therefore ascorbic acid only improves iron absorption of beans but not of soyabeans. However, in the study of Murray-Kolb et al ascorbate solution improved iron absorption of soyabean-based meals. As shown in one study the positive effect of ascorbic acid on iron absorption is dose dependent and works only on non-haem (plant) iron (Lynch & Cook, 1980). Therefore, it could be that differences in the amount of ascorbic acid influenced the effect on iron absorption and on iron status.

Dephytinization of legume-based foods hardly influenced iron bioavailability in the study of Davidsson et al (Davidsson, Ziegler, Kastenmayer, van Dael, & Barclay, 2004; Petry et al., 2010). Yet, in the study of Petry et al dephytinization increased iron absorption significantly. Petry et al also showed that dephytinization in combination with dehulling (removing polyphenols) increased iron bioavailability even more (by 260 %). Dehulling surprisingly decreased iron bioavailability by 38 %, even though polyphenol concentration was decreased by 85 % (Petry et al., 2010). Petry et al assumed that dehulling also removed compounds which positively influence iron absorption. However, Abizari et al conclude that rather the phytic acid-to-iron ratio than polyphenol concentration determines iron bioavailability. To summarize, these results indicate that dephytinization improves iron absorption but the exact role of polyphenols remains unclear.

Furthermore, comparing iron intake and absorption of the study of Petry et al (Petry et al., 2010) with the study from Abizari et al (Abizari, Moretti et al. 2012), the iron intake was lower in the common bean meals from the study of Petry et al (range: 4.7 – 6.2 mg) (Petry, Egli et al. 2010) than in the fortified white and red cowpea meals from the study of Abizari et al (range: 9.3 – 12.8 mg) (Abizari, Moretti et al. 2012). Iron absorption on the other hand was lower in the study of Abizari et al (range: 0.89 - 1.7 %) (Abizari, Moretti et al. 2012) than in the study of Petry et al (range: 1.6 – 20.2 %) (Petry, Egli et al. 2010). This inverse correlation cannot be explained by the choice of the target group, because both target groups are women with a similar age range and health status. It seems that dephytinization and dehulling have a greater effect on increasing iron bioavailability than fortifying a legume with $FeSO_4$ or NaFeEDTA.

Soy formula has a similar effect on iron status in infants with cow's milk allergy or with a low-birth weight than an extensively hydrolysed whey formula (Seppo et al., 2005) or a cow's milk formula (Rudolph et al., 1981). All three types of formula are not very rich in iron, consequently soy formula seems to not satisfy the iron requirements for infants.

Iron intake seems to be low when consuming legume-based diets. However, methods like dephytinization and fortification seem to be promising in increasing iron bioavailability in legume-based foods and improving iron status. Ascorbic acid supplementation is also promising in increasing iron bioavailability. Nonetheless, evidence about improving iron status with ascorbic acid supplementation is lacking.

7.4.2 **Zinc**

Although dephytinization had hardly any effect on iron absorption, it does affect zinc absorption. In the study of Davidsson et al (Davidsson et al., 2004) zinc absorption of the dephytinized soya formula (22.6 %) was significantly higher than in the non-dephytinized soya formula (16.7 %). Therefore phytic acid seems to be the most important inhibitor of zinc absorption. Furthermore, using a high-iron-high-zinc bean (HFeZnB) variety instead of a common bean variety did not significantly increase zinc bioavailability (~14 and ~16 % respectively) but it does significantly increase the total amount of zinc absorbed (0.7 and 0.36 mg respectively) (Donangelo et al., 2003). Lower zinc content increases zinc bioavailability (Hunt, Beiseigel, & Johnson, 2008), which is slightly indicated by these results as well. Even though zinc bioavailability did not differ between the varieties, the total zinc absorbed from the HFeZnB was almost twice as high as from the normal bean variety (0.7 and 0.36 mg respectively). However, the zinc absorption is still low.

In the study of Seppo et al (Seppo et al., 2005) the zinc content of whey formula was significantly lower than of soy formula. However, zinc absorption was similar in both groups, which could be due to a higher phytic acid content in the soy formula inhibiting the zinc absorption as seen in the study of Davidsson et al (Davidsson et al., 2004). Even though zinc bioavailability from soy formula was low, the zinc intake was sufficient for their requirements. For the recovery of malnourished infants the soy formula seems not to be a good choice (Golden & Golden, 1981). Comparing soy formula with cow's milk formula as possible therapeutic diets for the recovery of malnourished infants, the 'catch-up growth' of the infants fed the soy formula was significantly lacking behind. Golden et al associated growth failure with the amount of dietary zinc and phytic acid ingested. However, plasma zinc, as measured in this study, is not a good biomarker for zinc status due to its poor sensitivity and specificity (Hambidge, 2003). Therefore, no firm conclusion can be drawn on zinc intake or status from this study.

Zinc intake seems to be low when consuming legume-based diets. However, methods like dephytinization and a high-iron-high-zinc variety to be promising in increasing zinc bioavailability in legume-based foods and improving zinc status.

7.4.3 **Calcium**

Dephytinization of a soy formula did not increase calcium absorption in healthy infants and women (Davidsson et al., 2004; Petry et al., 2010). However, Seppo et al (Seppo et al., 2005) found that calcium intake from soy formula was comparable with recommended intake and the overall nutrient status of the infants was in a normal range. Hence, it seems that calcium intake from a legume-based diet is sufficient. Further, in the study of Seppo et al (Seppo et al., 2005) the target group was healthy cow's milk allergic infants which probably had already a normal calcium status. If there is a need to improve calcium status, calcium intake needs to increase. For this purpose calcium fortification seems to be effective. In the study from Ekbote et al (Ekbote et al., 2011) apparently healthy children with low habitual calcium intakes to whom a fortified cereal legume snack with 500 mg of calcium carbonate was given showed an improvement in calcium intake and status compared to apparently healthy children with low habitual calcium intake which were given a non-fortified cereal legume snack, showing that calcium fortification could improve calcium status of children. However, this study was done during one day measuring the percentage of serum calcium concentration from baseline values. The intake and status acutely improved but how the calcium intake and status is affected by a calcium fortified legume snack on the long-term remains unknown.

A legume-based diet seems to satisfy the calcium needs of healthy infants and women. However, in case calcium status is low and intake needs to be increased a legume-based diet does not sufficiently increase calcium intake. Calcium fortification of a legume snack seems to be effective in increasing calcium intake and improving calcium status of children.

7.4.4 **Copper, Selenium, Manganese, Vitamin A and Vitamin E**

How sufficient a legume-based diet is in different nutrients, is difficult to conclude based on the studies included in this literature review. How certain circumstances influence the bioavailability of nutrients in legume-based diets or how legume-diets compare to other diets can be discussed based on the results of the studies included. In studies which targeted infants the focus was on nutrients like copper, selenium, manganese, vitamin A and vitamin E, while studies which targeted women and children mainly focused on iron and zinc intake and status of legume-based foods. Copper intake from a soy formula of infants was comparable with recommended intakes (Seppo et al., 2005) and hence seems to be sufficient in this kind of legume-based diet for infants. Trying to increase copper absorption by dephytinization of a soy formula was not successful (Davidsson et al., 2004). However, dephytinization of soy formulas does not seem to be necessary to reach recommended copper intake in infants if looking at the results of Seppo et al (Seppo et al., 2005). Still, this is not enough evidence to make a clear conclusion about the sufficiency of copper intake of legume-based foods in infants. More studies would be needed, which conclude the same. Dephytinization of a soy formula has no significantly effect on copper, iron, calcium and manganese absorption (Davidsson et al., 2004). Looking at the manganese absorption of the dephytinized soy formula the difference, although not significant, was quiet high, indicating that there might be an increase in manganese absorption, which was not recognized in this study. In another study from Davidsson et al (Davidsson, Almgren, Juillerat, & Hurrell, 1995) in which the manganese absorption of a dephytinized soy formula in humans was tested, the 2.3 fold increase after dephytinizing the soy formula was significant. This study was not included in this review because the target group were both men and women. However, looking at the effect of dephytinization of soy formula on manganese absorption in humans it adds some information here. Nonetheless, the difference in outcome could be due to the difference in target group or difference in degree of dephytinization.

Adding iron to either a soy formula or a cow's milk formula increased erythrocyte selenium content compared to the cow's milk formula without added iron (Rudolph et al., 1981). Erythrocyte selenium content is rather an estimate for long term intake of selenium that from an acute intake. Considering 5 weeks as long term, the increase of selenium could be related to the consumption of iron fortified soy or cow's milk formula. Vitamin E status was also measured in this study but showed no significant differences between the three formulas, however, infants with low birth weight had lower serum levels of vitamin E, which did not change during the study period, indicating that there was an association between low birth weight and malabsorption for vitamin E and maybe also iron which could explain the low levels of haematocrit.

Feeding the Weanimix (75 % maize, 15 % soyabeans, and 10 % groundnuts) to Ghanaian infants improved vitamin A status, but fortifying the Weanimix with minerals and vitamins improved vitamin A as well as overall nutrient status even more (Lartey et al., 1999). This study as well as other studies (Abizari, Moretti, Schuth, et al., 2012; Abizari, Moretti, Zimmermann, et al., 2012; Rudolph et al., 1981; Schümann et al., 2005) indicate that fortification of legume-based foods, especially fortification of iron, seems to be advisable to improve or maintain nutrient status.

Evidence on the effect of copper, selenium, manganese, vitamin A and/or vitamin E from a legume-based diet on nutrient intake and status is inconsistent or poor.

7.4.5 **Protein/Amino acid composition**

The soya-maize mixture was found to be a good source of protein and energy to treat protein-energy malnutrition in children. Besides this, the incidence of diarrhoea was significantly lower in the children fed the soya-maize mixture than in the children fed the cow's milk diet (Baker, Baker, Margo, & Reuter, 1978). However, soyabean proteins are known for their deficiency in methionine. In the study of Graham et al. the addition of methionine to a soyabean diet resulted in a significantly higher methionine/essential amino acid ratio. Nevertheless, similar methionine concentrations were found in infants fed a soyabean diet with added methionine and infants fed a soyabean diet without added methionine (Graham, MacLean Jr, & Placko, 1976). The participating infants were not randomly assigned to one of the two groups and the number of infants participating in each intervention group also strongly varied. Furthermore, the study took six years, which makes it likely that the study conditions and environment were not controlled during the entire study period.

The net protein utilization was similar in infants fed a food based on skim milk solids and in infants fed a food based on groundnut flour. The groundnut based food contained considerably less lysine, methionine and total sulphur amino acids compared with the skim milk based food (Prasanna, Rao, & Chandrasekhara, 1970). In the literature of this study no randomization and no wash-out period were mentioned which may have resulted in confounded results.

Soyabean and groundnuts are limited in some essential amino acids. No solid conclusions can be drawn on the effect of legume-based diets on protein status based on these studies.

7.4.6 **Growth**

Misola, a mixture of millet (60 %), soya (20 %), peanut kernel (10 %), sugar (9 %) and salt (1 %), improved growth and weight gain in underweight children (HAZ <-3) considerably more than a traditional meal (control). However, in combination with Spiruline, a dietary supplement high in protein (and all essential amino acids), the increase in growth and weight gain was even greater (Simpore et al., 2006). Misola alone had a high energy content but a low protein content whereas Spiruline had a high protein content but a low energy content. Therefore, combining those two foods resulted in a high energy and high protein diet (energy intake of 767 ± 5 kcal/day with a protein assumption of 33.3 ± 1.2 g a day). Soya only contributed a small part to the diet, that is why it is difficult to attribute the improvement directly to soya. Still, it certainly improves the variety of the diet. In another study, improving the nutrient status of malnourished children with either soya milk or cow's milk were both successful (Dutra de Oliveira, Luiz, Netto, & Duarte, 1966). However, children with clinical oedemas had an higher initial weight loss than children without clinical oedemas. This seemed to be the case, because children with clinical oedemas lost more water than they gained weight, resulting in a negative weight balance. Furthermore, children without clinical oedema consuming the cow's milk lost less weight and needed less time to reach minimum body weight than children consuming soya milk. Using soya milk feeding in cow's milk allergic infants was also successful in reaching a normal growth (catch-up growth) by the age of 4 years(Seppo et al., 2005). However, concerns can be raised about the negative effect of catch-up growth in early life. A study showed that undernourished children who experienced an rapid weight gain after infancy commonly develop chronic diseases (Cesar G Victora et al., 2008).

A mixture of extruded maize and cowpea (Obatolu, 2003) or a cereal-legume blend (Weanimix) (Lartey et al., 1999) both improved weight and length gain in infants which are likely to be malnourished, like infants with a low socioeconomic background (Obatolu, 2003) or Ghanaian infants (Lartey et al., 1999). The control group from the study of Lartey et al was from a separate cross-sectional study, which was investigated at a different time point. This could have confounded the results. Other possible factors (confounders) which could have influenced the growth results were that in the intervention groups risk of contamination of project foods was reduced, the project food was for free, which could have increased consumption, and the increased attention and care of children in the intervention group. Some of these confounders were adjusted for in the results, whereas others still remain as possible confounders. How large the influence of these confounders were is not clear. However assuming that the effect of the confounders, for which the results were not adjusted for, is small, it can be concluded that the cereal-legume blend is likely a good food source to improve growth in Ghanaian children.

Protein intake from legume-based foods is sufficient in quantity but legumes are limited in some essential amino acids. Studies do show that legume-based diets improve growth in children.

7.5 Conclusion

Grain legumes add energy, proteins, minerals, B vitamins and a variety of tastes and textures to the African diet and thus are important for dietary diversity. They are part of two important complementary mixes, with cereals and with roots and fruits. Grain legumes add to these staples proteins, minerals, several B vitamins and extra energy intake. They supplement cereals for the essential amino acid lysine resulting in a higher quality of protein. When added to root and fruit staples, they only raise the protein content because both have similar limiting amino acids. Where energy and protein are both deficient, leguminous oilseeds can play an important role in improving diets. Legume leaves are significant sources of B-carotene (provitamin A) and vitamin C and compared with legume grain they add a little more of most B vitamins and more folic acid, calcium and iron to a meal. Evidence on the efficacy of the consumption of legume-based foods on nutrient intake and status of women of reproductive age, children and infants show that protein intake from legume-based foods is able to improve growth in children. Iron and zinc intake seem to be low when consuming legume-based diets. However, methods like dephytinization and fortification seem to be promising in increasing iron and zinc bioavailability in legume-based foods and improving iron and zinc status. Ascorbic acid supplementation is also promising in increasing iron bioavailability. Nonetheless, evidence about improving iron status with ascorbic acid supplementation is lacking. Evidence about other micronutrients is inconsistent or poor.

8 Impact of legume cultivation on nutrition

Malnutrition occurs when poverty and adverse circumstances restrict quantity and variety of food, and this is aggravated by disease and lack of health care. Agriculture is the primary source of calories and essential nutrients and is a major source of income for 80 percent of the world's poor. The N2Africa project aims at enhancing agricultural productivity and food security through the cultivation of grain legumes.

Hoddinott (2011) describes potential pathways through which improved agricultural interventions may improve nutritional status. These potential pathways are reflected in Figure 8.1, applies to the N2Africa project. First (1), improved agricultural productivity may increase food availability and directly, or indirectly through processing, lead to increased consumption of produced crops contributing to caloric, protein and micronutrient intake. Second (2), it may increase household income from the sale of produced crops and if this is used to purchase more nutritious foods this will contribute to improvement of nutritional status. If it is spent on non-food expenditures like health and education this will indirectly improve nutritional status via a decrease in frequency and severity of illness. Third (3), it may decrease consumer food prices from increased food availability and therefore increases the purchasing power. If this extra purchasing power is used to purchase more nutritious foods this will improve nutritional status. If it is spent on non-food expenditures like health and education this will indirectly improve nutritional status via improved care leading to decrease in frequency and severity of illness. Further, when nutrition education leads to improved knowledge about healthy dietary habits this may also increase the intake of nutritious foods. Fourth (4), agricultural work patterns may change due to the N2Africa project. Increased household income may decrease the time spent working on income-generating activities and therefore may increase time spent on care-giving. This may increase caloric, protein and micronutrient intake and/or decrease frequency and severity of illness of household members. Further, when the inputs of N2Africa trickle down to improved nutrition and health this may increase labour availability and/or improve labour productivity. This, in turn, may contribute to higher productivity (with or without inputs of N2Africa) and/or to increased other income-generating activities. Fifth (5), the inputs of N2Africa may introduce new food(s) into the diet which contributes to the diversity of the diet. This could be directly via the consumption of the produced legumes crops or indirectly via an increased income and new food(s) bought in the market. Sixth (6), the N2Africa project may affect gender roles within the household. N2Africa has the target to include 50 percent female farmers in the project. This may enhance their power within the household and may affect how household income is spent (income spent on nutritious foods and/or non-food expenditures contributing to health and nutrition) and how food is distributed among the household members. The intra-household distribution also influences whether the food available in the house for consumption leads to improved nutritional status of household members. For example, children under 2 years of age and women of reproductive age have special nutritional needs.

Often agricultural interventions which focus on increased agricultural productivity assume (implicitly) that improved production will trickle down to improved nutrition and health of household members (Hoddinott, 2011). The effect of an income increase on nutritional status is well known and is often found to be small in size (Deaton, 1997), because households tend to spend their additional income in tastier and less nutritious food. Further, higher intake (from increased food availability) does not immediately translate into improved nutritional status, as food intake is only one of the main determinants of nutritional status together with caring practices and an healthy environment (Smith & Haddad, 2000). Also, additional caloric intake can be spent in additional activity for work and play, thus not resulting in changes in nutritional status (Svedberg, 2000). Recent review studies (Berti et al., 2003; Kawarazuka, 2010; Leroy & Frongillo, 2007; Ruel, 2001; World Bank, 2007) indicate the lack of data showing the translation of agricultural productivity in improved nutrition and health. The most recent systematic review included only interventions with the explicit goal of improving nutritional status (Masset et al., 2012). It was found that these interventions (23 in total), including production diversification projects and bio-fortification projects, were successful in promoting consumption of specific foods but little evidence was available on changes in the diet of the poor. For example, there was no evidence of impact on the absorption of iron and some evidence of the impact on absorption of vitamin A. Furthermore, no evidence of impact on prevalence rates of stunting, wasting and underweight among children under five was found. Five of the eight studies which did examine the impact on children's nutritional status, showed no impact on any of the three indicators. However,

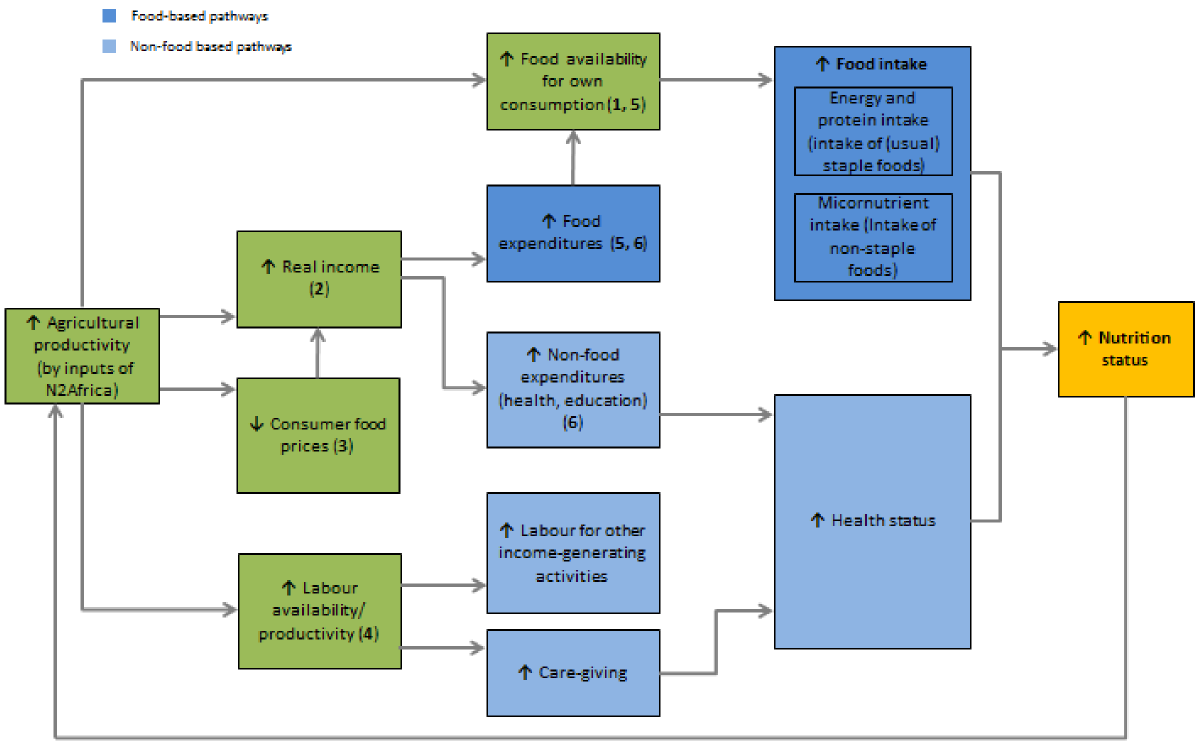

Figure 8.1: Pathways through which improved agricultural productivity may affect nutrition status

Masset et al. (2012) conclude that the absence of any reported statistically significant impact of agricultural interventions on children's nutritional status found by this review and other reviews should not be attributed to the inefficacy of these interventions. Rather it is the lack of power of the studies reviewed that could have prevented the identification of such impact, if any. Furthermore, data from non-participants is often not available and/or the following indicators are not measured: total household income, diet diversity & anthropometric measurements. Therefore the impact of agricultural interventions on nutritional status remains unknown.

9 Conclusions

Both protein-energy malnutrition and micronutrient deficiencies are highly prevalent in sub-Saharan Africa and result in substantial increases in overall disease burden and mortality, decreases in intellectual development and reduction in productivity and economic development. Grain legumes and legume leaves add energy, proteins, minerals and B vitamins to the sub-Saharan African diet. Consumption of legume-based foods improves growth in children. Iron and zinc intake are low when consuming legume-based diets. However, methods like dephytinization and fortification seem to be promising in increasing iron and zinc bioavailability in legume-based foods and improving iron and zinc status of infants, children and women of reproductive age. Evidence concerning other micronutrients is inconsistent or poor. The nutritional benefits of consumption of legume-based foods are influenced by many factors like bio-availability of micronutrients in legume-based foods but also intra-household shares and gender equity within the household which determines the food intake. Furthermore, it is often assumed that agricultural interventions translate into improved nutrition. Recent review studies show little or no measurable effect of agricultural interventions on nutrition and health.

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Appendices

Appendix I

Table AI-1: Child stunting and wasting prevalence in N2Africa countries

'N2Africa Countries'	Stunting prevalence (%) (children under 5 years old)	Wasting prevalence (%) (children under 5 years old)
Ghana	35.6	2.8
Nigeria	43.0	4.8
Liberia*	39.4	7.5
Sierra Leone**	36.4	10.2
DRC	44.4	11.9
Ethiopia	57.4	3.8
Kenya	35.8	2.4
Rwanda***	45.0	4.0
Tanzania	48.3	0.1
Uganda	44.8	1.5
Malawi	54.6	2.9
Mozambique	47.0	2.1
Zimbabwe****	33.8	2.1

Note. Data adapted from Black et al. (2008). Other sources: *Liberia Demographic and Health Survey 2007; **Sierra Leone Demographic and Health Survey 2008; ***Rwandan Demographic and Health Survey 2005; ****National Zimbabwe survey 2010.

Appendix II

Nutrient composition table for varieties of common bean

Table AII-1: Proximates for varieties of Common bean

Nutrient	Unit (p/100 g)	**Black bean**	**Cranberry bean**	**French bean**	**Great Northern bean**	**Kidney bean**	**Navy bean**	**Pink bean**	**Pinto bean**	**Yellow bean**	**Small white bean**	**White bean**
Energy	Kcal kJ	341 1425	335 1402	343 1435	339 1419	333 1393	337 1411	343 1435	347 1452	345 1443	336 1406	333 1393
Water	g	11.0	12.4	10.8	10.7	11.8	12.1	10.1	11.3	11.1	11.7	11.3
Total protein	g	21.6	23.0	18.8	21.9	23.6	22.3	21.0	21.4	22.0	21.1	23.4
Total fat	g	1.4	1.2	2.0	1.1	0.8	1.5	1.1	1.2	2.6	1.2	0.9
-polyunsaturated	*g*	0.6	*0.5*	*1.2*	*0.5*	*0.5*	*1.4*	*0.5*	*0.4*	*1.1*	*0.5*	0.4
Total carbohydrate	g	62.4	60.1	64.1	62.4	60.0	60.8	64.2	62.6	60.7	62.3	60.3
-dietary fibre	*g*	*15.5*	24.7	25.2	20.2	24.9	24.4	12.7	15.5	25.1	24.9	15.2
-sugars	*g*	2.1	-	-	2.3	2.2	3.9	2.1	2.1	-	-	2.1

Note. The data is adapted from 'USDA National Nutrient Database for Standard Reference, Release 24' by U. S. Department of Agriculture, 2011, available from: http://ndb.nal.usda.gov/ndb/foods/list; from 'West African Food Composition table' by FAO, Infoods, ECOWAS/WAHO and Biodiversity International, 2012, available from: http://www.fao.org/docrep/015/i2698b/i2698b00.pdf; & from 'South African Food Data System' by South African MRC, 2010, available from http://safoods.mrc.ac.za/.

Table AII-2: Amino acid composition for protein in varieties of Common bean

Nutrient	Unit (p/100 g)	**Black bean**	**Cranberry bean**	**French bean**	**Great Northern bean**	**Kidney bean**	**Navy bean**	**Pink bean**	**Pinto bean**	**Yellow bean**	**Small white bean**	**White bean**
Total protein	g	21.6	23.0	18.8	21.9	23.6	22.3	21.0	21.4	22.0	21.1	23.4
Essential AA												
Histidine	g	0.6	0.6	0.5	0.6	0.7	0.5	0.6	0.6	0.6	0.6	0.7
Isoleucine	g	1.0	1.0	0.8	1.0	1.0	1.0	0.9	0.9	1.0	0.9	1.0
Leucine	g	1.7	1.8	1.5	1.7	1.9	1.7	1.7	1.6	1.8	1.7	1.9
Lysine	g	1.5	1.6	1.3	1.5	1.6	1.3	1.4	1.4	1.5	1.4	1.6
Methionine	g	0.3	0.3	0.3	0.3	0.4	0.3	0.3	0.3	0.3	0.3	0.4
Phenylalanine	g	1.2	1.2	1.0	1.2	1.3	1.2	1.1	1.1	1.2	1.1	1.3
Threonine	g	0.9	1.0	0.8	0.9	1.0	0.7	0.9	0.8	0.9	0.9	1.0
Tryptophan	g	0.3	0.3	0.2	0.3	0.3	0.2	0.2	0.2	0.3	0.3	0.3
Valine	g	1.1	1.2	1.0	1.1	1.2	1.2	1.1	1.0	1.2	1.1	1.2
Non-essential AA												
Alanine	g	0.9	1.0	0.8	0.9	1.0	0.9	0.9	0.9	0.9	0.9	1.0
Arginine	g	1.3	1.4	1.2	1.4	1.5	1.0	1.3	1.1	1.4	1.3	1.4
Aspartic acid	g	2.6	2.8	2.3	2.6	2.9	2.6	2.5	2.3	2.7	2.6	2.8
Cysteine	g	0.2	0.3	0.2	0.2	0.3	0.2	0.2	0.2	0.2	0.2	0.3
Glutamic acid	g	3.3	3.5	2.9	3.3	3.6	3.1	3.2	3.0	3.4	3.2	3.6
Glycine	g	0.8	0.9	0.7	0.9	0.9	0.8	0.8	0.8	0.9	0.8	0.9
Proline	g	0.9	1.0	0.8	0.9	1.0	1.1	0.9	1.1	0.9	0.9	1.0
Serine	g	1.2	1.3	1.0	1.2	1.3	1.2	1.1	1.2	1.2	1.1	1.3
Tyrosine	g	0.6	0.6	0.5	0.6	0.7	0.5	0.6	0.4	0.6	0.6	0.7

Table AII-3: Mineral composition of varieties of Common bean

Nutrient	Unit (p/100 g)	**Black bean**	**Cranberry bean**	**French bean**	**Great Northern bean**	**Kidney bean**	**Navy bean**	**Pink bean**	**Pinto bean**	**Yellow bean**	**Small white bean**	**White bean**
Calcium, Ca	mg	123	127	186	175	143	147	130	113	166	173	240
Iron, Fe	mg	5.02	5.00	3.40	5.47	8.20	5.49	6.77	5.07	7.01	7.73	10.44
Magnesium, Mg	mg	171	156	188	189	140	175	182	176	222	183	190
Phosphorus, P	mg	352	372	304	447	407	407	415	411	488	445	301
Potassium, K	mg	1483	1332	1316	1387	1406	1185	1464	1393	1042	1542	1795
Sodium, Na	mg	5	6	18	14	24	5	8	12	12	12	16
Zinc, Zn	mg	3.65	3.63	1.90	2.31	2.79	3.65	2.55	2.28	2.83	2.81	3.67
Copper, Cu	mg	0.84	0.79	0.44	0.84	0.96	0.83	0.81	0.89	0.64	0.64	0.98
Manganese, Mn	mg	1.06	0.92	1.20	1.42	1.02	1.42	1.38	1.15	1.29	1.28	1.80
Selenium, Se	mg	3.2	12.7	12.9	12.9	3.2	11.0	13.0	27.9	12.8	12.8	12.8

Table AII-4: Vitamin composition of varieties of Common bean

Nutrient	Unit (p/100 g)	**Black bean**	**Cranberry bean**	**French bean**	**Great Northern bean**	**Kidney bean**	**Navy bean**	**Pink bean**	**Pinto bean**	**Yellow bean**	**Small white bean**	**White bean**
Thiamin (Vitamin B-1)	mg	0.90	0.75	0.54	0.65	0.53	0.78	0.77	0.71	0.69	0.74	0.44
Riboflavin (Vitamin B-2)	mg	0.19	0.21	0.22	0.24	0.22	0.16	0.19	0.21	0.33	0.21	0.15
Niacin (Vitamin B-3)	mg	1.96	1.46	2.08	1.96	2.06	2.19	1.89	1.17	2.43	1.34	0.48
Pantothenic acid (Vitamin B-5)	mg	0.90	0.75	0.79	1.10	0.78	0.74	1.00	0.79	0.73	0.73	0.73
Vitamin B-6	mg	0.29	0.31	0.40	0.45	0.40	0.43	0.53	0.47	0.44	0.44	0.32
Folate (Vitamin B-9)	µg	444	604	399	482	394	364	463	525	389	386	388
Vitamin K	µg	5.6	-	-	6.0	19.0	2.5	5.7	5.6	-	-	5.6
Ascorbic acid (Vitamin C)	mg	0.0	0.0	4.6	5.3	4.5	-	0.0	6.3	0.0	0.0	0.0
Vitamin E	mg	0.21	-	-	0.22	0.22	0.02	0.21	0.21	-	-	0.21
Vitamin A (mcg RAE / IU)	mcg IU	- 17	0 2	0 8	0 0	0 0	0 0	0 0	0 0	0 6	0 0	0 0

Appendix III

General physiology of proteins, carbohydrates, fat, vitamins and minerals

Protein

Chemical structure of protein. Proteins are compounds composed of carbon (C), hydrogen (H), oxygen (O) and nitrogen (N) atoms, arranged into amino acids linked in a chain. Each amino acid contains an amino group, an acid group, a hydrogen atom and a distinctive side group, all attached to a central carbon atom. Proteins are made up of 20 different amino acids, nine essential and eleven non-essential amino acids. Although all amino acids share a common structure, they differ in size, shape, electrical charge an other characteristics because of differences in the side groups. The body can synthesize the non-essential amino acids for itself given nitrogen for the amino group and fragments of carbohydrates and fat to form the rest of the structure. The nine essential amino acids must be supplied by the diet, either because the human body cannot make them at all or cannot make them in sufficient quantity to meet its needs. Sometimes a non-essential amino acid becomes essential under special circumstances. For example the body uses the essential amino acid phenylalanine to make tyrosine. But if the diet fails to supply phenylalanine or cannot make the conversion, then tyrosine becomes a conditionally essential amino acid (Rolfes et al., 2009).

Table AIII.1: Essential and non-essential amino acids in 'N2Africa legumes' *

Essential Amino Acids	Available in legumes (> 1g per 100g)	**Non-essential Amino Acids**	Available in legumes (> 1g per 100g)
Histidine	Soyabean	**Alanine**	Cowpea, soyabean, groundnut, pigeon pea
Isoleucine	Cowpea, soyabean	**Arginine**	Cowpea, soyabean, groundnut, chickpea, pigeon pea
Leucine	Cowpea, soyabean, groundnut, chickpea, pigeon pea	**Asparagine**	(Aspartic acid is precursor)
Lysine	Cowpea, soyabean, chickpea, pigeon pea	**Aspartic acid**	Cowpea, soyabean, groundnut, chickpea, pigeon pea
Methionine	(soyabean: 0.5g/100g)	**Cysteine**	(soyabean: 0.7g/100g)
Phenylalanine	Cowpea, soyabean, groundnut, chickpea, pigeon pea	**Glutamic acid**	Cowpea, soyabean, groundnut, chickpea, pigeon pea
Threonine	Soyabean	**Glutamine**	(Glutamic acid is precursor)
Tryptophan	(soyabean: 0.6g/100g)	**Glycine**	Cowpea, soyabean, groundnut
Valine	Cowpea, soyabean, groundnut	**Proline**	Cowpea, soyabean, groundnut, pigeon pea
		Serine	Cowpea, soyabean, groundnut, chickpea, pigeon pea
		Tyrosine	Soyabean, groundnut

Note. The data in column 2 and 4 are adapted from 'USDA National Nutrient Database for Standard Reference, Release 24' by U. S. Department of Agriculture, 2011, available from: http://ndb.nal.usda.gov/ndb/foods/list.
* nd for common bean

The protein content of most legumes averages 20 to 25 %, whereas the protein content of soyabean is about 40 %. Methionine is the most significant limiting amino acid in soyabean protein. But this difference is actually not really high and soyabean protein is equivalent in quality to animal protein (Mateos-Aparicio et al., 2008). For the other legumes methionine is also one of the limiting amino acids, like the other sulphur amino acid cysteine. Most of the legumes contain sufficient lysine, which is deficient in cereal protein (See table AIII-1). Therefore, legume amino acid profile is complementary to cereal amino acid protein (Mateos-Aparicio et al., 2008).

Digestion and absorption of protein. Proteins in food, supply the amino acids from which the body makes its own proteins. Proteins are crushed and moistened in the mouth and are partially broken down in the stomach (hydrolysis). Hydrochloric acid uncoils each protein's tangled strands so that digestive enzymes (pepsin) can attack the peptide bonds. When polypeptides enter the small intestine, several pancreatic and intestinal proteases hydrolyse them further into short peptide chains (tripeptides, dipeptides and amino acids). Peptidase enzymes on the membrane surfaces of the intestinal cells split most of the dipeptides and tripeptides into single amino acids. Specific carriers in the membranes of intestinal cells transport the amino acids into the cells, where they are released into the bloodstream (Rolfes et al., 2009).

Roles of protein. Versatility is a key feature of proteins. Whenever the body is growing, repairing, or replacing tissue, proteins are involved. Sometimes their role is to facilitate or to regulate; other times it is to become part of a structure. A few of the many roles proteins play are described in table AIII-2.

Table AIII.2: Different functions of protein

Function of protein	Explanation
Growth and maintenance	Proteins form integral parts of most body structures such as skin, tendons membranes, muscles, organs and bones (matrix of collagen). As such, they support the growth and repair of body tissues. (blood clotting)
Enzymes	Proteins facilitate chemical reactions (breakdown (digestion), new substances (bone) and transform one substance into another (amino acids into glucose). One enzyme can perform billions of reactions (they are not altered by the reactions).
Hormones	Proteins regulate body processes. (Some, but not all, hormones are proteins.) For example, insulin is produced by the pancreas when blood glucose rises. Insulin stimulates uptake of glucose by muscles and adipose tissues. After acting on the message, cells destroy the insulin.
Fluid balance	Protein help to maintain the volume and composition of body fluids. Fluids can flow freely between intracellular and extracellular but being large, proteins cannot. Proteins are trapped primarily within the cells. Once proteins are outside of cells, they cannot go back in and oedema occurs (plasma proteins attract water). Happens when: protein losses (kidney disease/large wounds), inadequate protein synthesis (liver disease) or inadequate dietary intake of protein. Results in a diminished capacity to deliver nutrients and oxygen to cells and remove wastes.
Acid-base balance	Protein helps maintain the acid-base balance of body fluids by acting as buffers. Acidosis (acidity) and alkalosis (base) lead to coma and death, largely because they denature working proteins (eg. Haemoglobin).
Transportation	Proteins transport substances, such as lipids (lipoproteins), vitamins, minerals, and oxygen (haemoglobin), around the body. Also in cell membranes, as a 'pump' (sodium and potassium concentrations).
Antibodies	Proteins inactivate foreign invaders, thus protecting the body against disease. Body detects antigens and manufactures specific antibodies (proteins). Body develops a molecular memory, immunity. Without sufficient protein the body cannot maintain its army of antibodies to resist infectious diseases.
Energy and glucose	Proteins provide some glucose if needed, for the body's energy needs. During times of starvation or insufficient carbohydrate intake, the body will break down its tissue proteins to make amino acids available for energy or glucose production (maintain blood glucose, losing lean body tissue).
Vision	Light-sensitive pigments in cells of eye's retina are molecules of the protein opsin. Opsin responds to light by changing its shape, thus initiating the nerve impulses that convey the sense of sight to the brain.

Protein metabolism. Proteins are continually being made and broken down. This is known as protein turnover. When protein breaks down, they free amino acids (endogenous). Together with amino acids from dietary intake (exogenous) they form the amino acid pool within cells and circulating blood.

Although rate of protein degradation and protein intake vary, the pattern of the amino acids within the pool remains fairly constant. The body's assimilation of amino acids into proteins and its release of amino acids via protein degradation and excretion (nitrogen in urine, faeces and sweat) can be tracked by nitrogen status (see Table AIII-3).

Table AIII.3: Nitrogen status

Nitrogen status	Explanation	Examples
Nitrogen equilibrium (N in = N out)	Nitrogen intake equals nitrogen output. Nitrogen balances studies are used to estimate protein requirements.	Healthy adults
Positive nitrogen (N in > N out)	Nitrogen intake exceeds nitrogen output. Protein is retained in tissues as they add blood, bone, skin and muscle cells to their bodies.	Infants; Children; Adolescents; Pregnant women; People recovering from protein deficiency or illness
Negative nitrogen (N in < N out)	Nitrogen output exceeds nitrogen intake. The body loses nitrogen as it breaks down muscle and other body proteins for energy.	People who are starving; People suffering from severe stresses like burns, injuries, infections, fever.

Note. The data is adapted from 'Understanding normal and clinical nutrition' by Rolfes, S. R., Pinna, K. & Whitney, E., 2009, Wadsworth, USA.

Amino acids are used to make nonessential amino acids, other compounds (neurotransmitters, pigment melanin, hormones, precursors for vitamins and neurotransmitters) and for energy and glucose (gluconeogenesis). When glucose and fatty acids are limited, proteins are used as energy source. Proteins are only available from working and structural components of the tissues and thus over time energy deprivation always causes wasting of lean body tissue. When amino acids are broken down, they are first deaminated (stripped of their nitrogen-containing amino group) which produces ammonia that is released into the bloodstream and converted into urea (less toxic compound) in the liver. The Kidneys filter urea out of the blood and amino nitrogen ends up in the urine. Protein eaten in excess of need is degraded and stored as body fat (when carbohydrate intake is adequate) (Rolfes et al., 2009).

Protein quality in foods. In countries where food is scarce and people eat marginal amounts of protein-rich foods, the quality of protein becomes crucial. High-quality proteins provide enough of all essential amino acids needed to support the body's work. Two factors influence protein quality: the protein's digestibility and its amino acid composition. Proteins must be digested before they can provide amino acids. This depends on the protein's source and other foods eaten with it. Animal protein is highly digestible (90 to 99 percent) but plant proteins are less digestible (70 to 90 percent for most), but for over 90 percent for soy and legumes). To prevent protein breakdown, dietary protein must supply at least the nine essential amino acids plus enough nitrogen-containing amino groups and energy for the synthesis of the others. If an amino acid is supplied in less amount than needed it is referred to as a limiting amino acid. The quality of a food protein is determined by its amino acid composition compared by the essential amino acids requirements of preschool-age children (if protein will effectively support a young child's growth and development then it will meet/exceed requirements of older children and adults). In general animal foods provide high quality proteins while plant proteins have more diverse amino acid patterns and tend to be limiting in one or more essential amino acids. Plants often also offer less protein (per weight). Several methods are developed for evaluating the quality of food protein and identifying high-quality proteins (see Table AIII-4) (Rolfes et al., 2009).

Table AIII.4: Methods for evaluation of the quality of food protein

Measures of protein quality	Explanation
Amino Acid Scoring	Compares a protein's amino acid pattern with that of a reference protein (chemical scoring); simple, inexpensive, identifies limiting amino acids and can score mixtures of different proteins without making a mixture and test it; not incorporates protein digestibility, substances limiting digestion or utilization and chemical procedure can destroy amino acids.
Protein Digestibility-Corrected Amino Acid Score (PDCAAS)	Compares the amino acid score of food protein with the amino acid requirements of preschool-age children and then correcting for the true digestibility of the protein (1 is maximum score (soyabean: 0.99, chickpeas: 0.66): % of amount of most limiting amino acid in reference protein multiplied by food's protein digestibility %) Recommended by FAO/WHO and used to establish protein quality of foods for Daily Value percentages on food labels
Biological Value (BV)	Measures the amount of protein nitrogen that is retained from a given amount of protein nitrogen absorbed. The more nitrogen retained, the higher the protein quality (is used in the body!). Based on human studies; actual nitrogen retention; expensive; not detect if one tissue is shorted.
Net Protein Utilization (NPU)	Measures the amount of protein nitrogen that is retained from a given amount of protein nitrogen eaten. Not distinguish between causes: digestibility and/or amino acid composition.
Protein Efficiency Ratio (PER)	Determines how well a given protein supports weight gain in growing rats (weight gain(g)/protein intake(g)); used to establish the protein quality for infant formulas and baby foods. Simple; time-consuming; in animals (ex. need more methionine than humans)

Note. The data is adapted from 'Understanding normal and clinical nutrition' by Rolfes, S. R., Pinna, K. & Whitney, E., 2009, Wadsworth, USA.

Although legumes are recognized as being high in protein, the quality of bean protein was often underestimated. This is because the Protein Efficiency Ratio (PER), which is based on the growth of laboratory animals, was the standard method. The PER of beans is quite low because bean proteins are relatively low in methionine and rats need about 50 percent more methionine than humans (Sarwar, Peace, & Botting, 1985). Currently, FAO and WHO recommend the use of PDCAAS. The PDCAAS of most beans is reasonably good, although their overall value is reduced somewhat by their low digestibility (Sarwar & McDonough, 1990). Combining plant protein foods that have different but complementary amino acid patterns (all essential amino acids in sufficient quantities to support health), improves the quality of proteins in plant-based diets. For example, legumes and grains (black beans and rice) can complement each other perfectly (Rolfes et al., 2009).

Health effects. Protein deficiencies arise both from energy-poor and protein-poor diets and leads to the diseases of marasmus and kwashiorkor (see Table AIII-5). When people are deprived of protein, energy or both, the result is protein-energy malnutrition (PEM). It most often strikes early in childhood and is one of the most prevalent and devastating forms of malnutrition in the world, afflicting one of every four children worldwide (WHO, 2001). But older children and adults are also often at risk or affected (United Nations High Commissioner for Refugees, 1999).

In PEM, antibodies are degraded to provide amino acids for other uses, leaving the malnourished child vulnerable to infections. Blood proteins are no longer synthesized so the child becomes anaemic and weak. In the marasmic child, once infection sets in, kwashiorkor follows, and the immune response weakens further. Infections combined with malnutrition are responsible for two-thirds of the deaths of young children in developing countries. PEM occurs in three clinical syndromes: marasmus, kwashiorkor and the combination of the two.

Table AIII.5: Characteristics of marasmus and kwashiorkor

Marasmus ('dry' PEM)	**Kwashiorkor** ('wet' PEM)
A Greek word meaning 'dying away'	Ghanaian word: the illness a child develops when the next child is born; from nutrient and protein dense breast milk to cereal
Infancy (< 2 years)	Older infants and young children (1 to 3 years)
Severe deprivation (and impaired absorption) of energy, protein, vitamins and minerals	Inadequate protein intake or infections (more common)
Develops slowly; chronic PEM	Rapid onset; acute PEM
Severe weight loss	Some weight loss
Severe muscle wasting	Some muscle wasting
No detectable edema	Edema (proteins out of cells & inflammation (infections and toxins)); in limbs and stomach (parasites)
No fatty liver	Enlarged fatty liver (lack of protein carriers that transport fat out of the liver); less enzymes in liver to clear toxic substances
Anxiety, apathy, inactivity (save energy for heart, lungs and brain)	Apathy, misery, irritability, sad
Good appetite possible	Loss of appetite
Hair is sparse, thin and dry	Hair is dry, brittle and becomes straight; Lack of tyrosine to make melanin: changes of hair colour
Skin is dry, thin and wrinkles	Skin develops lesions (inadequate protein synthesis)
Impaired brain development and learning ability	Free iron is common: lack of proteins to carry iron; promotes bacterial growth and free-radical damage
Reduced synthesis of hormones: slows metabolism and lowers body temperature	

Marasmus is marked by the severe wasting of fat and muscle, which the body has broken down for energy, leaving "skin and bones". It is the most common form of PEM in nutritional emergencies. Kwashiorkor is characterized essentially by oedema (swelling which usually starts in the feet and legs). Often the two diseases exist side by side in children consuming the same diet. A child who has marasmus can later develop kwashiorkor. The child suffers the effects of both malnutrition and infections, wasting of marasmus and edema of kwashiorkor (United Nations High Commissioner for Refugees, 1999). Prevention of PEM emphasizes frequent, nutrient-dense, energy-dense meals and resolution of the underlying causes of PEM as poverty, infections and illness. Rehabilitation of PEM emphasizes first replacement of lost fluid and minerals to help to raise blood pressure and strengthen heartbeat. After that, protein and food energy may be given in small quantities, with intakes gradually increased as tolerated. Severely malnourished people, especially those with edema, recover better with an initial diet that is relatively low in protein (Rolfes et al., 2009).

Carbohydrate

Chemical structure of carbohydrates. Carbohydrates are compounds composed of carbon (C), hydrogen (H) and oxygen (O), arranged as monosaccharides or multiples of monosaccharides. The simple carbohydrates are sugars which contain only one or two glucose (or fructose and/or galactose) unit(s) (monosaccharides and disaccharides). The complex carbohydrates contain many glucose units (polysaccharides). Three types of complex carbohydrates are important for nutrition: glycogen, starches and fibre. Both glycogen and starch are storage forms of glucose, glycogen in the body and starch in plants, and both yield energy for human use. Starch are long, branched or unbranched chains of hundreds or thousands of glucose molecules linked together. These giant starch molecules are packed together in grains such as wheat or rice, in root crops and tubers (yams and potatoes) and in legumes. When you eat the plant, your body hydrolyzes the starch to glucose and uses the glucose for its own energy purposes. Dietary fibres also contain glucose units but their bonds cannot be broken by human digestion enzymes, so they yield little or no energy (Rolfes et al., 2009). Dietary fibres are often sorted into two groups according to their solubility. Soluble fibres dissolve in water, form gels (viscous) and are easily digested by bacteria in the colon (fermentable). They are most often associated with protecting against heart disease and diabetes by lowering blood cholesterol and glucose levels, respectively. Oats, barley, legumes and citrus fruits are rich in soluble fibres. Insoluble fibres do not dissolve in water, do not from gels (non-viscous) and are less readily fermented. They promote bowel movements and alleviate constipation and are mostly found in whole grains and vegetables. The table below shows a summary of dietary fibres (Rolfes et al., 2009).

Table AIII.6: Descriptions of soluble fibres and insoluble fibres

Soluble fibres	**Insoluble fibres**
Gums, Mucialges, Pectins, Some hemicelluloses, Psyllium	Celluloses, Lignins, Resistant starches, many hemicelluloses
dissolve in water	not dissolve in water
form gels (viscous)	do not from gels (non-viscous)
easily digested by bacteria in the colon, fermentable	less readily fermented
protecting against heart disease (lowering blood cholesterol) and diabetes (lowering glucose levels)	promote bowel movements and alleviate constipation
In: oats, barley, legumes and citrus fruits	In: whole grains and vegetables

Furthermore, a few starches are classified as dietary fibres and known as resistant starches (insoluble fibres). These starches escape digestion and absorption in the small intestine. Starch may resist digestion for several reasons, including the individual's efficiency in digesting starches and the food's physical properties. Resistant starch is common in whole legumes, raw potatoes and unripe bananas.

Phytic acid is not classified as a dietary fibre but is often found accompanying them in the same foods. Because of this close association, researchers have been unable to determine whether it is the dietary fibre, the phytic acid, or both, that binds with minerals, preventing their absorption. This binding presents a risk of mineral deficiencies, but the risk is minimal when total fibre intake is reasonable and mineral intake adequate (Rolfes et al., 2009).

Digestion and absorption of starch and fibre. The digestion of starch begins in the mouth by the salivary enzyme amylase. Stomach acid inactivates salivary enzymes thereby halting starch digestion. The small intestine performs most of the work of carbohydrate digestion. Starch is broken down into glucose molecules. Within 1 to 4 hours after a meal most of the starches have been digested. In the stomach fibre is not digested and delays gastric emptying, thereby providing a feeling of fullness and satiety. Fibres are also not digested in the small intestine and they delay the absorption of other nutrients. Most fibres passes intact through the digestive tract to the large intestine. In the large intestine bacterial enzymes ferment some fibres into short-chain fatty acids and gas. The colon uses these small fat molecules for energy. Fibres in the large intestine attract water which softens the stools for passage without straining. Furthermore, they regulate bowel activity and bind substances, such as cholesterol, bile and some minerals, carrying them out of the body (Rolfes et al., 2009).

Health effects of starch and fibre. Whole grains, vegetables, legumes and fruits are noted for their starch, fibres and naturally occurring sugars. In addition, they supply valuable vitamins and minerals. The table shows how the intake of fibre affects health.

Table AIII.7: Health effect of diets high in complex carbohydrates

Health effect of diets high in complex carbohydrates	Explanation of mechanism
Protect against heart disease	Lower blood cholesterol by binding bile (liver must use its cholesterol to make new bile acids). High-fibre diets were shown to lower serum cholesterol (Messina, 1999).
Protect against diabetes	Slow glucose absorption (low glycemic index); slow transit of foods through GI tract
Contribute to health of GI tract	Hold moisture in stools, softening them; increase fecal weight and speed fecal passage through colon
May protect against colon cancer	May help by diluting, binding and rapidly removing potential cancer-causing agents from the colon
Weight management	Provide bulk and feelings of fullness; less energy per bite than fat (4 kcal/g versus 9 kcal/g)

Despite the benefits of fibres for health, a diet high in fibre also has a few drawbacks. A person who has a small capacity and eat mostly high-fibre foods may not be able to take in enough food to meet energy or nutrient needs. The malnourished, the elderly and young children adhering to all-plant diets are especially vulnerable to this problem. Launching suddenly into a high-fibre diet can cause temporary abdominal discomfort, gas, diarrhea and/or obstruct the gastrointestinal tract (GI tract). Furthermore, fibres may interfere with mineral absorption (Rolfes et al., 2009).

Fat

Chemical structure of fatty acids. Fatty acids are composed of carbon (C), hydrogen (H) and oxygen (O). Lipids have many more carbons and hydrogens in proportions to their oxygens and therefore they supply more energy per gram than carbohydrates or protein, 9 kilo calories per gram instead of 4 kilo calories per gram. Triglycerides is the chief form of fat in the diet and the major storage form in the body. A triglyceride consists of 3 fatty acids attached to a glycerol. Most triglycerides contain a mixture of more than one type of fatty acid. A fatty acid is an organic acid, a chain of carbon atoms with hydrogens attached, that has an acid group at one end and a methyl group at the other end. Fatty acids vary in the length of their carbon chains, their degree of unsaturation (number of double bounds) and the location of their double bounds. Fatty acids may be 4 to 24 (even numbers of) carbons long, the 18 carbon ones being the most common in foods. Those that are fully loaded are saturated; those that are missing hydrogens and therefore have double bounds are unsaturated (monounsaturated and polyunsaturated).

Table AIII.8: Description of different fatty acids

Saturation	Nr. of double bonds	Example	Food sources
Saturated fatty acid	0	Stearic acid	Most animal fats
Monounsaturated fatty acid (MUFA)	1	Oleic acid	Olive, canola oils
Polyunsaturated fatty acid (PUFA)	2 or more	Linoleic acid (2 double bonds), Linolenic acid (3 double bonds)	Sunflower, safflower, corn and soyabean oils Soyabean oils, flaxseed, walnuts

Furthermore, chemist identify polyunsaturated fatty acids by the position of the double bond nearest the methyl end of the carbon chain, which is described by an omega number. A polyunsaturated fatty acid with its first double bond three carbons away from the methyl end is an omega-3 fatty acid (linolenic acid). An omega-6 fatty acid is a polyunsaturated fatty acid with its first double bound six carbons away from the methyl end. Fatty acid saturation affects fats physical characteristics and storage properties. Hydrogenation, which makes polyunsaturated fats more saturated (protected against oxidation and more solid), give rise to trans-fatty acids, altered fatty acids that may have health effects similar to those of saturated fatty acids.

Digestion and absorption of fatty acids. The goal of fat digestion is to dismantle triglycerides into small molecules that the body can absorb. The body provides the emulsifier bile to make triglycerides accessible to the fat-digesting lipases that dismantle triglycerides, into mostly monoglycerides and fatty acids, for absorption by the intestinal cells. The intestinal cells assemble freshly absorbed lipids into chylomicrons, lipid packages with protein escorts, for transport so that cells all over the body may select needed lipids from them.

Roles and health effects of fatty acids. In the body triglycerides provide an energy reserve when stored in the body's fat tissue, insulate against temperature extremes, protect against shock and help the body use carbohydrate and protein efficiently. The human body needs fatty acids and it can make all but two of them: linoleic acid (18 carbons, omega-6) and linolenic acid (18 carbons, omega-3). They serve as structural parts of cell membranes and as precursors to the longer fatty acids that can make eicosanoids (powerful compounds that participate in blood pressure regulation, blood clot formation, and the immune response to injury and infection, among other functions). Because essential fatty acids are common in the diet and stored in the body, deficiencies are unlikely. High intakes of saturated and trans fats increases the risk of heart disease. Omega-3 fatty acids appear to be protective.

Vitamins

Vitamins are essential nutrients needed in tiny amounts in the diet both to prevent deficiency diseases and to support optimal health. The water-soluble vitamins are the B vitamins and Vitamin C; the fat-soluble vitamins are vitamins A, E and K (and D).

Carotenoids (provitamin A) are present in very small amounts in most legumes. However, the dark green leaves of cowpea and common bean contain a significant amount of provitamin A carotenoids but these are less well converted to retinol compared to yellow and orange coloured fruits. Vitamin A has a clearly defined role in vision: when retinal tissue is deprived of vitamin A, rod and cone function is impaired. Vitamin A is also required for the integrity of epithelial cells throughout the body, via the regulatory action of retinoic acid at the gene level. In addition, retinoic acid has an important role in embryonic development, as well as in the maintenance of immune function. Both cell-mediated and systematic and mucosal humoral immunity are affected (Gerster, 1997). Early signs of vitamin A deficiency in humans unclude growth failure, loss of appetite, and impaired immune response with lowered resistance to infection. Night blindness develops when liver reserves of vitamin A are nearly exhausted. Later, ocular lesions such as conjunctival xerosis, Bitot's spots, keratomalacia, and xerophthalmia may occur. Xerophthalmia and night blindness are endemic in many parts of Africa. Severe deficiencies of certain other nutrients may also stimulate vitamin A deficiency. Examples include protein-energy malnutrition and zinc deficiency. Protein-energy malnutrition decreases liver retinol-binding protein (RBP) production because of a limited supply of protein substrate (Rusell et al., 1983). Consequently, hepatic release of vitamin A is impaired, resulting in decrease serum retinol levels, despite the presence of adequate vitamin A stores in the liver. Zinc deficiency decreases serum retinol levels via its role in the hepatic secretion or synthesis of RBP, again even in the presence of vitamin A stores (Christian and West, 1998).

Vitamin E is present in larger amounts in soyabeans and groundnuts oils (higher content of fat). Soyabean oil is low in alfa-tocopherol but high in gamma and delta tocopherol. The bioavailability of vitamin E in the diet is variable, ranging from 20 % to 80 % in published studies, and depends on the form of the vitamin E and the amount per meal; absorption decreases at high intakes. Vitamin E functions primarily as a lipid antioxidant. It prevents cellular damage by inhibiting peroxidation of polyunsaturated fatty acids in cell membranes. Vitamin E performs this function by scavenging free radicals formed by the reaction of polyunsaturated fatty acids with oxygen (Brigelius-Flohe et al., 2002). In humans, vitamin E deficiency is rare

The B vitamins help the body to use the fuel provided by the energy-yielding nutrients carbohydrates, fat and protein. As regards to water-soluble vitamins, thiamin (Vitamin B1) content of legumes is equivalent, or slightly exceeds, that of whole cereals. Reported values range between 0.3 to 1.6 mg per 100 g. Much of the variation between and within species is doubtless due to differences in methods of estimating thiamin.

Minerals

The major minerals are found in larger quantities in the body (sodium, potassium, calcium, phosphorus, magnesium), whereas the trace minerals occur in smaller amounts (iron, zinc, copper, manganese and selenium). Minerals are inorganic elements that always retain their chemical identity (no carbon!). Minerals cannot be destroyed by heat, air, acid or mixing and therefore food preparation methods have no influence on minerals. The ash that remains when a food is burned contains all the minerals that were in the food originally. Minerals can be lost only when they leach into water that is then poured down the drain. The trace mineral contents of foods depend on soil and water composition. The bioavailability of minerals varies due to the present of binders that combine chemically with minerals and prevent their absorption and carry them out of the body with other wastes. Phytates are binders that are found primarily in legumes and grains. They may also interact with other minerals and thereby limiting absorption. For example, phosphorus binds with magnesium in the GI tract, so magnesium absorption is limited when phosphorus intakes are high. Because the minerals are active in all body parts, deficiencies can have wide-reaching effects and can affect people of all ages. For all minerals, mild deficiencies are easy to overlook. The most common result of a deficiency in children is failure to grow and develop. Minerals play different roles in the body. Sodium and potassium are most noted for their role to help to maintain the body’s fluid balance. Calcium, phosphorus and magnesium are most noted for their roles in bone growth and health. Each of the trace minerals perform a different vital role.

Magnesium. Like calcium and phosphorus, magnesium supports bone mineralization. Magnesium is also involved in numerous enzyme systems, building of protein normal muscle contraction, nerve impulse transmission, maintenance of teeth, functioning of immune system and in heart function. It is found abundantly in legumes and leafy green vegetables. A magnesium deficiency causes weakness and confusion and in case of extreme deficiencies it leads to bizarre muscle movements, hallucinations, difficulty in swallowing and in children growth failure.

Iron. Most of the body’s iron is in haemoglobin and myoglobin where it carries oxygen for use in energy metabolism; some iron is required for enzymes involved in a variety of reactions. Special proteins assist with iron absorption, transport and storage, all helping to maintain an appropriate balance, because both too little and too much iron can be damaging. Iron deficiency is most common among infants and young children, teenagers, women of childbearing age and pregnant women. Symptoms include fatigue and anaemia, impaired work performance and cognitive function and impaired immunity. Haem iron (iron-holding part of the haemoglobin and myoglobin proteins), which is found only in meat, fish and poultry, is better absorbed than non-haem iron, which occurs in most foods. Non-haem iron absorption is improved by eating iron-containing foods with foods containing the MFP factor (only in meat, fish and poultry) and vitamin C; absorption is limited by phytates and oxalates. The RDA for men and for women older than 51 years old is 8 mg/day. For women of 19 to 51 years old, 18 mg of iron per day is recommended. Vegetarians need 1.8 times as much to make up for the low bioavailability typical for plant-based diets. To maximize iron absorption, iron-rich foods should be consumed in a diet low in inhibitors, for example fermented soy products, and high in enhancers, foods high in vitamin c and organic acid found in fruits and vegetables. Meat, fish and poultry contribute the most iron per serving; other protein-rich foods such as legumes and eggs are also good sources. Good plant-based sources of iron include soy foods (soyabeans), seeds (pumpkin seeds), cereals (wheat), dried fruit (raisins) and vegetables (mushrooms and potatoes). Because women have higher iron needs and lower energy needs, they often have trouble obtaining enough iron.

Zinc. Zinc-requiring enzymes participate in a multitude of reactions affecting growth (involved in making genetic material and proteins), transport of vitamin A, immune reactions, normal development of fetus and pancreatic digestive enzyme synthesis, among others. Both dietary zinc and zinc-rich pancreatic secretions (via enteropancreatic circulation) are available for absorption. Absorption is monitored by a special binding protein in the intestine. Protein-rich foods derived from animals are the best sources of bioavailable zinc. Fibre and phytates bind zinc and limit absorption. Legumes and whole-grain products are good sources of zinc if eaten in large quantities. Vegetables vary in zinc content depending on the soil in which they are grown. In developing counties, zinc supplements play a major role in the treatment of childhood infectious diseases. They reduce the incidence of disease and death associated with diarrhea (Strand et al., 2002). Growth retardation and sexual immaturity are hallmark symptoms of zinc deficiency. Other symptoms are impaired immune function, hair loss, eye and skin lesions and loss of appetite. The RDA for zinc for men is 11 mg per day and for women 8 mg per day.

Copper. Copper is a component of several enzymes, all of which are involved in some way with oxygen or oxidation. Some act as antioxidants, others are essential to iron metabolism. Necessary for the absorption and use of iron in the formation of haemoglobin. Legumes, whole grains, nuts and shellfish are good sources of copper. Over half of the copper from food is absorbed. In case of zinc deficiency, symptoms of anaemia and bone abnormalities occur. The RDA for zinc for adults is 900 ug per day.

Manganese. Manganese-dependent enzymes are involved in bone formation and various metabolic processes. Because manganese is widespread in plant foods, deficiencies are rare, although regular use of calcium and iron supplements may limit manganese absorption. The AI (adequate intake) for zinc for men is 2.3 mg per day and for women 1.8 mg per day.

Selenium. Selenium is an antioxidant nutrient (defends against oxidation) that works closely with the glutathione peroxidase enzyme and vitamin E. Selenium is found in association with protein in foods (seafood, meat, whole grains, fruits and vegetables (depending on soil content)). Deficiencies are associated with a predisposition to a type of heart abnormality known as Keshan disease characterized by cardiac tissue becoming fibrous. The RDA for adults is 55 ug of selenium per day.

Appendix IV

Human nutritional requirements

Protein requirements

Table AIV.1: Safe level of protein intake for adult men and women[a]

Body weight (kg)	Safe level of protein intake (g/kg per day)[b]
40	33
45	37
50	42
55	46
60	50
65	54
70	58
75	62
80	66

[a] All ages >18 years.
[b] 0.83 g/kg per day of protein with a protein digestibility-corrected amino acid score value of 1.0.

Table AIV.2: Safe level of protein intake for infants, children and adolescent boys and girls

Age (years)	Boys			Girls		
	Weight[a] (kg)	Safe level of protein intake[b] (g/kg/day)	Safe level of protein intake (g/day)	Weight[a] (kg)	Safe level of protein intake[b] (g/kg/day)	Safe level of protein intake (g/day)
0.5	7.8	1.31	10.2	7.2	1.31	9.4
1	10.2	1.14	11.6	9.5	1.14	10.8
1.5	11.5	1.03	11.8	10.8	1.03	11.1
2	12.3	0.97	11.9	11.8	0.97	11.4
3	14.6	0.90	13.1	14.1	0.90	12.7
4–6	19.7	0.87	17.1	18.6	0.87	16.2
7–10	28.1	0.92	25.9	28.5	0.92	26.2
11–14	45.0	0.90	40.5	46.1	0.89	41.0
15–18	66.5	0.87	57.9	56.4	0.84	47.4

Table AIV.3: Extra protein requirements for pregnancy and lactation

	Safe intake (g/day)	Additional energy requirement (kJ/day)	Protein:energy ratio
Pregnancy trimester			
1	1	375	0.04
2	10	1200	0.11
3	31	1950	0.23
Lactation			
First 6 months	19	2800	0.11
After 6 months	13	1925	0.11

Table AIV.4 Adult essential amino acid requirements

Amino acid protein	Adults		1985 FAO/WHO/UNU[a]	
	Mg/kg per day	Mg/g protein[b]	Mg/kg per day	Mg/g protein
Histidine	10	15	8-12	15
Isoleucine	20	30	10	15
Leucine	39	59	14	21
Lysine	30	45	12	18
Methionine & cystine	15	22	13	20
Methionine	10	16	-	-
Cystine	4	6	-	-
Phenylalanine & tyrosine	25	23	7	11
Threonine	15	23	7	11
Tryptophan	4	6	3.5	5
Valine	26	39	10	15
Total essential amino acids	184	277	93.5	141

[a]Adapted from ... in 1985, by WHO, from: http://www.nap.edu/openbook.php?record_id=1349&page=57
[b]Calculated as the individual amino acid requirement divided by the total protein requirement (0.66 g protein/kg per day)

Appendix V

General description of the West, East and South African diets

West Africa

Within West Africa, there is considerable variation in the staple food. Rice is predominant from Mauritania to Liberia and across to the Sahel, a region that stretches across the continent between the Sahara and the southern savannahs. Couscous is the prevalent dish in the Sahara. Along the coast from Coôte d'Ivoire (Ivory Coast) to Nigeria and Cameroon, root crops, primarily varieties of yam and cassava, are common. Cassava, imported from Brazil by the Portuguese, is boiled and then pounded into a nearly pure starch. Yam is the chief crop in West Africa and is served in a variety of dishes, including *amala* (pounded yam). Millet is also used for making porridge or beer. Palm oil is the base of stew in the Gambia, southern, and eastern regions. In the Sahalian area, groundnut paste (peanut butter) is the main ingredient for stew. Other stews are based on okra (a vegetable native to the rainforests of Africa), beans, sweet potato leaves, or cassava. Other vegetables are eggplant, cabbage, carrots, chilies, french beans, lettuce, onions, and cherry tomatoes. All the stews in this territory tend to be heavily spiced, often with chilies. Meat sources of protein include cattle, sheep, chicken, and goat, though beef is normally reserved for special occasions. Fish is eaten in the coastal areas. Because of the Islamic influence, pork is localized to non-Muslim areas. In these regions, “bush meat” is widely eaten, including bush rat, a large herbivorous rodent, antelope, and monkey. Giant snails are also eaten in various parts of West Africa.

East Africa

Extensive trade and migrations with Arabic countries and South Asia has made East African culture unique, particularly on the coast. The main staples include potatoes, rice, *matake* (mashed plantains), and a maize meal that is cooked up into a thick porridge. Beans or a stew with meat, potatoes, or vegetables often accompany the porridge. Beef, goat, chicken, or sheep are the most common meats. Outside of Kenya and the horn of Africa, the stew is not as spicy, but the coastal area has spicy, coconut-based stews. This is quite unique in comparison to the central and southern parts of Africa. Two herding tribes, the Maasai and Fulbe, have a notably different eating pattern. They do not eat very much meat, except for special occasions. Instead, they subsist on fresh and soured milk and butter as their staples. This is unusual because very few Africans consume milk or dairy products, primarily due to lactose intolerance. The horn of Africa, which includes modern-day Somalia and Ethiopia, is characterized by its remarkably spicy food prepared with chilies and garlic. The staple grain, teff, has a considerably higher iron and nutrient content than other grain staples found in Africa. A common traditional food here is *injera*, a spongy flat bread that is eaten by tearing it, then using it to scoop up the meat or stew.

South Africa

Outside of the temperate zones, in the southern part of the continent, a greater variety of fruits and vegetables are available. Fruits and vegetables in southern Africa include bananas, pineapples, papaya, mangoes, avocadoes, tomatoes, carrots, onions, potatoes, and cabbage. Nonetheless, the traditional meal in southern Africa is centred on a staple crop, usually rice or maize, served with a stew. The most common dish made from maize flour is called *mealie meal,* or *pap* in South Africa. Also known as *nshima or nsima* further north, it is usually eaten with stew poured over it. The stew may include a few boiled vegetables, such as cabbage, spinach, or turnips, or on more special occasions, fish, beans, or chicken.

Appendix VI

Table AVI.1 RCTs evaluating the efficacy of legume-based foods consumption on nutrient intake and status of reproductive women, children and infants

Article	Target group	Sample size	Length of the trial	Treatment	Measurement	Nutrient intake	Nutrient status	Outcome
Abizari 2012 Cross-over study Cowpea	Apparently healthy young **women**, age 18-40 y	N=16	Total 30 days (2x15)	- White cowpea meal (low polyphenol) + 4 mg ^{57}Fe as NaFeEDTA -White cowpea meal (low polyphenol) + 4 mg ^{58}Fe as FeSO4 -Red cowpea meal (high polyphenol) + 4 mg ^{57}Fe as NaFeEDTA -Red cowpea meal (high polyphenol) + 4 mg ^{58}Fe as FeSO4	Blood analysis (haemoglobin, serum ferritin, soluble transferrin receptor, C-reactive protein, α1-acid glycoprotein) Iron isotope measurement	4 mg iron either as NaFeEDTA or FeSO4 9.3 mg WC EDTA (3:1) 9.3 mg WC FS (3:1) 12.8 mg RC EDTA (3.3:1) 12.8 mg RC FS (3.3:1)	Iron absorbed (erythrocyte incorporation of stable iron isotopes) 0.16 mg white cowpea and EDTA (1.7 %) 0.11 mg white cowpea and FS (1.2 %) 0.19 mg red cowpea and EDTA(1.4 %) 0.11 mg red cowpea and FS (0.89 %)	-Test meals made from red cowpea had sig. higher (P < 0.05) concentrations of native iron, PA, and PP than did test meals made from white variety. -Similar molar ratios of PA to iron -Fortification with NaFeEDTA resulted in sig. higher amounts of iron absorbed than with FeSO4 (P < 0.05) -Red-cowpea NaFeEDTA-fortified meals resulted in 0.08 mg more iron absorbed compared with FeSO4-fortified meals -Irrespective of the fortificant used, there was no sig. difference in the amount of iron absorbed between the 2 varieties of cowpea - Iron status (serum ferritin concentration) was inversely and sig. correlated with fractional iron absorption from all test meals
Petry 2010 6 cross-over studies Common bean	Apparently healthy, non-pregnant, non-lactating **women** aged between 18 and 45 y and weighing below 60 kg	N=97	Total 16 days	1 A) RM + bean hulls (20 mg PP) B) RM 2 A) RM + bean hulls (50 mg PP) B) RM 3 A) RM + bean hulls (200 mg PP) B) RM 4 A) Whole bean meal B)Dehulled bean meal	-Fe isotope analysis (^{57}FeSO4 and ^{58}FeSO4) -Iron status, haemoglobin, ferritin, and C-reactive protein concentrations	Iron 4.7 mg RM + bean hulls (20 mg PP) 4.7 mg RM + bean hulls (50 mg PP) 4.8 mg RM + bean hulls (200 mg PP) 4.6 mg RM 6.1 mg Whole bean meal 6.2 mg Dehulled bean meal 6.1 mg Dephytinized bean meal 6.0 mg Dephytinized, dehulled bean meal Ca, Zn, Mg see table article	Fractional iron absorption Study 1: Meal A (RM1 + bean hulls (20 mg PP)): 13.9% Meal B (RM): 14.2% Study 2: Meal A (RM1 + bean hulls (50 mg PP)): 20.2% Meal B (RM): 17.3 % Study 3: Meal A (RM1 + bean hulls (200 mg PP)): 14.3% Meal B (RM): 7.9% Study 4: Meal A (Whole bean meal): 2.6% Meal B (Dehulled bean meal): 1.6%	-The lowest amount of PP (20 mg GAE), fed in study 1, did not affect iron absorption. Fifty milligrams of GAE from beans, fed in study 2, reduced the mean iron absorption by 14% (P < 0.05), whereas 200 mg GAE (study 3) decreased mean iron absorption by 45% (P < 0.001) -Dehulling of whole beans decreased the PP concentration by 85% with a negligible effect on PA -Dephytinization of whole beans decreased the PA concentration to below analytical detection limits (8 mg/100 g) with little or no influence on PP concentration -The dehulled, dephytinized beans were low in both PP and PA -Dephytinization had little influence on the iron, zinc, calcium, and magnesium concentrations of

				5 A) Whole bean meal B) Dephytinized, dehulled bean meal 6 A) Dephytinized bean meal B) Dephytinized, dehulled bean meal			Study 5: Meal A (Whole bean meal): 2.4% Meal B (Dephytinized, dehulled bean meal): 8.7% Study 6: Meal A (Dephytinized bean meal): 3.5% Meal B (Dephytinized, dehulled bean meal): 7.1%	the whole beans -Dehulling resulted in relevant losses of zinc (18%), magnesium (34%), and calcium (72%) but not iron -Removing the PP by dehulling was expected to increase absorption; however, iron absorption decreased by 38% (P < 0.001) -Removing both PA and PP increased iron absorption 2.6-fold (P < 0.001) -Removing the hulls, and thus most of the PP from beans prior to dephytinization, doubled iron absorption
Lönnerdal 2006 Cross-over study Soybean	Healthy, nonanemic **women**	N=16	Total 56 days (2x28)	Meal: -59Fe-labelled soybean ferritin meal -59Fe-labeled FeSO4 meal (control) (Each containing 1 mg Fe)	Whole body radioactivity counting Haemoglobin and ferritin concentration	1 mg iron either as soybean ferritin or FeSO4	Mean haemoglobin 134 g/L Mean serum ferritin 32.6 ng/mL Absorption soybean ferritin 29.9 % (Fe absorption) or 33 % (Fe RBL incorporation) Absorption FeSO4 34.3 % (Fe absorption) or 35.3 % (Fe RBL incorporation)	- Whole body counting: Iron absorption was 29.9 ± 19.8% from soybean ferritin and 34.3 ± 23.6% from FeSO4, as assessed by whole-body counting - RBC incorporation of iron: Iron absorption was 33.0 ± 20.1% from soybean ferritin and 35.3 ± 23.4% from FeSO4 -A sig. inverse relation between serum ferritin and iron absorption from soybean ferritin and between serum ferritin and iron absorption from FeSO4 was found in both methods
Simpore 2006 RCT Misola (mixture of millet (60%), soya (20%), peanut kernel (10%), sugar (9%) and salt (1%))	Undernourished **children** of less than 5 years old 455 showed severe marasma, 57 marasma of medium severity and 38 kwashiorkor plus marasma	N=550	8 weeks	-170 were given Misola (731 ± 7 kcal/day) -170 were given Spiruline plus traditional meals (748 ± 6 kcal/day) -170 were given Spiruline plus Misola (767 ± 5 kcal/day) -40 children received only traditional meals (722 ± 8 kcal/day) (control group)	Age, Height, brachial parameters, HAZ, WHZ, WAZ, energy intake, protein intake	100 g Misola 12% lipids 16% protein 61% glucide 410 kcal 100 g Spiruline 4.9% water 10.4%ash 7.8% fiber 6% lipids 57.1% protein 13.8% glucide	WHZ before A -1.73 B -2.88 C -3.05 D -2.42 WHZ after A -1.14 (34.1 %) B -1.8 (37.5 %) C -1.18 (62.9 %) D -2.0 (17.3 %) WAZ before A -4.01 B -3.88 C -4.38 D -3.99 WAZ after A -2.95 (26 %) B -3.10 (20 %) C -2.71 (38 %) D -3.45 (14 %)	-The nutritional pre/post changes improved in all children, but more sig. in the group that received Misola plus Spiruline -This improvement corresponds to an increment of weight which was on average 20 g a day in the Misola group, 25 g a day in the Spiruline plus traditional meals group, 34 g a day in the Misola plus Spiruline group and 15 g a day in the control group -Spiruline and Spiruline plus Misola gave a gain of 61% and 38 % respectively -Many showed an increase in Hb levels (less sig. in control group) -Growth recovery slower than weight recovery -These characteristics confirm the suitability of supplementing Misola with Spirulina (this association gave an energy intake of 767 ± 5 kcal/day with a protein assumption of 33.3 ± 1.2 g a day), both greater than Misola or Spiruline alone
Murray-Kolb 2003	**Women** with marginal iron deficiency	N=18	Total 28 days	Day1: Intrinsically labelled (^{55}Fe) soybeans as soup (n	Complete blood count including hemoglobin and	Iron either as soup (46.5 g soybean, 4.5 mg Fe) or muffin (23.25 g soybean, 3	Geometric means Haemoglobin 130 g/L Haematocrit 40%	-Iron absorption was high among the subjects in the study, with a geometric mean absorption of 24.5% (range: 9–36%) of the soybean dose and

RCT Soybean				= 11) or muffins (n = 7) Day2: A reference dose of ^{59}Fe as ferrous sulfate in ascorbate solution for all Until day 28 only meals which were given to the subjects	hematocrit, plasma iron, and total-iron-binding capacity and serum ferritin, and measurement of incorporated red cell radioactivity Background blood radioactivity	mg Fe) Reference meal (3 mg Fe)	Transferrin saturation 26% Ferritin 9.1 µg/L Mean iron absorption test meal 24.5 % (d14) to 27% (d28)	57.3% (range: 26–84%) of the reference dose at day 14 -Absorption values measured at 14 d did not differ sig. from those measured at 28 d (P > 0.1), nor was there a sig. difference between absorption of the soup or muffins -A sig. (r = 0.793, P < 0.001) inverse correlation was observed between serum ferritin concentration and iron absorption -The results of the present study show that iron in soybeans is in fact a bioavailable source of iron for iron-deficient humans
Abizari 2012 RCT Cowpea	5- to 12-y-old Ghanaian school **children**	N=241 (228)	~7 months	Group 1: Cowpea meal fortified with 10 mg Fe/meal as NaFeEDTA Group 2: An identical but nonfortified cowpea meal 3d/wk Mass deworming and malaria antigenemia screening and treatment were carried out at baseline and 3.5 mo into the trial	-Iron status determined by the serum concentration of soluble transferrin receptor (sTfR) - Haemoglobin concentration, SF, and prevalence of ID, IDA, and anemia	Tubani (cowpea dish) / Sauce / Total Energy, kcal: 222 / 209 / 431 Fat (g): 1.3 / 16.0 / 17.3 Protein (g): 12.3 / 1.9 / 14.2 Carbohydrate (g): 40.2 / 4.6 / 44.8 Fe (mg): 11.4 / 2.2 / 13.6 Phytate (Inositol hexaphosphate) (mg): 256 / 119 / 374 PP (mg GAE): 24.8 / 20.3 / 45.1	Results Control / NaFeEDTA Hb endpoint, g/L: 117 / 120 SF endpoint, mg/L: 26.2 / 35.1 sTfR endpoint, mg/L: 8.8 / 7.4 BI endpoint mg/kg body weight: 2.4 / 4.1	- Sig. increase in the Hb concentration in both the NaFeEDTA and control groups -The SF and transferrin receptor concentrations and blood iron (BI) stores sig. decreased in both treatment groups after 7 months of intervention relative to baseline -Compared with nonfortified flour, consumption of cowpea flour fortified with NaFeEDTA resulted in increases in Hb, SF concentration, transferrin receptor concentration, and BI stores - The postintervention prevalence of anemia, ID, and IDA was sig. lower compared with baseline in both groups -Consumption of NaFeEDTA-fortified Tubani did not result in a sig. decrease in the prevalence of anemia relative to control - Fortification resulted in a 30 and 47% reduction in the prevalence of iron deficiency (ID) and iron deficiency anemia (IDA) relative to control, respectively - Fractional absorption of fortification iron was ~7% - Malaria antigenemia was found in 81% of the participating children in both groups at the start of the trial. At midpoint during the trial, the prevalence decreased to 35 and 45% in the control and NaFeEDTA groups, respectively, and to 5% in both groups at the end of the trial (no sig. differences between groups)
Wijaya-Erhardt 2011 RCT Fermented	Indonesian iron-deficient pregnant **women** (12-20 weeks of gestation)	N=252	Mean feeding days 109 (from 12-20 to 32-36 weeks of gestation)	-Optimized diet group (Average weekly food provided compromised 600 g of tempeh, 30g of meat, 350 g of	-Changes in Fe concentration -Hb, plasma ferritin, TfR, CRP, AGP concentration -Height and body	Nutrient content in supplementary foods per day Iron 3.97 mg Vitamin C 173 mg Protein 23 g	Optimized diet (supplementary food) Hb (g/L) 124.22 Ferritin (µg/L) 37.77 Control Hb (g/L) 118.90 Ferritin (µg/L) 38.12	-During intervention, no sig. change in Hb concentration was observed between the groups -Plasma ferritin concentration and body Fe were sig. lower in both groups -TfR concentration was sig. higher in both groups -Separate analysis for Fe-deficient and Fe-replete

soybean				guava, 300 g of papaya and 100 g orange, 6d/week) -Control group	weight -Gestational age, birth weight, infant's length -24h recall -Collection of fresh stool samples			women: sig. smaller decrease in plasma ferritin concentration in Fe-deficient women but not in Fe-replete women compared with control -Intake of Fe increased sig. in the optimized diet group -Intake of protein increased sig. in both groups -Excluding supplementary food: no difference in change of nutrient intake between the two groups except vitamin C intake -Median intake of tempeh was 56g -None of the differences shown in birth outcomes were sig.; optimized diet group tended to have shorter mean gestational age and higher percentage of low birth weight than control group -Consumption of optimized diet with fermented soya bean (tempeh) and vitamin C-rich fruit in the present study had no effect overall in preventing the worsening of Fe status in Indonesian pregnant women; only in women with ID at baseline could a positive effect of ferritin be found -22mg more Fe in women who received the supplementary food (absorption only 5.1 %)
Davidsson 2004 Crossover study Soybean protein isolate	Healthy **infants** (69-191 d old)	N=9	2 x 13 days 10 d wash-out period, 3 d metabolic balance	Soya bean protein isolate with a relatively low native content of phytic acid before and after enzymatic degradation of phytic acid (300 mg and <6 mg phytic acid/kg liquid formula, respectively) After 10 days wash-out period: 2 x 150g isotopically labelled formula	Hb, ferritin -Apparent absorption of Zn, Cu and Ca measured by a stable isotope technique based on 72 h faecal excretion of non-absorbed stable isotopes after intake of 300g labelled formula -Apparent absorption of Mn, Zn, Cu ad Ca evaluated by chemical balance technique, based on dietary intake and faecal excretion of minerals and trace elements during 72 h -Fe absorption measured by a stable isotope technique	Ready-to-feed soya formula Regular (batch A) Phytic acid (mg/kg) 250 Ca (mg/kg) 600 Fe (mg/kg) 7840 Cu (mg/kg) 839 Zn (mg/kg) 8440 Mn (mg/kg) 305 Regular (batch B) Phytic acid (mg/kg) 300 Ca (mg/kg) 581 Fe (mg/kg) 2940 Cu (mg/kg) 313 Zn (mg/kg) 886 Mn (mg/kg) 303 Dephytinised (batch C) Phytic acid (mg/kg) <6 Ca (mg/kg) 593 Fe (mg/kg) 8620 Cu (mg/kg) 738 Zn (mg/kg) 8480	Apparent absorption (%) based on the stable isotope technique Regular soya formula Zn 16.7 Cu 31.2 Ca 64.2 Dephytinised soya formula Zn 22.6 Cu 35.0 Ca 65.6 Apparent absorption based on the chemical balance technique Regular soya formula Zn 21.1 Cu 41.7 Ca 48.6 Mn 25.4 Dephytinised soya formula Zn 28.4 Cu 38.7 Ca 55.9 Mn 42.1 Iron absorption (%), based on	-Zn absorption, measured by stable isotope technique, sig. greater from dephytinised formula (22.6 %) than regular soya formula (16.7 %); based on 72 h chemical balance studies no sig. difference -Cu and Ca absorption with either technique not sig. different -Mean apparent absorption of Mn increased from 25.4 (regular soya formula) to 42.1 % (dephytinised soya formula), not sig. -Erythrocyte incorporation of Fe stable isotope did not increase sig. after dephytinisation (6.3 vs. 8.3 % respectively) nor with faecal monitoring -Inhibitory effect of phytic acid on Zn absorption in infants -No inhibitory effect of phytic acid on Fe, Ca, Mn and Cu

					based on erythrocyte incorporation 14 d after intake, as well as by faecal monitoring	Mn (mg/kg) 303 Dephytinised (batch D) Phytic acid (mg/kg) <6 Ca (mg/kg) 585 Fe (mg/kg) 2800 Cu (mg/kg) 299 Zn (mg/kg) 872 Mn (mg/kg) 303	<u>erythrocyte incorporation of stable isotopes / faecal excretion</u> Regular soya formula 6.3 / 13.9 Dephytinised soya formula 8.3 / 16.8	
Obatolu 2003 RCT Cowpea (mixture of extruded malted maize and cowpea)	Nigerian **infants**, 4 months old	N=90 (3 x 30)	14 months	-30 infants from a low socioeconomic background weaned onto an extruded formulated complementary diet from maize and cowpea (L1A1) -30 infants with a similar socioeconomic background (L2N, control group) -30 infants from an above-average socioeconomic background (HN, reference group) without the supplementary diet	-General household information from mothers with specially design questionnaire and personal observation -Infant's place among its siblings, duration of breast feeding, type of complementary food -Age, education level, mothers' occupation, estimated annual family income -Birth weight, length	<u>Mixture of extruded malted maize and cowpea</u> 17.3% protein 5.0% fat 2106 kJ of energy 5.1 % crude fibre 5.7 mg iron 4.6 mg calcium 1.1 mg zinc	Figure 1 Growth-monitoring weight curve Length and weight data	-Mean weight at birth and 4 mo before the feeding intervention in HN infants was statistically (P 0.05) higher than in L1A1 and L2N infants -At the end of the study, L1A1 and HN infants had a mean length within -1 standard deviation of the standard length for age -The mean length of L2N infants was within -3 standard deviations of the standard length for age - The chemical composition of the formulated blend was 7.1 +- 0.34% moisture, 17.3 +- 0.61% protein, 5.0 +- 0.17% fat, 5.1 +- 0.29% crude fibre, 2106.5 +- 34.5 kJ of energy, 5.7 +- 0.15 mg of iron, 4.6 +- 0.30 mg of calcium, and 1.1 +- 0.17 mg of zinc - Similarities in the mothers' level of education of infants in groups L1A1 and L2N was observed - By age 6 mo, the weight of female L1A1 infants was statistically higher than that of their L2N counterparts, an indication that female infants responded sooner to the feeding intervention in the present study - the average length of the L1A1 infants was statistically the same as that of L2N infants and statistically lower than that of HN infants -By age 9 mo, L1A1 infants caught up in terms of weight and length to HN infants -Based on similarities in socioeconomic status and weight at birth and 4 mo between L1A1 and L2N infants, the improved nutrition status of the L1A1 is attributed to the formulated complementary diet. The contribution of this mixture to total nutrient intake seemed substantial enough to meet the nutrition requirements of the children
Beiseigel 2007 Two randomized, 2 x 2 factorial	Generally healthy women	N=13	2 x 29 d	-Great northern bean variety - Great northern bean variety + ascorbic	Iron absorption was assessed from red blood cell radioisotope incorporation and	<u>Great northern bean meal</u> 1.9 mg iron 78 mg calcium 1.1 mg zinc 289 mg phytate	IRON BIOAVAILABILTY <u>Great northern</u> 2.2 % 42 µg/meal 3.0 % normalized to a serum ferritin	-Without AA supplementation, women absorbed only about 2% of the iron from the bean meals -The results were unaffected by the variety of beans. Adding AA (15–20 molar ratios of AA:iron) roughly tripled the iron absorption (P 0.0001) from

experiments Beans				acid (AA) -Pinto bean variety - Pinto bean variety +AA	whole-body scintillation counting	With added ascorbic acid: 112 mg ascorbic acid, ascorbic acid:Fe ratio 19 Pinto bean meal 2.1 mg iron 58 mg calcium 1.2 mg zinc 270 mg phytate With added ascorbic acid: 112 mg ascorbic acid, ascorbic acid:Fe ratio 17	concentration of 23 µg/L Great northern + AA 6.6 % 124 µg/meal 9.0 % normalized to a serum ferritin concentration of 23 µg/L Pinto 1.6 % 33 µg/meal 2.1 % normalized to a serum ferritin concentration of 23 µg/L Pinto + AA 5.4 % 116 µg/meal 7.4 % normalized to a serum ferritin concentration of 23 µg/L	all test meals -The iron content of the pinto bean was not sig. different from that of the great northern bean. The pinto bean had 25% less calcium (sig.) and 7% less phytate (sig.) than did the great northern bean
Donangelo 2003 RCT Common bean	Young **women** with low iron reserves	N=23	14 days (1 day, one meal)	Group 1: Common bean (CB) test meal (n = 12) Group 2: HFeZnB test meal (n = 11) Two bean (Phaseolus vulgaris) genotypes, containing normal (CB) or higher (HFeZnB) iron and zinc concentrations (zinc and iron were 98 and 65% higher, respectively)	Iron and zinc absorption measured from radio-iron activity in red blood cells and from urinary excretion of zinc isotopes	Common bean Iron total intake in meal: 2.33 mg Zinc total intake in meal: 2.21 mg High Fe/Zn bean Iron total intake in meal: 3.20 mg Zinc total intake in meal: 5.08 mg Common bean zinc (µg/g) 28.0 iron (µg/g) 50.4 manganese (µg/g) 17.8 copper (µg/g) 8.44 molybdenum (µg/g) 10.8 potassium (mg/g) 16.2 calcium (mg/g) 1.38 magnesium (mg/g) 1.78 phosphorus (mg/g) 7.77 phytic acid (µmol/g) 28.2 phytate/iron molar ratio 31.2 phytate/zinc molar ratio 65.8 tannins (mg/g) 1.40 High Fe/Zn bean zinc (µg/g) 55.4 iron (µg/g) 82.9 manganese (µg/g) 16.1 copper (µg/g) 8.75	Common bean Iron absorption: 1.83 – 1.86 % Iron total absorption from meal: 0.041-0.042 mg Zinc absorption: 16.1 % Zinc total absorption from meal: 0.36 mg High Fe/Zn bean Iron absorption: 1.03 – 1.01 % Iron total absorption from meal: 0.033 – 0.032 mg Zinc absorption: 15.2 – 13.4 % Zinc total absorption from meal: 0.77 – 0.68 mg	-Iron absorption was low (geometric mean < 2%) in both bean types, and total iron absorbed was not different between types -Selective breeding for high-zinc bean genotypes may improve zinc status. However, high-iron genotypes appear to have little effect on iron status when fed alone in single meals to women with low iron reserves

						molybdenum (µg/g) 13.3 potassium (mg/g) 17.8 calcium (mg/g) 0.90 magnesium (mg/g) 1.72 phosphorus (mg/g) 7.76 phytic acid (µmol/g) 30.2 phytate/iron molar ratio 20.3 phytate/zinc molar ratio 35.6 tannins (mg/g) 0.48		
Schümann 2004 RCT Black bean	**Children** (12-36 months with initial Hb values between 100 and 115 g/L)	N=110	10 weeks	Five 156-g cans of refried black beans per week for 10 consecutive weeks Beans-only (control) group: 155 mg iron FeSO4 group: 1625 mg iron Haem iron group: 1700 mg iron	Haemoglobin (Hb) and ferritin concentrations were determined at baseline and after 5 and 10 weeks. Compliance was examined weekly	Bean only group: 120 mg additional iron/10 weeks Haem iron group: 1352 mg additional iron/10 weeks FeSO4 group: 1319 mg additional iron/10 weeks	After 10 weeks (baseline value): <u>Haemoglobin</u> Bean only group: 116 g/L (109) Haem iron group: 120 g/L (109) FeSO4 group: 117 g/L 109) <u>Ferritin concentration</u> Bean only group: 10.9 µg/L (15.7) Haem iron group: 15.3 µg/L (14.7) FeSO4 group: 10.1 µg/L (12.0) Post hoc analysis (low and high ferritin group): <u>Haemoglobin (g/L)</u> Bean only group: Low: 115 (108) High: 118 (110) Haem iron group: Low: 121 (108) High: 119 (111) FeSO4 group: Low: 113 (107) High: 121 (111) <u>Ferritin concentration (µg/L)</u> Bean only group: Low: 5.4 (7.8) High: 24.5 (37.1) Haem iron group: Low: 9.0 (6.8) High: 33.9 (38.3) FeSO4 group: Low: 5.6 (5.5) High: 22.9 (32.9)	-The cumulative intake of beans was approximately 80% of that offered, signifying an additional ~1300 mg of either haem or inorganic iron in the corresponding treatment groups over 10 weeks -Hb concentrations increased by the order of 7.3–11.4 g/L during the intervention, but without sig. differences across treatments -Average ferritin concentrations were unaffected by treatment assignment -However, post hoc analysis by subgroups of initial high ferritin and initial low ferritin found the Hb increments after 10 weeks in the haem iron group (13.1±7.7 g/L) to be sig. greater than the respective increases (6.8±11.2 and 6.4±8.5 g/L) in the inorganic iron and beans-only groups - Canned refried beans are a candidate vehicle for fortificant iron. Given its (heam iron) additional potential for benefiting the iron status of consumers with iron deficiency may recommend it over FeSO4.
Ekbote 2011 RCT	**Children** (8 – 12 years)	N=24	1 Day (5h)	Group A: Calcium-fortified (500 mg of calcium carbonate)	Serum concentrations of ionized calcium and	Only figure with percentages (see article)	Only figure with percentages (see article)	-In group A, a peak of 6% above baseline was observed at 1 h in serum ionized calcium, whereas group C showed a peak of 5.5% at 4 h and group B

Soybean, groundnut				cereal-legume snack (laddoo) Group B: Similar but non-fortified snack Group C: Calcium carbonate (500 mg) alone	intact parathyroid hormone were measured at 0, 1, 2, 3, 4, and 5 h			showed a small increase of 1.8% at 1 h -The change in area under curve of groups A and C were of similar order (4.6 and 5.5, respectively), whereas that of group B was sig. lower (0.82) -Serum parathyroid hormone was lowest at 2 h in groups A and B and at 3 h in group C -Conclusion: The fortified cereal-legume laddoo may act as a novel vehicle for increasing calcium intake in children
Seppo 2005 RT Soy formula	**Infants** with cow milk allergy	N=168	Until age 2 y/4y	84 infants were fed a soy formula 84 infants were fed an extensively hydrolysed whey formula	-Weight and length -Serum alkaline phosphatase activity, haemoglobin concentrations, red blood cell indexes, leukocyte concentrations, serum calcium, serum ferritin, serum transferrin receptor, serum zinc, and copper concentrations	DAILY NUTRIENT INTAKE Soy formula (1y/2y) Energy (kJ/kg) 387/364 Energy form the study formula (%): 45/22 Protein (g/kg) 2.6/3.0 Fat (g) 33/40 Carbohydrate (g) 125/139 Calcium (mg) 518/506 Riboflavin (mg) 0.82/1.03 Iron (mg) 9.7/9.1 Zinc (mg) 7.9/8.0 Vitamin E (mg) 9.9/8.2 Extensively hydrolysed whey formula (1y/2y) Energy (kJ/kg) 384/372 Energy form the study formula (%): 41/14 Protein (g/kg) 2.6/3.1 Fat (g) 32/39 Carbohydrate (g) 125/144 Calcium (mg) 449/464 Riboflavin (g) 0.98/1.11 Iron (mg) 8.8/8.6 Zinc (mg) 5.9/6.7 Vitamin E (mg) 8.0/6.9 (Table 2:composition of the formulas)	Soy formula (baseline/1y/2y) Transferrin receptor (mg/L) 6.4/6.6/6.0 Ferritin (µg/L) 61/30/27 <12 µg/L (%) 11/7/22 Zinc (mg/L) 0.71/0.67/0.72 <0.70 mg/L (%) 15/60/47 Hb (g/L) 115/117/121 <110 g/L (%) 21/16/6 S-AFOS (U/L) 643/635/580 >1000 U/L (%) 4/4/0 Calcium (mmol/L) 2.61/2.56/2.50 Copper (µg/L) 0.9/1.1/1.1 Extensively hydrolysed whey formula (baseline/1y/2y) Transferrin receptor (mg/L) 5.8/6.0/5.7 Ferritin (µg/L) 88/44/29 <12 µg/L (%) 4/12/24 Zinc (mg/L) 0.69/0.66/0.74 <0.70 mg/L (%) 21/72/52 Hb (g/L) 117/116/121 <110 g/L (%) 16/19/6 S-AFOS (U/L) 834/790/637 >1000 U/L (%) 7/5/6 Calcium (mmol/L) 2.62/2.58/2.53 Copper (µg/L) 1.0/1.1/1.1 + Growth values (see figures)	-The length (SD score) of the infants was close to the mean Finnish reference growth by age 2 y in both groups -Weight-for-length measurements continued to reach the 50th percentile by age 4 y in both study groups -The mean nutrient intake followed the recommended intake in both groups, although most of the infants were supplemented with calcium and vitamin D -The observed serum transferrin receptor concentrations indicated a greater iron inadequacy in the tissue of infants in the soy formula group than in the hydrolysed whey formula group (P = 0.08) -However, there were no sig. differences between the groups either in the percentages of abnormally low laboratory values (mean cell volume, haemoglobin, zinc, and ferritin) or in the percentages of high alkaline phosphatase activity, which indicates the comparable safety and effectiveness of the formulas studied
Lartey 1999 RT + cross-sectional study Cereal-legume blend	Ghanaian breastfed **infants** 6 – 12 months of age (recruited already at 1 month of age)	N=208 (+ 464 control infants not inclu-ded in inter-	6 months (+5 months breastfeeding)	Weanimix (W) Weanimix plus vitamins and minerals (WM) Weanimix plus fish powder (WF)	Age 1-12 months: Monthly anthropometric measurements (weight, length, triceps and subscapular skinfold thicknesses, and	Nutrient content of complementary food per kg dry weight Weanimix (W, cereal-legume blend): Energy (kJ) 18 200, (kcal) 4350 Protein (g) 150	Weight gain from 6 to 12 months of age (kg) W: 1.2 WM: 1.3 WF: 1.3 KF: 1.2 Length gain from 6 to 12 months of age (cm)	-The percentage of infants with low ferritin values increased sig. between 6 and 12 mo of age in groups W, WF, and KF but not in group WM -Change in plasma retinol between 6 and 12 mo of age was sig. greater in group WM than in the other 3 groups combined -All 4 foods improved growth relative to the NI group.

		ven-tion)		Koko plus fish powder (KF) No treatment (NI)	midupper arm and head circumference) & Information on infant-feeding practices and morbidity data were collected (months 6-12: weekly infant morbidity and maternal recall) 6 months and 12 months of age: Blood sample (haemoglobin, haematocrit, plasma levels of iron, zinc, ferritin, C-reactive protein, retinol, transferrin, and erythrocyte riboflavin) Growth and micronutrient (iron, zinc, riboflavin, and vitamin A) status	Fat (g) 114 Calcium (mg) 530 Iron (mg) 56 Zinc (mg) 28 Copper (mg) 4 Magnesium (mg) 1400 Potassium (mg) 5660 Sodium (mg) 30 Phosphorus (mg) 2920 Ascorbic acid (mg) 1 Niacin (mg) 39 Pyridoxine (mg) 3.5 Riboflavin (mg) 0.4 Thiamine (mg) 4.8 Vitamin B-12 (mg) 0 Folic acid (mg) 670 Vitamin A (RE) 360 For weanimix plus vitamins and minerals (WM), weanimix plus fish powder (WF), and koko plus fish powder (KF) see table 1 <u>Estimated contribution of project complementary foods to daily iron, zinc, vitamin A, and riboflavin intakes from 7 / 8/ 10 / 12 months</u> Weanimix: Iron: 1.68 / 2.4 / 2.1 / 2.8 mg Zinc: 0.8 / 1.1 / 0.9 / 1.3 mg Vitamin A: 8.2 / 15.8 / 11.2 / 17.5 µg RE Riboflavin: 0.012 / 0.028 / 0.018 / 0.056 mg For WM, WF, KF see also table 5 in article	W: 7.0 WM: 7.0 WF: 6.9 KF: 6.9 Figure 1 in the article shows weight-for-age and length-for-age z-score, which both are decreasing from 6 to 12 months of age Haemoglobin, haematocrit, plasma transferrin saturation, plasma ferritin, plasma zinc, plasma retinol, erythrocyte riboflavin values for each group shown in table 7 in the article	-Infants fed WM had better iron stores and vitamin A status than those fed nonfortified foods - As expected, the intake of these micronutrients was sig. higher in the group fed the fortified product (WM). There were no sig. differences in intake between the other 3 groups (W, WF, and KF) - For the WM group, even at 12 mo of age, the fortified food still contributed >75% of the total micronutrient intake from foods - At 7 mo, intake of energy from complementary foods was sig. higher in the WM group than in the WF group -At 10 mo the percentage of energy from complementary foods contributed by the project food was sig. higher in the WM group than in the KF group -WAZ, LAZ, anthropometrics did not differ Sig. between the 4 intervention groups -WAZ, LAZ between 9 and 12 mo (though not between 6 and 9 mo of age) was sig. lower in the latter group - Head circumference, midupper arm circumference, and triceps skinfold thickness were sig. different between the intervention (n = 183) and cross-sectional (n = 74) groups only at 12 mo of age - General decline in mean haemoglobin and haematocrit between 6 and 12 mo of age - The percentage of infants with low ferritin increased sig. ($P < 0.05$) between 6 and 12 mo of age (reaching 48–57% at 12 mo) in groups W, WF, and KF, but not in group WM (10.7% at 12 mo) -Similarly, the prevalence of low plasma retinol concentrations decreased sig. between 6 and 12 mo in group WM ($P < 0.05$) but not in the other 3 groups - All 4 foods improved growth relative to the NI group. Infants fed WM had better iron stores and vitamin A status than those fed nonfortified foods. - Whether local foods can achieve the same results is not clear. Fortification with some nutrients such as iron and vitamin A may be the most effective strategy.
Baker 1978	**Children** aged 5 years or less	N=48	4 weeks	Group 1: Milk + supportive treatment	-Weighing on alternate days	<u>Formulation of vitamin-supplemented soya-maize</u>	Increase of serum albumin and serum transferrin during the 4 weeks	-Recovery rate in both groups comparable -Protein intake and the rate of rise in serum

IT Soya-maize mixture	with kwashiorkor			Group 2: Soya-maize porridge (supplemented with vitamins and calcium) + supportive treatment Both groups fed every 4 h Both diets approx. 500 kJ/kg/d and 150 ml/kg/d of fluid	-Recording of feeds and fluid intake, and voiding -Stools and urine checked for parasites -Blood sample (haemoglobin, serum iron, serum transferrin, serum folate, and serum albumin concentrations)	mixture (per 100 g dry weight) Maize meal: 80 g Full-fat soya flour: 20 g Protein: 12 g Ash: 0.3 g Fibre: 0.3 g Fat: 4 g Carbohydrate: 74.4 g Vitamin A: 100 U Vitamin D: 200 U Riboflavin: 0.5 mg Thiamine: 6.1 mg Folic acid: 0.1 ng Nicotinic acid: 5.0 ng Ascorbic acid: 50 mg Calcium carbonate: 150 mg Energy intake Soya-maize group: 550 kJ/kg/d Milk group: 540 kJ/kg/d Protein intake Soya-maize group: 2.95 g/kg/d Milk group: 4.16 g/kg/d	After 4 weeks Serum albumin (g/100 ml) Soya-maize group: ~3.5 Milk group: ~4.5 Serum transferrin (mg/100 ml) Soya-maize group: ~250 Milk group: ~325 Haemoglobin and serum iron concentration did not sig. change Saturation of transferrin and serum folate concentrations fell in both groups over the study period	albumin and transferrin concentrations were greater in the milk-fed group, but levels in both groups acceptable by the 3rd week -Haemoglobin did not change sig. and in general values were low -Fall in percentage saturation of transferrin with iron and in serum folate concentration in both groups -Incidence of diarrhoea sig. less in the children fed soya-maize
Steichen 1987 RCT Soy protein	Healthy term appropriate for gestational age **infants**	N=36 (35)	12 months	Group I infants (n = 18) were fed soy protein isolate-based formula (Isomil with Iron) Group 2 infants (n = 17) were fed a cow milk protein-based formula (Similac with Iron) All infants were given the formula within the first 24 hours of life, and were fed the study formula through the first year of life	During the first 18 days of life, and again at 6 weeks, and 3, 6, 9, and 12 months postnatally: Weight, length, and head circumference were recorded; bone mineral content (BMC) and bone width (BW) were measured at one-third distal length (midshaft) of the left radius and ulna	Nutrient composition of the soy-based / cow milk-based formula Protein (g/L) 20 / 15.5 Fat (g/L) 36 / 36.1 Carbohydrate (g/L) 68 / 72.3 Minerals (g/L) 3.8 / 3.7 Calcium (g/L) 0.70 / 0.51 Phosphorus (g/L) 0.50 / 0.39 Sodium (g/L) 0.30 / 0.25 Potassium (g/L) 0.71/ 0.78 Chloride (g/L) 0.53 / 0.53 Magnesium (mg/L) 50 / 41 Iron (mg/L) 12 / 12 Zinc (mg/L) 5.0 / 5.0 Copper (mg/L) 0.5 / 0.41 Manganese (mg/L) 0.15 / 0.41 Iodine (mg/L) 0.02 / 0.03 Vitamins Vitamin A (IU/L) 2500 / 2500 Vitamin D (IU/L) 400 / 400	Sig. lower BMC and BMC/BW in soy protein formula fed infants than in infants fed cow milk-based formula	-Food and energy intake were similar in the two groups of infants -No differences in weight, length, and head circumference between groups at entry into the study -Weight, rate of weight gain, length, rate of length gain, head circumference, and rate of head circumference gain for each infant at all periods were within the normal range and not different between groups -BMC and BMC/BW were similar for both groups at entry into the study -Group I infants had sig. lower BMC and BMC/BW at 3, 6, 9, and 12 months of age (P <0.05 to P <0.0001) compared with group 2 infants -Healthy term AGA infants fed soy formulas have normal body growth but lower BMC compared with infants fed cow milk formula, and similar BMC to that in previously studied infants fed human milk -Lower Ca and P availability in soy milk fed formula relative to cow milk formula may explain the

						Vitamin E (IU/L) 15 / 15 Vitamin C (mg/L) 55 / 55 Thiamine (B0 (mg/L) 0.40 / 0.65 Riboflavin (B2) (mg/L) 0.60 / 1.0 Vitamin B6 0.40 /0.40 Niacin (mgEq/L) 9.0 / 7.0 Folic acid (mg/L) 0.1 / 0.05 Panthothenic acid (mg/L) 5.0 / 3.0 Vitamin B~2 (/zg/L) 3.0 / 1.5 Biotin (mg/L) 0.15 / 0.009 Vitamin K (mg/L) 0.15 / 0.03		differences
Rudolph 1981 IT Soy-based formula with iron	Preterm **infants** with birth weights between 1,001 and 1,600 gm (1 week of age)	N=30 (26)	5 weeks	Standard milk-based formula Standard milk-based formula with iron Soy-based formula with iron	Haemoglobin, haematocrit, reticulocyte count, hydrogen peroxide haemolysis, red cell and plasma selenium concentrations serum concentrations of cholesterol and vitamin E, and glutathione peroxidase concentration/levels	Approximate nutrient composition Milk-based formula: Energy (kcal/L): 680 Protein (gm/L): 15.5 Fatty acids (gm/L): 36 Vitamin E (IU/L): 15 Iron (mg/L): trace Selenium (µg/L): 3.4 Milk-based formula with iron: Energy (kcal/L): 680 Protein (gm/L): 15.5 Fatty acids (gm/L): 36 Vitamin E (IU/L): 15 Iron (mg/L): 12.0 Selenium (µg/L): 3.4 Soy-based formula with iron: Energy (kcal/L): 680 Protein (gm/L): 20 Fatty acids (gm/L): 36 Vitamin E (IU/L): 15 Iron (mg/L): 12.0 Selenium (µg/L): 4.8	Haematocrit values of first / sixth postnatal week (%) Milk-based formula: 49 / 28 Milk-based formula with iron: 44 / 25 Soy-based formula with iron: 46 / 25 Haemoglobin values of first / sixth postnatal week (mg/dl) Milk-based formula: 15.1 / 8.6 Milk-based formula with iron: 14.1 / 7.2 Soy-based formula with iron: 14.6 / 7.6 Plasma selenium values of first / sixth postnatal week (µg/ml) Milk-based formula: 0.10 / 0.09 Milk-based formula with iron: 0.09 / 0.10 Soy-based formula with iron: 0.10 / 0.09 Serum vitamin E values of first / sixth postnatal week (mg tocopherol/dl) Milk-based formula: 0.27 / 0.59 Milk-based formula with iron: 0.27 / 0.61 Soy-based formula with iron: 0.23 / 0.34	-No sig. differences were noted among the three groups in the rate of decline of either hematocrit or haemoglobin values -By 5 weeks of age there was a negative correlation of borderline significance between birth weight and decline in haematocrit (P < 0.I0) when the data from all three formula groups were combined; by 6 weeks of age this correlation was highly sig. (P < 0.01) -The reticulocyte count was increased (P < 0.001) at weeks 2, 3, 4, and 5 when compared to the value at week 1, with no intergroup differences - Progressive decrease in mean hydrogen peroxide haemolysis (P < 0.001, but no sig. intergroup differences - Plasma selenium concentrations did not change sig. in any of the three groups - sig. decline in plasma GSH-Per activity in each group (P < 0.001), with no intergroup differences - Erythrocyte selenium content varied among formula groups at different periods -At weeks 4, 5, and 6, the adjusted mean erythrocyte selenium values of groups A1 and B1 were each sig. higher (P < 0.05) than those of Group A - No sig. differences among formula groups were found at specific weeks -Within each group, individual infants, especially those with the lowest birth weights, had low serum concentrations of vitamin E throughout the study period, and in some instances had more rapid declines in haematocrit and haemoglobin values

								-By the fifth postnatal week the decline in haematocrit was sig. greater in those infants who had not achieved vitamin E sufficiency - This finding suggests that the formulas fortified with 12 mg iron/L, and containing approximately 26% of fat as PUFA, with an E: PUFA ratio of 1.1, did not accelerate haemolysis, when compared with the formula not fortified with iron
Graham 1976 ? Soybean	Convalescent malnourished **infants** (5 – 42 months)	N=54	6 years	7 infants: diet based on isolated soybean protein, containing 4.0% to 5.3% of dietary metabolizable energy (calories) as protein (A) 20 infants: 6.4% to 6.7% of dietary metabolizable energy as protein (B) 23 infants: at 6.4% to 6.7% protein calories with added DL-methionine (C) 4 infants: with 8.0% to 12.3% protein calories (D)	Fasting plasma free amino acids TAA = Total plasma free amino acids EAA = Total plasma free essential amino acids (+ Cys and Tyr)	Energy intake: 90 to175 kcal/kg bw/d (individually determined as sufficient) Vitamins and Minerals supplements at all times met the recommended dietary allowances A)4.0 to 5.3 % of dietary metabolizable energy as protein B) 6.4 to 6.7 % of dietary metabolizable energy as protein C) 6.4 to 6.7 % of dietary metabolizable energy as protein with added methionine D) 8.0 to 12.3 % of dietary metabolizable energy as protein	See table 1 (TAA, EAA/TAA, Lys/EAA, Cys/EAA, Met, Met/EAA)	-The ratio of the sum of the concentration of the eight essential and two “semiessential” amino acids (EAA) to that of total amino acids (TAA) in the 4.0 to 5.3 % protein group (A) was sig. lower by an unmatched “t” test than that of either of the 6.4 to 6.7 % diets (B and C) -No differences in the EAA:TAA ratios among the unsupplemented 6.4 to 6.7 % diets (B), the supplemented 6.4 to 6.7 % diets (C), and the 8.0 to 12.3 % diets (D)
Prasanna 1970 Cross over study Infant food based on groundnut flour	Healthy **infants**	N=12	2 x 7 days	Experimental food (based on groundnut flour): Five different levels of protein intake, viz. 1.9, 2.7, 3.5, 5.2 and 7.2 g/kg body weight Control food (based on skim milk solids): Three different levels, viz., 1.9, 2.6 and 3.4 g/kg body weight	Nitrogen balance (B) was estimated from the relationship B=I--(U+ F) where I is the nitrogen intake and U and F, the nitrogen excreted in urine and faeces respectively, and the net protein utilisation (NPU) was B/Ix 100	Nutrient intake almost the same in both groups <u>Amino acid composition experimental food / control food (G/16 G. nitrogen.) :</u> Lysine 4.7 / 10.0 Methionine 1.6 / 2.8 Cystine 1.0 / 1.0 Total sulphur amino acids 2.6 / 3.8 Phenylalanine 5.9 / 4.6 Leucine 3.1 / 8.1 Isoleucine 5.4 / 4.2 Tryptophane 1.0 / 1.4 Arginine 7.4 / 3.3	Net protein utilization (NPU) in both foods comparably good	-Both the infant foods used in this experiment had a high protein content, but were deficient sulphur-containing amino acids compared to the FAO reference protein pattern - It is seen that at a low intake of 2.7 g protein per kg body weight the NPU values for the experimental food was 81.5 while for the control milk food at 3.5 g protein per kg it was 81.8 - The new-born infants tolerated the experimental food very well and did not reveal any dysfunction - The present study has shown the NPU of the experimental food based on groundnut flour containing only 25 per cent skim milk solids was fairly high and compared well with that of the whole milk based infant food for the new-born

						Valine 6.7 / 6.4 Threonine 3.5 / 5.2 Histidine 2.1 / 2.3		
Dutra de Oliveira 1966 IT Soy milk	Malnourished **children**, 1 to 3 years of age	N=24	20 days	Soya milk or Cow's milk with similar protein content	Every day weighed Analysis of total serum protein, albumin levels Two metabolic balance studies (nitrogen)	Mean nitrogen intake (mg/kg/day) Soy milk (clinical oedema): 565.5 Soy milk (no clinical oedema): 705.0 Cow's milk (clinical oedema): 621.6 Cow's milk (no clinical oedema): 622.2	Mean nitrogen absorption (% of intake) Soy milk (clinical oedema): 85.1 Soy milk (no clinical oedema): 82.0 Cow's milk (clinical oedema): 80.8 Cow's milk (no clinical oedema): 78.8 Mean nitrogen retention (% of intake) Soy milk (clinical oedema): 37.1 Soy milk (no clinical oedema): 19.8 Cow's milk (clinical oedema): 23.8 Cow's milk (no clinical oedema): 34.4 Total serum protein levels (% increase from initial values) after 10/20 days Soy milk (clinical oedema): 28.5/34.8 Soy milk (no clinical oedema): 16.6/12.0 Cow's milk (clinical oedema): 28.9/35.3 Cow's milk (no clinical oedema): 28.8/25.8 Total albumin levels (% increase from initial values) after 10/20 days Soy milk (clinical oedema): 39.2/56.3 Soy milk (no clinical oedema): 21.7/27.4 Cow's milk (clinical oedema): 32.7/56.7 Cow's milk (no clinical oedema): 33.3/32.6 Mean number of days to attain minimum bw Soy milk (clinical oedema): 15 Soy milk (no clinical oedema): 13 Cow's milk (clinical oedema): 10 Cow's milk (no clinical oedema): 8	-Soya milk compared favourably with skimmed cow's milk in the initial treatment of these children - The soya milk was readily accepted and well tolerated - The appetite improved promptly and the diarrhoea subsided sooner than in the group receiving cow's milk -Weight loss and the time taken to attain minimum weight were greater in the group of children admitted with clinical oedema. This indicates that the two milks produce similar effects when the children initially have clinical oedema -In the group without clinical oedema the loss of weight was greater in the group receiving soya milk, and more time was required to reach the minimum body weight - The absorption of soya milk protein by the children with and without clinical oedema was equally good(average 80 % of absorption) - The low content of methionine in soya milk is well known, but the higher cystine content seems to offer sufficient amounts of sulfur amino acids - The cow's milk protein appears to be better than the soya milk protein for treatment of the group without clinical oedema - Total serum protein and serum albumin levels increased similarly in response to soya milk or cow's milk in the group with clinical oedema -In the group without clinical oedema, there was a smaller, although adequate, increase in total serum protein and albumin for those who were fed soya milk than for those who received cow's milk - The average nitrogen retention was greater with soya milk in the children with clinical oedema, but it was greater with cow's milk in the children without clinical oedema -These studies indicate that soya milk is a good source of protein for the correction and prevention of infantile malnutrition
Golden 1981 IT	Malnourished **children** (4 to 31 months)	N=34	No information	Stage 1: Maintenance diet Stage 2:	Body weight was recorded at the same time each morning Height was	Nutrient composition of Cow's milk / Soy diet: Protein (g/l) 31 / 31 Energy (MJ/l) 5.67 / 5.67	Plasma zinc concentration (baseline / later stage): Marasmic children (μmol/l) 13. 9 / 9.9 (soya group 5.8, cow's milk group 12.4)	-The plasma zinc concentration of the marasmic children (13.9 ± 0.8 μmol/l) was not different from the control children (14.3 ± 0.6 μmol/l) -The plasma zinc concentration of the kwashiorkor

Soy milk				-Cow's milk based diet (n=24) -Soya protein based formula diet (n=10) Stage 3: Ordinary mixed diet	measured weekly Plasma zinc concentrations The values were compared with those of 16 control children whose weight and height were normal for their age and who had never suffered serious illness	Zinc (µmol/l) 69 / 52 Phytic acid (µmol/l) 0 / 1330 Cow's milk group (774 ± 25 KJ/kg/day) Soya group (740 ± 50 KJ/kg/day)	Edematous malnutrition (µmol/l) ~11.0 / 10.1 (soya group 5.7, cow's milk group 11.6)	children (11.4 ± 1.7 µmol/ 1) was the same as the value of the children with marasmic-kwashiorkor (10.6 ± 0.9.µmol/l) -These two groups of oedematous malnutrition were combined. Their values were sig. lower than those of the control children (p < 0.005) - For the marasmic children the fall in plasma zinc was much more profound in those that were given the soya based formula (to 5.8 ± 0.5 µmol/l) than in those given the cow's milk based diet (to 12.4 ± 0.3 µmol/l) - In the soya fed children, there was a tendency for the plasma zinc to continue to fall as the children remained on the diet - Our results show that zinc supply may be a limiting factor in the ability to resynthesize lost tissue, particularly from diets high in phytic acid. A relatively low protein diet in conjunction with zinc deficiency may lead to excess adiposity in man

AA=Ascorbic acid; BMC=Bone mineral content; bw=Body weight; BW=Bone width; CB=Common bean; EAA=Total plasma free Essential Amino Acids plus Cys and Tyr; FeSO4=Ferrous sulfate; Hb=Haemoglobin; HFeZnB=High-iron-high-zinc bean; HN=High socioeconomic background, no intervention food; ID=Iron deficiency; IDA=Iron deficiency anaemia; IT=Intervention trial; KF=Koko plus fish powder; L1A1=Low socioeconomic background, intervention food;L2N=Low socioeconomic background, no intervention food; NaFeEDTA=Ferric sodium ethylenediaminetetraacetate; NI=No Intervention (control); NPU=Net protein utilization; PA=phytic acid; PP=Polyphenols; RCT=Randomized controlled trial; RM=Reference meal; RT=Randomized trial; SF=Serum ferritin; sTfR=soluble transferrin receptor; TAA=Total plasma free amino acids; W=Weanimix; WAZ=Weight-for Age Z-score; WHZ=Weight-for-Height Z-score; WM=Weanimix plus minerals and vitamins

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6. Plans for interaction with the Tropical Legumes II project (TLII) and for seed increase on a country-by-country basis
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26. A revised manual for rhizobium methods and standard protocols available on the project website
27. Update on Inoculant production by cooperating laboratories
28. Legume Seed Acquired for Dissemination in the Project Impact Zones
29. Advanced technical skills in rhizobiology: East and Central African, West African and South African Hub
30. Memoranda of Understanding are formalized with key partners along the legume value chains in the impact zones
31. Existing rhizobiology laboratories upgraded
32. N2Africa Baseline report

33. N2Africa Annual country reports 2011
34. Facilitating large-scale dissemination of Biological Nitrogen Fixation
35. Dissemination tools produced
36. Linking legume farmers to markets
37. The role of AGRA and other partners in the project defined and co-funding/financing options for scale-up of inoculum (banks, AGRA, industry) identified
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Partners involved in the N2Africa project

Bayero University Kano (BUK)

Caritas Rwanda

Diobass

Eglise Presbyterienne Rwanda

Resource Projects-Kenya

Sasakawa Global; 2000

Université Catholique de Bukavu

University of Zimbabwe