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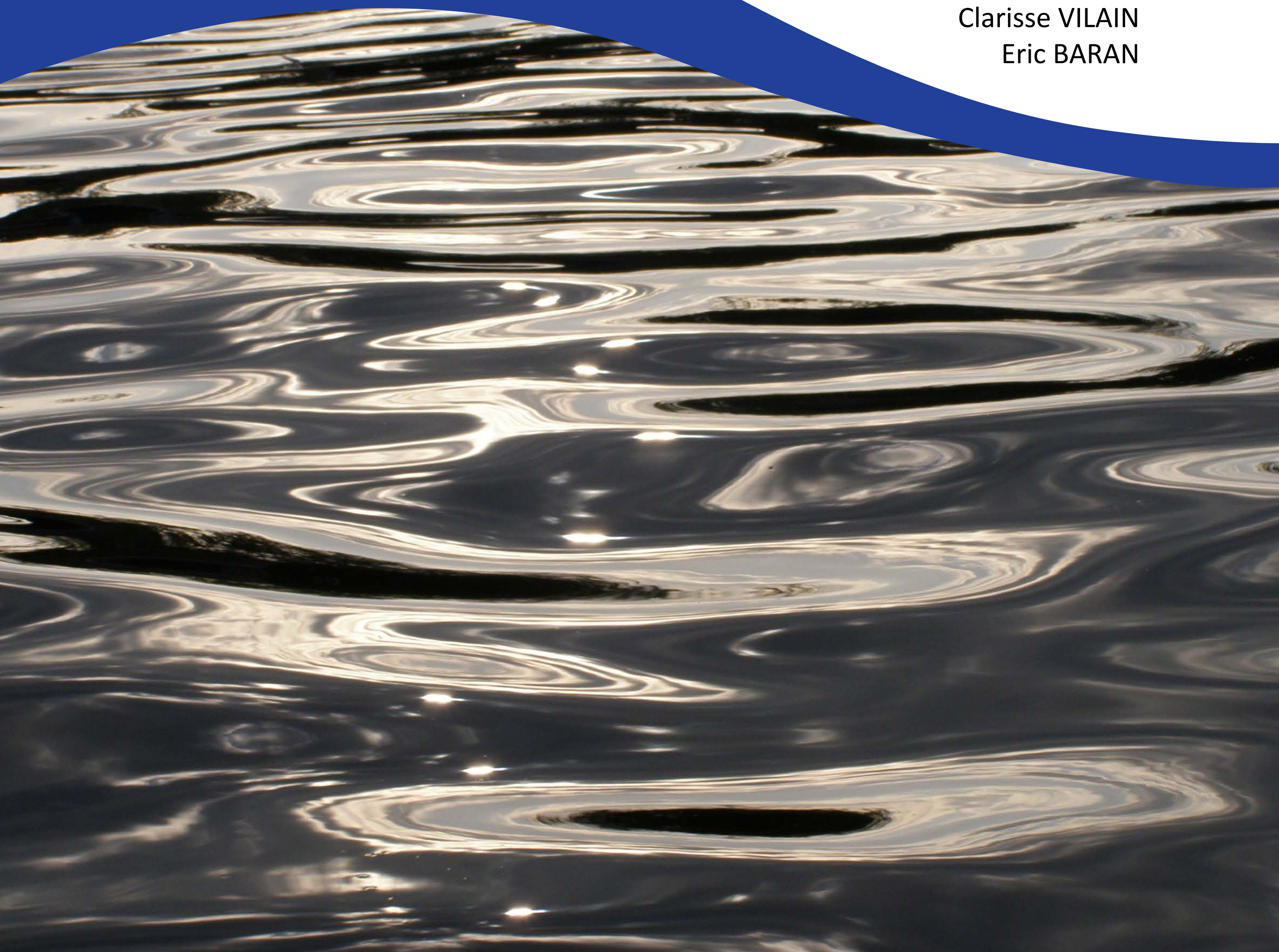
NUTRITIONAL AND HEALTH VALUE OF FISH: THE CASE OF CAMBODIA

Clarisse VILAIN
Eric BARAN



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2016

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EXECUTIVE SUMMARY

With 18.6% of the population below the poverty line and 84% living in the countryside, Cambodia is a poor rural country. It also features large freshwater fisheries (400,000 tonnes/year) and very high fish consumption (63 kg/person/year). Thus, fish plays an exceptionally important role in Cambodia's food security.

In a context of recognized contribution of fish to protein intake, we focus in this study on the benefits of non-protein nutrients from fish. For this study, 176 documents were reviewed, and the following questions are addressed:

- What, in the Cambodian diet, is beneficial and found only in fish?
- What is found in fish and not widely available in other food sources?
- What is responsible for malnutrition in Cambodia despite the high consumption of fish?

THE CAMBODIAN DIET

Rice represents 40% of the food absorbed and is consumed 7 times a week (302 g/person/day); it provides 60% of the total energy intake and 35% of the total (i.e. animal + vegetal) protein intake.

Fish and fish products represent 18% of the food absorbed. Fish is consumed cooked, dried, smoked, and, importantly, in the form of fermented fish paste and fish sauce. Fish meat, fish paste and fish sauce are consumed respectively 5.3, 3.7 and 3.7 times/week.

Fish, fish products and other aquatic animals contribute 12% of the total energy intake, 28% of the total fat intake and 37% of the iron consumed. Fish and other aquatic animals also provide 37% of the total protein intake and 76% of the *animal* protein intake (49% from freshwater fish and 5% from freshwater aquatic animals, 20% from marine fish and animals and 2% from aquaculture fish).

Other sources of nutrients are meat and poultry (about one third of fish consumption) and vegetables (92 g/person/day), which represents less than 50% of the recommended intake. The consumption of vegetable oil is also low, at 8g /person/day, or less than 50% of the total fat consumption.

BENEFICIAL NON-PROTEIN NUTRIENTS FOUND ONLY IN FISH

Omega-3 polyunsaturated fatty acids (PUFAs) are very beneficial to health, abundant in fish and cannot be found in other food items. Among them, two are especially important: EPA (eicosapentaenoic acid) and **DHA** (docosapentaenoic acid). **EPA** is converted into hormones particularly involved in coronary protection, brain and eye cell-functioning and immune-system response through white cells. DHA plays an important role in the structure of cells and substantially contributes to brain functioning (neurotransmitters) and eye development.

More generally, the consumption of omega-3 fatty acids is beneficial to brain development in fetuses and babies, optimum nervous system functioning among adults, and in mental health (e.g. prevention of Alzheimer's disease). Fatty acids are beneficial to the cardiovascular system by reducing blood pressure, blood clotting, atherosclerosis and the risk of coronary heart diseases. They also play a positive role in reducing inflammatory diseases (e.g inflammatory bowel disease, rheumatoid arthritis). They improve the metabolism of lipids (positive role on obesity) and reduce the glycemic index and subsequently the risk of diabetes. Last, they also contribute to eye development. Among freshwater fish, common carp contains the highest percentage of the total fatty acids (18.2 %) followed by catfish and climbing perch.

BENEFICIAL MICRONUTRIENTS FOUND IN FISH AND NOT WIDELY AVAILABLE ELSEWHERE

Five other important non-proteic nutrients are found in fish and are not widely available in other food items in Cambodia: iron, zinc, calcium, Vitamin A and iodine.

Iron mainly contributes to oxygen transportation between lungs and organs, but also to oxidative metabolism resulting in energy transfer from nutrients to the body. It also contributes to the immune system, through the killing of bacteria by leukocytes, and to body growth via steroid hormone synthesis. In case of deficiency, body growth is altered, the cognitive, neurological and the immune systems are impaired, and even muscles can become dysfunctional. In Cambodia, fish contributes 37% of the iron consumed and sour soup made with the small Mekong flying barb (*Esomus longimanus*) (*trey chanwa plieng* in the Khmer language) can cover as much as 45% of the daily iron requirement for women and children. In fish, iron is concentrated in the head and in viscera. However, iron absorption is reduced by rice consumption and in Cambodia 70% of pregnant women and 74% of children under five years are affected by iron deficiency.

Vitamin A is mostly involved in eyesight, in particular in the generation of the optic nerve impulse. This substance also takes part to reproduction and growth processes, and to cellular integrity and immune functions. Among males, Vitamin A takes part to spermatogenesis whereas in women it is involved in embryogenesis. Vitamin A deficiency impairs eyesight (eye dryness, followed by night blindness, corneal scars then by full blindness). In Cambodia 6.8% of lactating women and 8.4% of pregnant women suffer from night blindness. Vitamin A deficiency is also associated with measles (20% of measles-related mortality among children), diarrhea (duration of the symptoms) and malaria (20% of malaria incidence and mortality among children). Vitamin A deficiency is a global health problem, in Africa, Southeast Asia and particularly in Cambodia. Fish is the main source of bioavailable Vitamin A in the Cambodian diet. Vitamin A can be found in small fishes eaten with their bones, especially in their eyes and viscera. Species *Parachela siamensis* (*trey chanteas phluk* in the Khmer language) and *Rasbora tornieri* (*trey changwa mool*) in particular contain a very high proportion of this vitamin.

Zinc is in involved in multiple catalytic, structural, and cellular regulatory functions. At the cellular level, zinc is present in all six classes of enzymes, is essential to their activity and is subsequently involved in more than 300 catabolic and metabolic reactions. Zinc is also involved the three-dimensional configuration of proteins responsible for their biologic activity. At the body level, zinc plays an important role in growth (in particular bones), regulatory functions, immunity (including cell membrane integrity) and the transmission of the nervous influx. Zinc deficiency is dangerous and its expression depends on age. Among infants, it results in diarrhea and neuro-behavioral impairments (cognitive and memory issues), plus skin or gastrointestinal problems. Among school-aged children, it may result in growth retardation and recurrent infections (e.g. pneumonia). Zinc-deficient adults experience chronic pathologies such as leg ulcers and infections. Zinc bioavailability is best in aquatic food items, in particular in *Esomus longimanus (trey changwa plieng)*, a cheap small fish species in Cambodia. However, zinc bioavailability is reduced by rice consumption, and the categories most at risk of deficiency are children, pregnant women and elderly people.

Calcium is an essential mineral for the body and its skeleton. Calcium is involved in neuromuscular functions (especially the heart), multiple metabolic processes and above all in the skeleton's rigidity. Calcium deficiency leads to skeleton decalcification and osteoporosis (low bone density and fractures). Calcium deficiency among children results in bad dentition; among pregnant women, it leads to hypertension, preterm birth or fetal death. In Cambodia, fish is the most important source of calcium since dairy products are nearly non-existent, and calcium availability is considered high. Small fish constitute up to 86% of the total calcium intake from fish and other aquatic animals. In particular, the bioavailability of calcium from small fish bones is as high as that from milk.

Iodine is a key component of thyroid hormones and a precursor of triiodothyronine (T3) and thyroxine (T4). These hormones facilitate normal growth and multiple metabolism activities throughout life, especially during pregnancy and infancy. Chronic iodine deficiency can lead to goiter, a swelling of the neck resulting from an enlargement of the thyroid gland, but also in cretinism, an irreversible mental retardation. Reproductive failure, infant mortality, abnormalities of hearing, posture and short stature can also be related to iodine deficiency. However, young children may recover by iodine supplementation, and childbearing women should get iodine supplement.

Fish also contains other beneficial substances that are not widely available in rural Cambodia:

- **Minerals**, in particular phosphorus (component of cell membranes and of ATP, the essential form of energy in the body), potassium (nerve influx regulation together with sodium, but also muscle control and blood pressure) and selenium (antioxidant, thyroid regulation, immune functions);

- **Vitamins**, in particular the Vitamin B-complex group, with Vitamin B6 (red blood cell formation and insulin and hemoglobin synthesis), Vitamin B12 (brain and nervous system regulation), Vitamin D (good status in Cambodia) and Vitamin E (skin integrity, nervous system, heart and circulatory systems; and

- **Peptide derivatives**, such as carnosine and creatine (antioxidant activity in the brain and muscle).

WHY DO RURAL CAMBODIANS SUFFER FROM MALNUTRITION?

In Cambodia, the population is severely underweight (6.7%) and affected by moderate and severe stunting (39.9%) and wasting (10.9%). Eighty-nine percent of rural people obtain the recommended intake of protein, but only 51% of the population meets the adequate energy intake, 25% reach recommended levels of energy and 19% meet the recommended levels of iron. In general, children and women are more sensitive to deficiencies.

The causes of malnutrition are multiple and include: i) the insufficient consumption of vegetables and fruits in rural families (less than 50% of the recommended daily intake); ii) issues about poverty and the limited affordability of nutrient-rich food items; iii) a negative synergy between poor health and malnutrition, one leading to the other (e.g. chronic diarrhea or infestation by worms leading gastrointestinal malabsorption of ingested nutrients); iv) issues about beliefs and culture (in particular damageable food restrictions among pregnant or breastfeeding women); v) the negative role of rice that contains phytate inhibiting the absorption of proteins, iron, zinc, and calcium; vi) the impact of some processing techniques (e.g. sun-drying) or cooking methods (e.g boiling and deep-frying) on micronutrient content, and vii) a sex bias leading women and elderly people to give up some of their food to men and older children.

In conclusion, fish is an irreplaceable animal-source in the Cambodian diet. But fish alone is not able to ensure nutrition security in the population, and we propose six themes for further studies leading to improved nutritional security.

1 INTRODUCTION

Nutrition status in Cambodia

Cambodia is one of the poorest countries in Southeast Asia: 18.6% of the population was considered below the poverty line of US$1.25/day between 2007-2011 (UNICEF, 2013) and 84% of the population is classified as rural (Hortle, 2007). The infant mortality rate is 5.8% and life expectancy is 59 years for men and 63 years for women (Nam So and Bunthang Touch, 2011). Due to the Khmer Rouge rule from 1975 to 1979, and until 1998, Cambodia's nutrition status can't be retraced chronologically. Studies show that poverty and malnutrition are severe societal problems. The country has the highest malnutrition rate in the Asia-Pacific region (Nam So and Bunthang Touch, 2011) and rural Cambodia, where micronutrient deficiencies are widespread (SCN, 2004; Roos *et al.*, 2007 c), is particularly affected.

Fisheries in Cambodia

Cambodia features 461 freshwater fish species, 468 marine species and 26 species found in both environments (Baran *et al.*, 2014). The country is fifth in inland fisheries productivities after China, India, Bangladesh and Myanmar with an average of 400 000 tons per year. Furthermore, the coastal area has also a high potential for fisheries, providing approximately 75 000 tons per year (Nam So and Bunthang Touch, 2011). Thus, fisheries play a fundamental role in Cambodia for three main reasons. First, fish is the second food item consumed after rice (IFReDI, 2013), with 173 grams per person consumed per day, i.e. 63 kg per person per year (Baran *et al.*, 2014). Thus, fisheries contribute very substantially to national food and nutrition security. Second, fisheries have represented as much as 12% of growth domestic product in the past, making the sector very important for the national economy. Last, fisheries contribute to improving people's livelihoods since at least 45% of the population is working full time in fisheries or fisheries-related activities (Nam So and Bunthang Touch, 2011).

Role of fish in nutrition

Fish, especially freshwater fish, and other aquatic animals (OAAs) such as mammals, amphibians, reptiles, mollusks, crustaceans and insects (Hortle, 2007) represent 76% of the total animal protein intake of Cambodian people whereas meat accounts for 20% and poultry for 4% (Baran *et al.*, 2014). Thus, the role of fish and OAAs is essential (Mogensen, 2001; Nam So and Bunthang Touch, 2011). In particular, fish and OAAs provide a range of essential micronutrients such as Vitamin A, calcium, iron, zinc and iodine which alleviate micronutrient malnutrition (Roos *et al.,* 2003; Chamnan *et al.*, 2009).

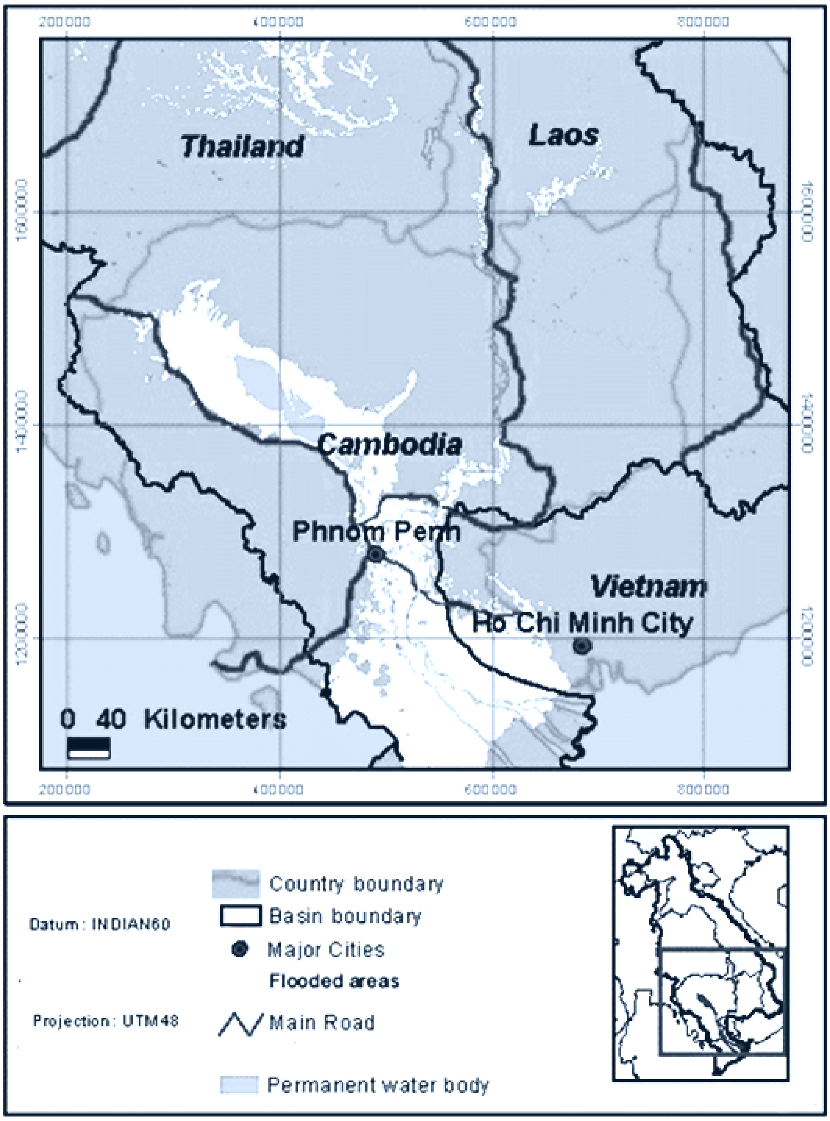

Figure 1: Location map. Source: modified from the MRC flood risk map in the Lower Mekong Basin

Purpose of the study

The aim of this report is to review actual knowledge of fish as a nutritious staple food for rural Cambodians. Since fish provides a major and self-explanatory 76% contribution of the animal protein supply, the study focuses on benefits of non-proteic nutrients from fish for human consumption. Answers to the following questions will be proposed:

- What, in the Cambodian diet, is beneficial and found only in fish?
- What is found in fish and not widely available in other food sources?
- What is responsible for malnutrition in Cambodia despite the high consumption of fish?

Approach

Technical documents were gathered about contributions and benefits to the human diet of non-protein fish derived nutrients in rural Cambodia. The WorldFish bibliographic database, search engines and professional resources such as Science Direct, Mendeley and Research Gate were used. Searches by author, substance, disease and key words were the most common way to find relevant information. To illustrate the document, graphics and figures were either copied from the original documents or found via Google Images. As a result, 176 documents were preselected and 89 of them were used to compose this final document.

Content of the report

This paper starts with a description of the Cambodian diet with a particular emphasis on the role of fish and other aquatic animals. Second, beneficial non-proteic nutrients found only in fish are reviewed. The report then details beneficial nutrients found in fish and not widely available in other foods. In these two last sections, substances, generic benefits and risks in case of deficiencies are described. The last part explains reasons why rural Cambodians suffer from malnutrition despite the important role of fish in their diet. This review doesn't focus on protein content of fish, contamination and pollution.

2 THE CAMBODIAN DIET

In the Cambodian diet, rice and fish are the two most consumed food items (IFReDI, 2013). Although the size of portions is variable depending on the seasons (Wallace *et al.*, 2014), the total food consumption has been estimated at around 955 g per individual per day, including 173 g of fish (IFReDI, 2013).

The household consumption of food is illustrated in the diagrams below (Figure 2 and Figure 3).

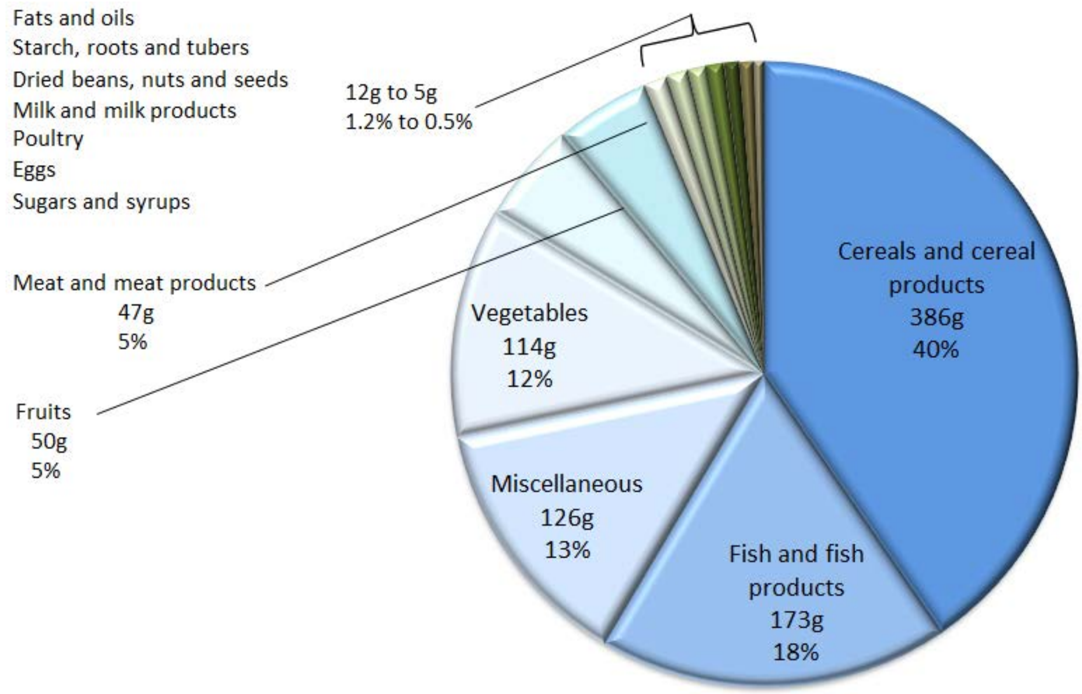

Figure 2 : Average one-day individual food intake (in grams) and percent of total food intake by groups: Cambodia, 2011. Source: IFReDI, 2013

Rice and fish are the two most frequent food items. In a recent study, Mousset *et al.* (2016) found that rice is the most frequently consumed item (i.e. 6.9 days per household per week), fish being second (5.3 days/week), followed by fish sauce (3.0 days/week) and fish paste (2.2 days/week). All fish and fish products together represent 120 grams/person/day or 43.2 kg/person/ year. Mousset *et al.* also find that the average total quantity of food consumed amounts to 580 g per person per day (39% difference with IFReDI's results above).

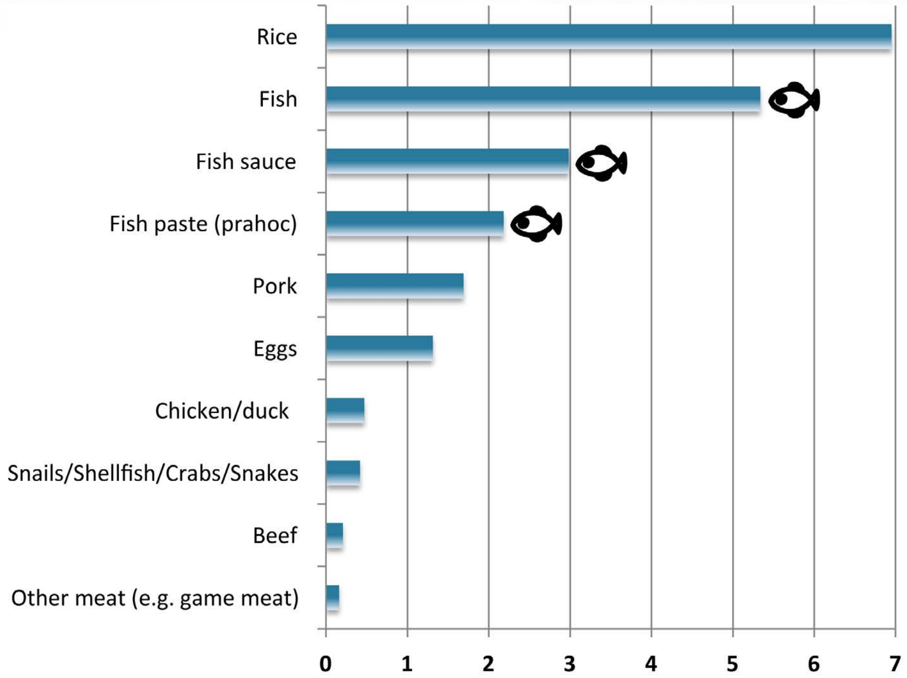

Figure 3: Frequency of food consumption. Source: Mousset *et al.*, **2016**

Fish meat, fish paste and fish sauce are consumed respectively 5.3, 3.7 and 3.7 times/week.

The proportion of nutrients available for body biological functions is called bioavailability; as rice is the dominant food, its influence on the bioavailability of other foods is important (Mogensen, 2001). In rural poor households, it was shown that the most common dishes prepared by women were fish sour soup, lemongrass spicy soup, grilled fish, soup with meat and vegetables, and fried fish (Chhoun. *et al.*, 2009). Thus, this diet provides respectively 151%, 27%, 118% and 45% of the recommended intakes of protein, Vitamin A, iron and calcium of an adult male (Mogensen, 2001).

2.1 RICE

Rice is the most consumed staple food in Cambodia, providing carbohydrates and energy. The Cambodian diet is culturally based on rice; “to eat” means “to eat rice” in Khmer (Mogensen, 2001). Rice is generally consumed every day at every meal (Mogensen, 2001), up to 302 g/person/day (Mousset *et al.*, 2016), and provides an average of 1,095 kcals, i.e. 60% of the total energy intake (IFReDI, 2013). It is the second most important source of protein per capita, as it contributes to 35% of that protein intake (IFReDI, 2013) and it provides 17% of fats and 32% of the iron per capita (IFReDI, 2013).

The production of rice depends on the rainfall from May to October. During this period, 88% of the total national production of rice is grown. The remainder is grown during the dry season and needs supplementary irrigation (Sarom, 2007). There is usually a single crop of rice per year because irrigation is rarely available. After December, rice is abundant even if the stock varies from one household to the other (Mogensen, 2001). Most households can’t cover their annual needs and have to buy rice before the next harvest (Mogensen, 2001).

2.2 FISH

Fish is the second dietary compound of the Cambodian diet; it is affordable and provides protein and essential micronutrients not widely available elsewhere in the diet. Fish contributes in average to 17% of the world consumption of animal source foods but in Cambodia, it clearly exceeds this share (FAO, 2014). Cambodians are one of the highest consumers of fish and other aquatic animals per capita in the world (Hortle *et al.*, 2007). This staple food is more available in November and December, the lean season being in April and May during the hot season (Mogensen, 2001). Fish and fish products are eaten two or three times a day.

Fish, fish products and other aquatic animals contribute 12% of the total energy intake, 28% of the total fat intake and 37% of the iron consumed. They also provide 37% of the total protein intake and 76% of the animal protein intake (Figure 4).

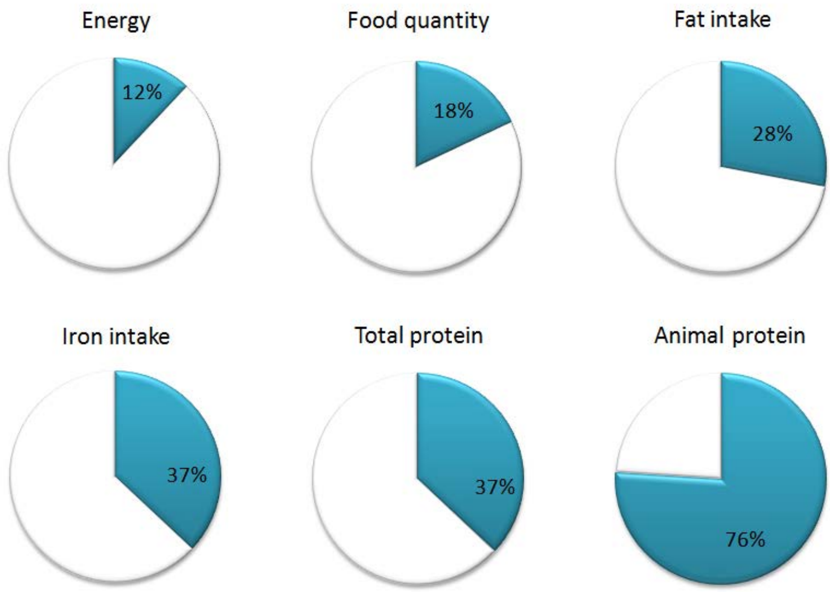

Figure 4: Contribution of fish and other aquatic animals to the diet of Cambodian people. Source: IFReDI, 2013

Fish and other aquatic animals also provide 37% of the total protein intake and 76% of the animal protein intake (49% from freshwater fish and 5% from freshwater aquatic animals, 20% from marine fish and animals and 2% from aquaculture fish); see Figure 5.

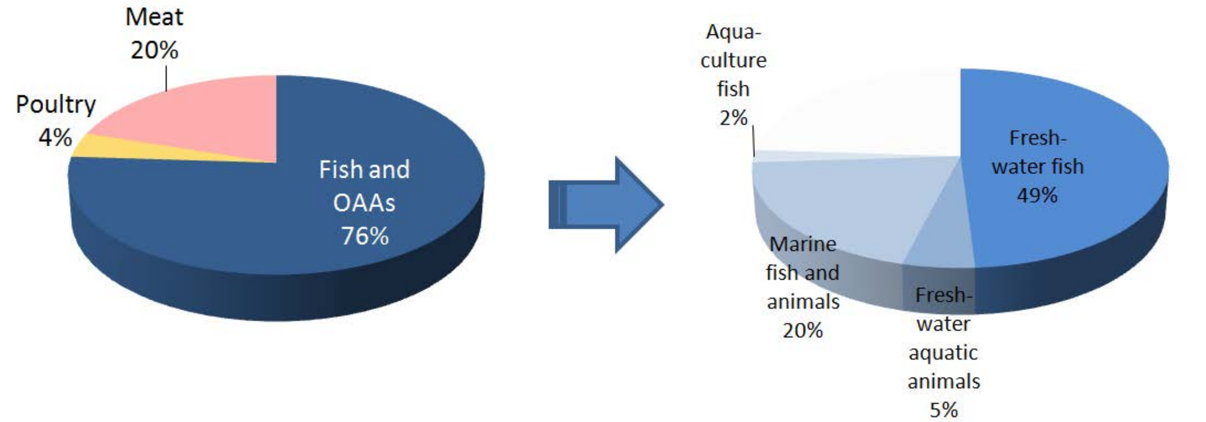

Figure 5 : Animal intake and breakdown of fish sub-group contribution. Source: IFReDI, 2013

Fish is the central and preferred source of food for rural poor Cambodians because these resources are abundant (Belton and Thilsted, 2013; Nam So and Bunthang Touch, 2011). Small fish in particular are very beneficial to nutrition and health as they are available for a long period through processing and storing, and also because they are more affordable for the poor who usually buy smaller portions at local markets (Kawarazuka and Béné, 2010). In terms of eating habits, soup is often the most common cooking method used to serve fish and other aquatic animals.

Frying, drying and fermentation are also frequent (Mogensen, 2001). Fresh fish is preferred, although processed fish is also often eaten (Mogensen, 2001). This term refers to fish paste like prahok (Figure 6), smoked fish, sun- or salt-dried fish and fish sauce (MacKey, 2007). Fish paste consumption represents 18g per capita per day (Mogensen, 2001). Prahok and fish sauce are particularly appreciated and consumed as condiments and may be involved in micronutrient supplementation (MacKey, 2007).

Figure 6: ***Prahoc*** **or fermented fish.** Source: C. Vilain, September 2014, Takeo Province, Cambodia.

Fish has a crucial role as it provides energy when the latter can't be supplied by rice and other starchy food items (IFReDI, 2013). It is more nutritious than staple foods and thus is favored to tackle micronutrient deficiencies (Kawarazuka, 2010). It contributes indirectly to improving household income and purchasing other foods such as lower cost staple foods (Kawarazuka, 2010).

Fish is the first contributor of both macro- and micronutrients in the Cambodian diet (IFReDI, 2013). It is traditionally considered as a good source of protein, essential fatty acids, vitamins or minerals which are particularly bioavailable. Fish provides in particular Vitamin A, calcium, iron, zinc and iodine (Nam So and Bunthang Touch, 2011; FAO, 2014; Kawarazuka, 2010). In addition, adding fish to the diet increases both intake and absorption of protein (Kawarazuka, 2010) as well as the absorption of nutrients from vegetables (Belton and Thilsted, 2013).

2.3 OTHER SOURCES OF NUTRIENTS

In addition to rice and fish, other foods are consumed by the poor (Kawarazuka, 2010).

2.3.1 Other aquatic animals

Cambodians consume on average 4.5 kg of such aquatic animals per person and per year (Hortle, 2007). Aquatic animals consumed by rural Cambodians consist of frogs, crabs, snails, insects, shrimps and wetland birds (Mogensen, 2001).

2.3.2 Meat and poultry

Cambodian households living by water bodies consume 2.8 times more fish than meat and poultry (Mousset *et al.,* 2016). Meat and poultry contribute to respectively 4% and 20% of the total animal intake (Mogensen, 2001). In rural areas, livestock is produced over the year (Mogensen, 2001); chicken is somewhat inexpensive and a rich source of iron (Wallace *et al.*, 2014).

2.3.3 Vegetables

Vegetable consumption is too low in Cambodia. This category refers to legumes, fruits, nuts, roots, and aquatic plants other than rice (Mogensen, 2001). Vegetables are available in Cambodia and often imported from Vietnam. However their consumption is low and represents only 92 g of the intake per capita per day, that is to say less than 50% of the recommended daily intake (Mogensen, 2001).

Vegetable growing is highly influenced by the seasons, with the peak of production observed between December and February (Mogensen, 2001). During this period, cabbage, Chinese cabbage, onions, lettuce, tomato and Chinese radish are the most commonly grown vegetables (Mogensen, 2001). In the early wet season, cucumbers, gourds, shallots, beans, Chinese kale, hot peppers, leaf mustard and morning glory are cultivated whereas in the late wet season aquatic plants and some beans and gourds are produced (Mogensen, 2001).

Other vegetables such as eggplant, mung bean, papaya, peanut, pepper, different pickled vegetables, sour ingredients (tamarind, tamarind leaves, lemon, red ants and fermented rice with insects), ginger and other roots, sweet potato, tomato, gourd, leek and pumpkin may also be purchased but in small quantities (Mogensen, 2001).

2.3.4 Oil and fats

Cambodians consume 19 grams of total fat per capita and per day (Mogensen, 2001). Cambodia imports about 26,000 tonnes and produces 20,000 tonnes of vegetable oils; the latter is consumed by Cambodians on an average basis of 3 kg per capita per year i.e. 8 g/person/day (Mogensen, 2001).

2.3.5 Infant nutrition

According to the Cambodian demographic health survey in 2010, breastfeeding is common in Cambodia as 96% of children are partly breastfed and 74% exclusively breastfed (NIS, 2011). Between 6-9 months, 82% of Cambodian children have an enriched diet composed of milk and complementary foods, which reduce the risk of malnutrition (NIS, 2011).

Breast feeding is very common in Cambodia. According to the Cambodian demographic health survey (NIS, 2011), 96% of children are partly breastfed and 74% are exclusively breastfed. Between 6-9 months, 82% of Cambodian children have an enriched diet composed of milk and complementary foods, which reduce the risk of malnutrition (NIS, 2011).

2.4 CONCLUSION

The Cambodian diet, as in many other Asian countries, is based on rice consumption. This staple food provides especially energy in the form of calories. In addition, vegetables are cultivated but consumed in small quantities and thus don't allow for meeting the recommended intakes. Likewise, meat and poultry are rarely consumed. Thus, fish contributes to the most important part of the micronutrient intake, and can be available year round thanks to processing methods. Its role is dominant and, at present, no other food sources may represent an alternative.

RECOMMENDED DIET AND WHAT CAMBODIANS ACTUALLY EAT

The illustrations below represent the recommended diet according to the Ministry of Health in Cambodia (MoH, 2010), and what rural Cambodians actually eat, according to IFReDI (2013).

The surface area of each feed group (carbohydrates at the bottom, then vegetables and fruits, then fish, meat and/or dairy products, then oil and sugar at the top) represents its proportion in the diet.

RECOMMENDED NUTRITION PYRAMID — WHAT CAMBODIAN PEOPLE ACTUALLY EAT

3 BENEFICIAL NON-PROTEIN NUTRIENTS FOUND ONLY IN FISH

Fish consumption leads to clear nutritional benefits. Fish provides high-quality protein, minerals and trace elements, fat-soluble vitamins and essential fatty acids, including long chain omega-3 poly-unsaturated fatty acids (FAO, 2010). This chapter will focus on elements found only in fish, and their role and specific contribution for human growth, development, physiology and performance. In addition, this chapter will review why these substances are metabolized and how.

3.1 EPA AND DHA, TWO OMEGA-3 POLYUNSATURATED FATTY ACIDS

3.1.1 EPA and DHA in fish

Fish contain high quality fat that can't be found elsewhere. Fat composition of fish is unique compared to other animal food sources (Kawarazuka, 2010). Fishes can be classified depending on their fat content. White-fleshed fishes such as cod comprise 1 to 2% of fat and store it in the liver, whereas oil-rich or fatty fishes like salmon contain 5 to 20% fat and store it in muscles (McKeown, 2006). In Cambodia, fish, especially white and black species, account for 27.81 % of the total fat intake of the household (IFReDI, 2013)

Fish meat is characterized by its high content of beneficial polyunsaturated fatty acids. Chemically, fatty acids are carboxylic acids with an analiphatic tail (Ratnayake and Galli, 2009). Their structures vary depending upon their hydrocarbon chain length (from 2 to 40 carbons) and saturation. In fish fat, the chain is classified as long because it is composed of more than 12 carbons (Vannice and Rasmussen, 2014). In addition, fatty acids in fish have more than one double bound in their tails and are thus qualified as polyunsaturated (Karawazuka, 2010; Vannice and Rasmussen, 2014). The latter are often further classified based on the position of the first double bond from the fatty acid methyl terminus, creating omega-3 and omega-6 fatty acids (Vannice and Rasmussen, 2014). In the omega-3 polyunsaturated fatty acid (PUFA) family (Table 1), fish contains eicosapentaenoic acid and docosahexaenoic acid (McKeown, 2006; Morris, 2008; Kawarazuka and Béné, 2010).

Table 1 : Important omega-3 polyunsaturated fatty acids. Source: Ratnayake and Galli, 2009

Common name	Abbreviation	Typical sources
α-Linolenic acid	18:3n-3 (ALA)	Flaxseed oil, perilla oil, canola oil, soy bean oil
Stearidonic acid	18:4n-3(SA) 20:4n-3 (SA)	Fish oils, genetically enhanced soybean oil, blackcurrant seed oil, hemp oil, very minor component in animal tissues
Eicosapentaenoic acid	20:5n-3 (EPA)	fish, especially oily fish
Docosapentaenoic acid	22:5n-3 (n-3 DPA)	fish, especially oily fish
Docosahexaenoic acid	22:6n-3 (DHA)	fish, especially oily fish

DHA and EPA are derivatives of alpha-linolenic acid (ALA, Figure 7). This acid is widely available in food of plant origin, like vegetable oils, but cannot be synthesized by humans and has to be ingested to produce C20 and C22 omega-3 fatty acids (Ratnayake and Galli, 2009). Although the human body can convert ALA into DHA and EPA (Table 2: Metabolic pathway of the omega-3 fatty acids), the conversion rate is very low (below 5% from ALA to EPA and even less to DHA (Lavie *et al.*, 2009). Thus, food items of aquatic origin rich in EPA and DHA must be regularly ingested to ensure a sufficient supply (McKeown, 2006; Ratnayake and Galli, 2009; Mozzafarian *et al.*, 2011; Vannice and Rasmussen, 2014).

Table 2: Metabolic pathway of the omega-3 fatty acids. Source: Morris 2008

Omega 3 fatty acids	Enzymes
α-Linolenic acid 18:3n-3 (ALA)	Δ6-denaturase
↓	
Stearidonic acid 18:4n-3 (SA)	elongase
↓	
20:4n-3 (SA)	Δ6-denaturase
↓	
Eicosapentaenoic acid 20:5n-3 (EPA)	elongase
↓	
Docosapentaenoic acid 22:5n-3 (n-3 DPA)	elongase
↓	
24:5n-3	Δ6-denaturase
↓	
24:6n-3	β-oxidation
↓	
Docosahexaenoic acid 22:6n-3 (DHA)	

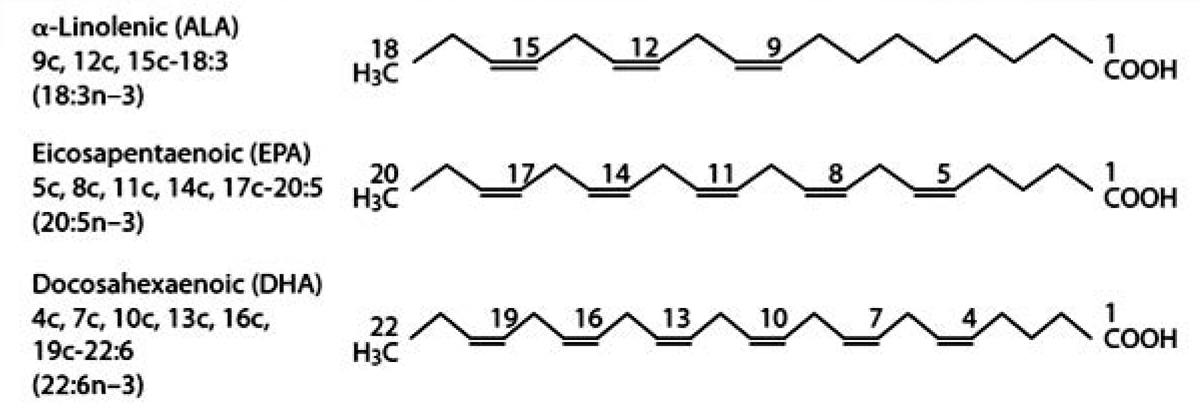

Figure 7: Structures of ALA, EPA and DHA. Source: Ratnayake and Galli, 2009

Eicosapentaenoic acid (EPA) is mainly involved in coronary protection and immune response. EPA is converted to eicosanoids after stimulation, thus this substance is not accumulated in cells (Ratnayake and Galli, 2009). Ecosanoids act as hormones in the human body and include prostaglandins, thromboxanes, leukotrienes and lipoxins (Ratnayake and Galli, 2009). They are mainly found in highly specialized membranes such as synaptic terminals in the brain, retinal cells in the eyes and heart myocytes (Ratnayake and Galli, 2009). Prostaglandins and thromboxanes derived from EPA are vasodilators and have an anti-aggregative action. Moreover, increased intakes of EPA from fish oil most likely reduce the inflammatory activity associated with eicosanoids derived from omega-6 acids and are therefore helpful in suppression of inflammation (Ratnayake and Galli, 2009). Last but not least, leukotrienes are produced in white blood cells called leukocytes; they are involved in vascular parameters and thus are part of the immune system response (Ratnayake and Galli, 2009).

Docosahexaenoic acid (DHA) is involved in brain development. DHA is part of phospholipids hence its structural role in membranes or muscular cells. In the brain, it is highly concentrated in membrane lipids of the central system and in the grey matter; in the eyes it takes part of retina (Ratnayake and Galli, 2009). This fatty acid has also functional roles and is concentrated in receptor functions, ion channels and neurotransmitter release (Ratnayake and Galli, 2009). DHA is also the precursor of docosanoids (Ratnayake and Galli, 2009). These substance acts in human tissues especially in cardiac muscle cells, sperm, and retinal and synaptic cells in the brain (Ratnayake and Galli, 2009).

Although most studies have focused on EPA and DHA, n-3 DPA is another intermediate in the conversion of EPA to DHA, which can also be found in fish and may be positively involved in inflammatory processes in the cardiovascular system (Ratnayake and Galli, 2009).

3.1.2 Benefits for the human body

These metabolized substances influence cellular functions and benefit human health and development in several ways. This part of the report will review the actual knowledge about benefits for the human body of EPA and DPA fatty acids.

Brain

In babies and children, early neurogical development is positively influenced by omega-3 fatty acids consumed by pregnant or nursing women. Young people’s brains and other neural tissues are particularly rich in long chain polyunsaturated fatty acids (Ruxton *et al.*, 2005). The latter are required components of the rapidly growing perinatal central nervous system (FAO, 2010) and boost cognitive development (Kawarazuka and Béné, 2010). These omega-3 fatty acids, particularly DHA, are transferred from the mother to the fetus across the placenta and later by breast milk (McKeown, 2006). DHA is incorporated into the membranes of neural cells in the developing fetal nervous system and is, for instance, an essential structural component of the nerve cell membranes of the cerebral cortex (McKeown, 2006). The concentration of DHA in this tissue is very high and represents up to 50% of total fatty acids present (McKeown, 2006). In the last trimester of pregnancy and the first few months after birth, the overall brain volume increases. During this period and throughout the first two years of life, DHA is still accumulated in tissues (McKeown, 2006). Moreover, fish intake may also be related to intelligence quotient and memory. For instance, scores from some tests of language comprehension and social activity were "modest but consistently higher" among children who consumed fish and whose mothers ate fish during pregnancy (McKeown, 2006).

Among adults, polyunsaturated fatty acids are also involved in optimal brain function. They are part of phospholipid membranes and thus act in favor of brain tissue development such as neuronal membrane fluidity and regulate neurotransmitters (Ruxton *et al.*, 2004).

Mental health and behavior disorders

Mental health and behavior disorders can be improved by omega-3 consumption. Cell culture and animal models show promising mechanistic support regarding docosahexaenoic acid positive influence in Alzheimer's disease (FAO, 2010). A protein derived from docosahexaenoic acid called neuroprotectin D1 displays potent anti-inflammatory and neuroprotective bioactivity against oxidative stress. The latter is responsible of Alzheimer's disease (Ratnayake and Galli, 2009). Depression, especially postnatal depression, has been linked with a low omega-3 polyunsaturated fatty acid status, which results from high fetal requirements of docosahexaenoic acid (Ruxton *et al.*, 2004). In addition, plasma studies support the evidence that low omega-3 levels are associated with dementia (Ruxton *et al.*, 2004).

Blood and cardio protection

Omega-3 fatty acids favor heart protection. In the blood, omega-3 polyunsaturated fatty acids produce vasodilation thanks to prostaglandins (Lavie *et al.*, 2009). They reduce free fatty acids, plasma triglyceride and cholesterol concentration and lower platelet aggregation via thromboxanes (FAO, 2010; Lavie *et al.*, 2009). These actions lead to decreasing blood pressure (Lavie *et al.*, 2009; Kawarazuka and Béné, 2010), blood clotting (McKeown, 2006) and reduce atherosclerosis. In fact, Danish scientists found that high consumption of EPA in Greenland Eskimos with a fish-based diet proved virtually free from arteriosclerosis (FAO, 2010).

I**n addition, studies have demonstrated the health benefits of fish consumption thanks to the correlation between omega-3 fatty acids and a decrease in glycemic index** (Fernandes, 2012). It was also correlated to a reduction in stenosis (abnormal narrowing of blood vessels) in diabetic women that have reached menopause (Fernandes, 2012). These improvements in blood quality lead to convincing evidence of lower coronary heart disease risk when polyunsaturated fatty acids replace saturated fatty acids (FAO, 2010).

Most cardiovascular benefits of omega-3 polyunsaturated fatty acids are conferred through DHA and EPA (Ruxton *et al.*, 2005) as part of membrane phospholipids (Lavie *et al.*, 2009).

Dietary intake of fish plays multiple cardio-protective roles, particularly in:

- preventing effect in coronary heart disease because EPA as precursor of eicosanoids leads to prostaglandins and leukotrienes (which are involved in contraction and relaxation of muscles), plus thromboxane production. The latter are involved in vasoconstriction (McKeown, 2006);

- protection against heart arrhythmia (Ruxton *et al.*, 2005) even achieved at low doses of DHA and EPA (Lavie *et al.*, 2009). This role is due to the ability of omega-3 fatty acids to modify electrophysiological activity of ion channels (voltage-dependent sodium channels, L-type calcium channels; Lavie *et al.*, 2009);

- reduction of incidence of myocardial infarction (McKeown, 2006). In fact, omega-3 DHA and EPA are thought to decrease mean platelet volume and thus the risk of acute myocardial infarction (Ratnayake and Galli, 2009);

- protection against thrombosis (McKeown, 2006). Omega-3 fatty acids provide greater atherosclerosis cholesterol plaque stability and thus have anti-thrombosis properties (Ruxton *et al.*, 2005);

- secondary preventing role of cardiovascular disease in patients who have known coronary heart disease (McKeown, 2006); and

- reduction of the risk of sudden death (Albert et *al.*, 2002).

As a conclusion, all this cardio-protective actions decrease coronary heart disease mortality rates (McKeown, 2006).

Inflammatory diseases

Eicosanoid products are potent anti-inflammatory and inflammation resolving factors. Studies on humans have largely focused on the effects of long chain polyunsaturated fatty acids on inflammation (FAO, 2010). These explain many of the clinical effects of n-3 long chain polyunsaturated fatty acids (FAO, 2010). In fact, EPA and DHA consumed from fish or fish oil results in the incorporation of these n–3 polyunsaturated fatty acids (PUFAs) in anti-inflammatory cells such as monocytes, macrophages, neutrophils and lymphocytes (Ratnayake and Galli, 2009). The n–3 fatty acids affect cytokines and other factors released by cells involved in inflammatory process and in the regulation of the immune system (Ratnayake and Galli, 2009).

Inflammatory bowel disease (IBD)

Omega-3 fatty acids are beneficial to patients who suffer from inflammatory bowel disease. There are two main forms of IBD: Crohn’s disease and ulcerative colitis (FAO, 2010). In Crohn’s disease, there are benefits of omega-3 long chain polyunsaturated fatty acids, as studies reported better gut histology and maintenance in remission (FAO, 2010). However, studies in ulcerative colitis show insufficient evidence of the benefits of omega-3 LCPUFA (FAO, 2010).

Rheumatoid arthritis

Omega-3 fatty acids have a positive action against inflammation and rheumatoid arthritis. There is evidence of the role of n-3 long chain polyunsaturated fatty acids in maintaining immune functions and reducing inflammation for the treatment of all forms of inflammatory arthritis (Ruxton *et al.*, 2005). According to the FAO, studies underlined benefits such as a reduced number of swollen or tender joints, decreased duration of morning stiffness and reduced use of anti-inflammatory medication (FAO, 2010). In fact, n–3 polyunsaturated fatty acids have been shown to reduce expression of genes such as COX-2, 5-LOX and 5-LOX activating protein in cartilage cells called chondrocytes, and thus decrease inflammation (Ratnayake and Galli, 2009).

Metabolism of lipids

Omega-3 polyunsaturated fatty acids (PUFAs) are involved in lipid metabolism and reduce obesity by regulating gene transcription factors. Fatty acids have lipid-lowering effects because they are endogenous ligands for peroxisome proliferator-activator receptor (Lavie *et al.*, 2009) and retinoic acid receptors (Uauy and Castillo, 2003). The peroxisome receptor regulates the expression of genes controlling fatty acid uptake (Lavie *et al.*, 2009) and transport and oxidation (Ratnayake and Galli, 2009). It also also suppresses the expression of genes of de novo synthesis, storage and synthesis of lipids (Ratnayake and Galli, 2009). In addition, polyunsaturated fatty acids repress transcription of the leptin gene: this adipose-derived hormone regulates appetite and body weight adiposity (Ratnayake and Galli, 2009).

Eyesight

Fish consumption has a good influence on eyesight. DHA is incorporated into the nerve cells of the retina during pregnancy and represent half of the concentration of total fatty acids in this tissue (McKeown, 2006); this accumulation is completed in a full-term infant (McKeown, 2006). In fact, DHA can represent up to 50% of the fatty acids inphosphatidylethanolamine and phosphatidylserine. These two proteins are responsible for rapid transmission of light and part of the outer segments of the retina rods and cones (Ratnayake and Galli, 2009). Moreover, in the elderly, fish consumption may prevent cataracts (Fernandes, 2012).

Pregnancy

Omega-3 fatty acids may improve fetal development in pregnancy. In addition to DHA effects on babies developing brains, it was suggested that omega-3 fatty acids might lengthen gestation (McKeown, 2006) and boost fetal growth through changes in blood viscosity that lead to increasing placental blood (McKeown, 2006).

CONSEQUENCES OF LACK OF DHA DURING CHILD GROWTH

Insufficient levels of DHA are illustrated in the case of peroxisomal disorders such as Zellweger's syndrome, a rare congenital disease. Patients with the syndrome and its variants have very low levels of DHA in the brain (Martinez, 2001). The brain is profoundly affected in this disease, resulting in neuronal abnormalities. In particular, children with this syndrome linked to DHA deficiency are very floppy, have a high forehead, convulsions and die early. Zellweger's syndrome is treated thanks to DHA supplementation (Martinez *et al.* 2000)

Photo: Baby with Zellweger's syndrome and lacking DHA

Cancer and skin diseases

Consumption of omega-3 long chain polyunsaturated fatty acids has been related to reducing the risk of cancer and skin diseases. According to the FAO, EPA and DHA, have probable evidence to decrease the risk of colorectal cancer. Moreover, as meat is a risk factor for colorectal cancer, fish consumption also reduces this risk (FAO, 2010). Secondly, EPA and DHA reduce effect on breast cancer risk. Omega-3 fatty acid consumption is also important for preventing skin diseases (FAO, 2010).

3.2 DIETARY REQUIREMENTS

Fish should be consumed at least twice a week to meet dietary requirements in EPA and DHA. Fish, especially fatty fish, contain high levels of omega-3 fatty acids (Table 3). The FAO recommends 250 mg EPA and DHA per day for men and non-pregnant women (FAO, 2010). However, to avoid coronary heart disease, it advised to consume at least 225 g of fish or shellfish per week per person (Vannice and Rasmussen, 2014). This represents two or more servings of fish per week with an average daily intake of 450 to 500 mg EPA and DHA.

Pregnant, lactating and nursing women need to consume more fish than other people. To avoid neurological development risk in children, it is also important to underline the role of pregnant and lactating women. Fetal requirement for long chain polyunsaturated fatty acids is met by the placenta (Ruxton, 2004). Newborn plasma measures of DHA correlate to maternal intake of DHA from fish during pregnancy (McKeown, 2006). Similarly, during lactation, maternal DHA is transmitted to the infant through breast milk and reflects maternal intake from diet (McKeown, 2006). However, maternal n-3 polyunsaturated fatty acid stores in adipose tissues may be affected by multiple pregnancies or a vegetarian diet (Ruxton, 2004; McKeown, 2006). Thus, it has been suggested that childbearing women require double their normal intake of DHA from diet to accommodate the needs of the fetus or infant (McKeown, 2006).

Table 3: Composition of selected fatty acids in fish and other animals (% of total fatty acid).
Source: Michaelsen *et al*., 2011

	ALA	EPA	DHA	Total omega-3 PUFA
Marine fish				
Thai sardine (*Sardinella gibbosa*)	0.5	6.1	9.7	16.3
Cod liver oil	0.7	8.9	9.3	18.9
Cold-water freshwater fish				
Atlantic salmon (*Salmo salar*)	4.6	5.1	17.6	27.3
Warm-water freshwater fish				
Snakehead (*Channa striata*)	0.5	0.3	1.5	2.3
Common carp (*Cyprinus carpio*)	2.9	8.8	6.5	18.2
Nile tilapia (*Oreochromis niloticus*)	0.8	0.8	9.0	10.6
Eel (*Monopterus albus*)	0.9	2.7	0.2	6.1
Catfish (*Clarias macrocephalus*)	2.7	3.2	6.7	12.6
Climbing perch (*Anabas testudineus*)	1.3	1.1	9.2	11.6
Other animals				
Field cricket (*Teleogryllus testaceus*)	9.0	0.0	0.0	9.0
Cambodian spider (*Haplopelma albostriatum*)	3.6	1.6	1.7	6.9

3.3 CONCLUSION

Fish fat content is unique as it contains some essential pre-formed long chain polyunsaturated fatty acids called DHA and EPA. These omega-3 fatty acids can't be provided as such by any other food sources. In the human body, they are converted into docosanoids and eicosanoids, which respectively mainly contribute to brain development, coronary protection and immune response.

To combat deficiencies and meet dietary requirements in EPA and DHA, fish, especially fatty fish (Fernandes, 2012) should be consumed at least twice a week, which is the case in Cambodia (see Section 2).

4 BENEFICIAL MICRONUTRIENTS NOT WIDELY AVAILABLE IN OTHER FOOD ITEMS

As seen in Section 2, the Cambodian diet is mostly rich in rice and fish. Health benefits of fish are largely accepted and mostly related to its content of n-3 long chain polyunsaturated fatty acids. However, fish or seafood contains other nutrients leading to important health benefits. Seafood is among the best source of macro and micronutrients frequently under-represented in standard diets such as iron, zinc, calcium, Vitamin A and iodine (McManus and Newton, 2011; Chamnan *et al.*, 2009) (Figure 8). These essential vitamins and minerals are especially available in small fish species eaten whole (Nam So and Bunthang Touch, 2011), which can contribute to national food security and be used to alleviate micronutrient malnutrition (Chamnan *et al.*, 2009).

Thus this chapter will review beneficial nutrients found in fish and not widely available in other foods. First of all, the focus will be on iron, zinc, calcium, Vitamin A and iodine; then other nutrients found in fish but considered as secondary will also be reviewed.

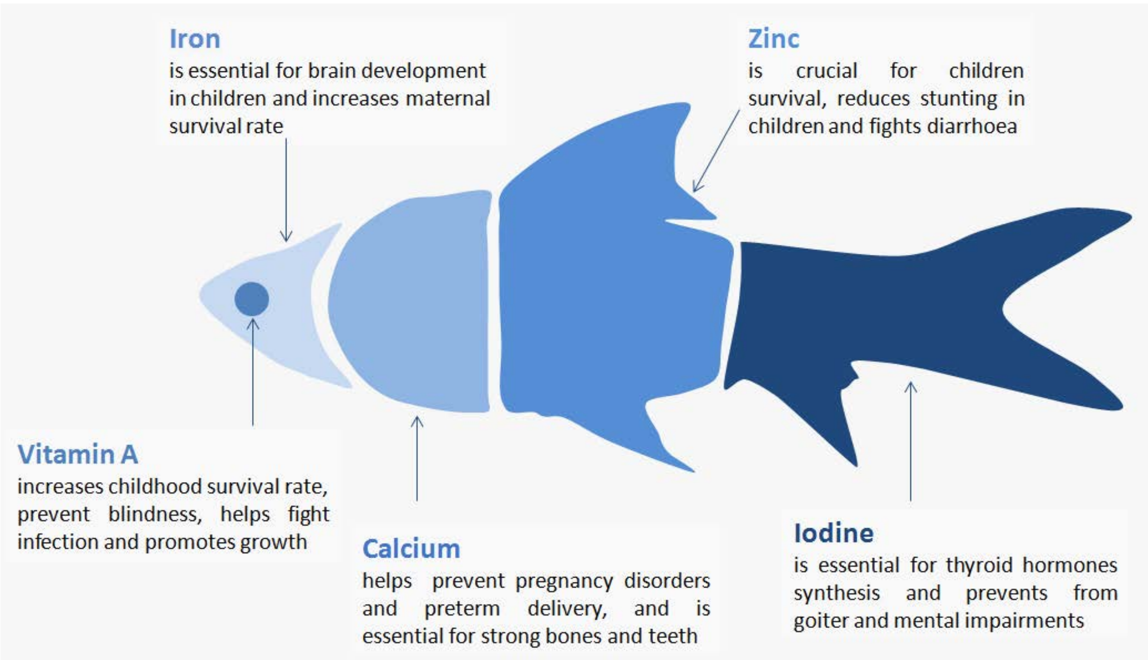

Figure 8: Fish as a source of Vitamin A, zinc, calcium, iodine and iron.
Source: adapted from WorldFish infographics

4.1 KEY MICRONUTRIENTS FOUND IN FISH

4.1.1 Iron

Fish consumption is essential to absorb heme iron. Iron is an essential mineral absorbed by the gut into two different forms: non-heme iron (ionic Fe^{2+}; Fe^{3+}) and heme iron (Mogensen, 2001). The heme is a compound consisting of an Fe^{2+} (ferrous) ion in the centre of an organic ring; hemes are components of hemoglobin, the red pigment in blood.

Heme iron is found in fish and meat whereas non-heme iron is found in foods of vegetable origin, and is less absorbed than heme iron (Mogensen, 2001; McManus and Newton, 2011).

Benefits for the human body

Iron mainly contributes to oxygen transportation. Heme iron is part of the hemoglobin complex, a red blood cell metalloprotein responsible for oxygen transport (McManus and Newton, 2011). Thus, iron is essential to the metabolism and provides energy to the body by carrying oxygen from lungs to the tissues.

The other benefits of iron include roles in immunity, healing, energy and growth. Iron is an essential element for the ribonucleoide reductase function. This enzyme takes part in the immune system against infections and is involved in DNA synthesis and replication when stimulated by a pathogen (WHO, 2001; FAO/WHO, 2004). For instance, it enables phagocytosis and killing of bacteria by leukocytes (FAO/WHO, 2004).

Cytochromes called hemeproteins are enzymes dependent upon iron. They are involved in oxidative metabolism and are responsible for energy transfer. This process involves oxidoreduction chemical reaction leading to conversion between Fe^{2+} (reduced) and Fe^{3+}(oxidized) states of iron. These electrons transfer occurs within cell membranes and mitochondria (FAO/WHO, 2004; McManus and Newton, 2011). Other cytochromes are also involved in steroid hormone synthesis, responsible for growth and development (FAO/WHO, 2004). This was demonstrated by supplementation in iron-deficient children resulting in improved growth of these children (WHO, 2001).

Risk in case of deficiency

Iron deficiency is related to problems in growth as well as in cognitive and immune system impairments in children along with serious impacts on the health of pregnant women. Iron deficiency is the result of a long-term negative iron balance (WHO, 2001). It has been described as the most common disorder in Cambodia, affecting more than 70% of pregnant women and 74% of children under 5 years (Roos *et al.*, 2007 d). This deficiency is related to a low concentration of ferritin in serum (<15mg/liter) and has several important effects on the human body. Adverse effects on human health also include a higher prevalence of infections, impairments of gastrointestinal functions and a decrease thyroidal hormones production (WHO, 2001). Thus, it leads to neurological and muscular dysfunctions and varying body temperatures (WHO, 2001). In children, iron deficiency is related to retarded growth and cognitive development (Roos *et al.*, 2007 d), less attention, memory and learning capacities (FAO/WHO, 2004) due to altered neurotransmitters (WHO, 2001). In fact, some parts of the brain contain high concentrations of iron, comparable to those in the liver. It has also been shown in rats that iron deficiency irreversibly damages brain cells (FAO/WHO, 2004). Iron deficiency in pregnant women can also have serious impacts on health such as increasing mother morbidity, infant loss and prematurity (WHO, 2001).

The most severe stage of iron deficiency is anemia, linked to 40% of perinatal maternal deaths as well as muscle dystrophy and heavy-metal poisoning (WHO, 2001). This disease is defined as a hemoglobin concentration <95% of healthy references of hemoglobin concentration (FAO/WHO, 2004). This long-term iron deficiency may also reduce physical working capacity as the body runs out of sources of iron and uses energy from muscle tissue (FAO/WHO, 2004). This is the abnormal condition that affects muscle fibers and leads to muscle atrophy. Iron deficiency may also be related to heavy-metal poisoning by toxic metals such as lead and cadmium. This was observed in children as their total metal absorption capacity from the diet increases to balance the deficiency but this capacity is not only specific to iron (WHO, 2001). Thus, they also absorb other heavy metals.

Dietary requirements

Women and children require more iron than men. Children's needs are very important due to their growth (Mogensen, 2001). Moreover, women have to balance menstrual losses as it was shown that the mean menstrual iron loss is about 0.56 mg every day (WHO/FAO, 2004). Women during pregnancy or lactation period also have to compensate fetus and placenta growth and milk production (Mogensen, 2001). During the birth process, women lose on average 250 mg iron (FAO/WHO, 2004). Thus, in countries where weddings happen early, special attention must be given to pregnancy in adolescents because young mothers also require iron to cover their own growth needs.

Fish consumption has an important impact on daily iron intake (Table 4). For instance, traditional sour soup made with the Mekong flying barb (*Esomus longimanus*, known as *trey changwa plieng* in Khmer) covers 45% of the daily iron requirement for women and children (Roos *et al.*, 2007 d). However, iron in the fish is concentrated in the head and viscera and thus is dependent upon processing and cooking habits (Kawarazuka and Béné, 2010).

Table 4: Iron, non-heme iron and heme iron content in fish and other aquatic animals.
Source: Mogensen, 2001

Species	Heme iron mg/100g	Non-heme iron mg/100g	Total iron mg/100g
Whisker's sheat fish	0.2	0.3	0.6
Snakehead	0.5	0.2	0.7
Striped croaking gourami	0.5	0.3	0.7
Blue danio	0.5	0.4	0.9
Spiny eel	0.6	0.5	1
Catfish	0.7	0.6	1.3
Frog	0.7	0.7	1.4
Climbing perch	1.1	0.6	1.7
Shrimp	0.8	0.9	1.7
Juvenile blue danio	2.2	1.7	3.8
Juvenile climbing perch	5	4.1	9.2
Big crab	11	7.2	18.2
Small crab	30.1	7.4	37.5

In this table, it has been shown that almost all species contain more heme- than non-heme iron representing between 42 and 80% of total iron. Thus, on the nutritional side of iron intake, crabs, climbing perch, and catfish are among the most interesting species.

Iron absorption is reduced by rice consumption. Cambodian diet is rich in rice; this cereal contains a high concentration of phytate, which is the most important inhibitor of non-heme iron availability, heme iron is less influenced by inhibitory factors (Mogensen, 2001). Thus, the Cambodian diet is based on a wrong combination of food.

However, iron absorption may be improved by the "meat factor" induced by fish and the consumption of Vitamin A. When heme and non-heme iron are ingested, they are more easily absorbed when food intake also includes meat (Mogensen, 2001). Although this effect has not been studied enough yet, it is has been shown that iron absorption was more efficient with meat from fish than from beef (Mogensen, 2001). Vitamin A also shown a positive effect on non-heme iron absorption and it has been suggested that it might inhibit phytate actions (Mogensen, 2001).

4.1.2 Vitamin A

Vitamin A is an essential fat-soluble nutrient (Ahmed, 1998; Michaelsen *et al.*, 2011). In the body, it includes preformed biologically-active Vitamin A (retinol, retinoic acid) and pro Vitamin A carotenoids (McLaren and Frigg, 2001; Michaelsen *et al.*, 2011).

Benefits for the human body

Vitamin A is responsible of many functions, in particular vision. Vitamin A is mostly involved in the visual system. In the rod cells of the retina, retinal is composed of Vitamin A and generates nerve impulse after being stimulated by light. Thus, in case of deficiency, as the retinal supply is too small, rod function may be affected and the vision impaired (McLaren and Frigg, 2001). This substance also acts in favor of reproduction, growth, epithelial cellular integrity, and immune functions (Ahmed, 1998, McLaren and Frigg, 2001). Among males, Vitamin A takes part in spermatogenesis whereas in women it prevents placental necrosis or fetal absorption and is involved in embryogenesis (McLaren and Frigg, 2001). Muscles and skeleton development also require Vitamin A, which favors cell differentiation.

Risk in case of deficiency

Vitamin A deficiency impairs eyesight. The first stage is xerophthalmia (inability to produce tears), followed by night blindness (McLaren and Frigg, 2001), which it can be reversible or not depending of the severity of the Vitamin A deficiency. In addition, subjects with xerophthalmia also suffer from corneal scars (McLaren and Frigg, 2001) (Figure 9). In Cambodia, 6.8% of lactating women and 8.4% of pregnant women suffer from night blindness (NIS *et al.*, 2011). Xerophtalmia can lead to blindness and often death (McLaren and Frigg, 2001; Thorseng, 2007). In developing countries, more than 50% of children with xerophtalmia die and the rest remain blind (HKI, 1998).

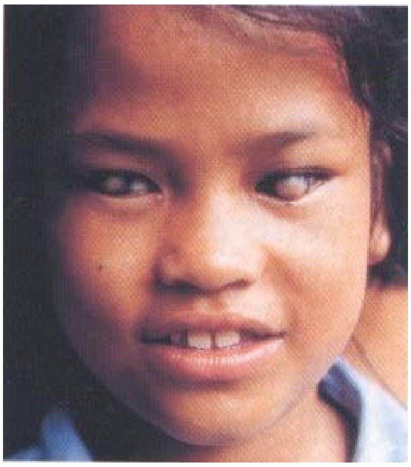

Figure 9: Child suffering from corneal scars caused by Vitamin A deficiency
Source: www.ssc.education.ed.ac.uk

Vitamin A deficiency is also associated with measles, diarrhea, and malaria. Vitamin A deficiency is associated with 20% of measles-related mortality among children (Rice *et al.*, 2005). Fatal consequences are seen where malnutrition is common, and that it is especially influenced by Vitamin A deficiency (McLaren and Frigg, 2001; Rice *et al.*, 2005). Vitamin A deficiency is not directly related to diarrhea mortality. However, it has an impact on the severity of the problem, especially in terms of duration of the symptoms (Rice *et al.*, 2005). Among children, 24% of individuals dying of diarrhea also suffered from Vitamin A deficiency (Rice *et al.*, 2005). Vitamin A deficiency is also associated with 20% of malaria incidence and mortality among children (Rice *et al.*, 2005). Vitamin A supplementation may reduce the incidence and the severity of malaria illness (Rice *et al.*, 2005). Among childbearing women, Vitamin A deficiency may decrease the breast milk concentration and increase both morbidity and mortality during pregnancy (HKI, 1998). Other consequences of Vitamin A deficiency are congenital malformation during embryogenesis, low growth, impaired immune response and higher rates of infections as epithelial tissues are more vulnerable to pathogens (McLaren and Frigg, 2001).

Vitamin A deficiency is a global health problem. Vitamin A deficiency is a serious public health problem worldwide, especially in Africa and Southeast Asia (Lee *et al.*, 2008). Children, because of their growth spurt, and pregnant or lactating women are more likely to lack Vitamin A (McLaren and Frigg, 2001). Vitamin A intakes in Cambodia are low, and Vitamin A deficiency is also a major health problem in the country (Mogensen, 2001).

Dietary requirements

Fish is the main source of bioavailable Vitamin A in the Cambodian diet. Carotenoids are found in yellow, red and brown pigments of vegetables, but preformed Vitamin A is found only in animal source foods (McLaren and Frigg, 2001, Michaelsen *et al.*, 2011) and has a better bioavailability than carotenoids (McManus and Newton, 2011; Mogensen, 2001). In most developing countries, vegetables and fruits make up to 70-90% of the Vitamin A dietary intake. However, in the Cambodian diet, it accounts for less than 20% (Mogensen, 2001). It is actually fish and other aquatic animals that are the main contributors to the Vitamin A intake in the country (Mogensen, 2001).

Small fishes integrally eaten provide a high proportion of Vitamin A. Vitamin A can be found in small fishes eaten with their bones, especially their eyes and viscera (Kawarazuka, 2010) (Figure 10) because Vitamin A is stocked in their liver (McLaren and Frigg, 2001). Some species are twice as concentrated in Vitamin A than carrot or spinach (Kawarazuka, 2010), and fish liver oils are much more concentrated in preformed Vitamin A than any other food item (McLaren and Frigg, 2001). In Cambodia, two species have been identified for their high Vitamin A content: the small carp *Parachela siamensis* (*trey chanteas phluk* in Khmer) and yellowtail rasbora (*Rasbora tornieri*; or *trey changwa mool*), with more than 1 500 µg/100 g (Roos *et al.*, 2007 c). Fish cooked with leafy vegetables and vegetable oil could enhance absorption (Kawarazuka, 2010).

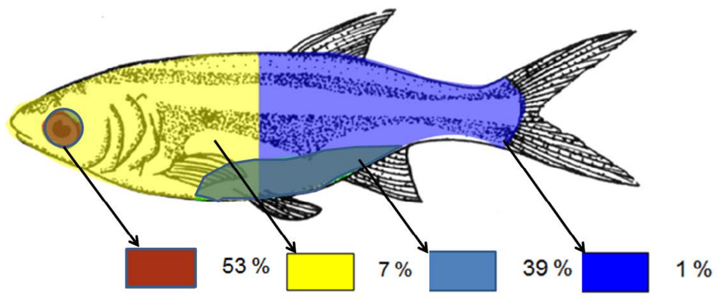

Figure 10: Percentage distribution of Vitamin A in *Amblypharyngodon mola.*
Source: Thilsted, 2010, from Roos *et al.*, 2007a

Vitamin A supplementation has been proposed as the cheapest and most effective way to reduce mortality in developing countries, especially among children under five (McLaren and Frigg, 2001). In addition to xerophthalmia-related mortality, Vitamin A supplementation would reduce postpartum infection, mothers' mortality and meningococcal disease, and may even prevent HIV transfer from mother to child (McLaren and Frigg, 2001).

4.1.3 Zinc

Zinc is an essential metal involved in more than 300 metabolic functions all over the body. In the human body, zinc is present in all biologic systems such as organs, tissues, fluids or secretions, and reaches a concentration of 30 mg/kg of tissue in fat-free mass (Hotz and Brown, 2004). Zinc can't be stored by humans (WHO/FAO, 2004) and its daily requirements are high.

Benefits for the human body

Zinc is essential to human health and is involved in multiple functions and compounds. Zinc is involved in catalytic, structural, and cellular regulatory functions. At least 300 catalytic reactions are enabled by zinc (FAO/WHO, 2004); this element is an electron acceptor (Hotz and Brown, 2004) and is found in all six enzyme classes: oxidoreductases, transferases, hydrolases, lysases, isomerases, and ligases (Vallee and Falchuk, 1993). These catalytic reactions are involved in the metabolism of nutrients and micronutrients (WHO/FAO, 2004). Enzymes lose activity if the catalytic site doesn't have enough zinc (Hotz and Brown, 2004). In addition, zinc is involved in folding of proteins into three-dimensional configurations, which are responsible for their biologic activity (Hotz and Brown, 2004). This essential mineral also contributes to cell and organ integrity, as it stabilizes the molecular structure of cellular components and membranes (WHO/FAO, 2004).

Zinc plays an important role in growth. This metal is involved in bone metabolism (Michaelsen *et al.*, 2009) as it is concentrated in skeletal muscle. Its proportion in this tissue represents 60% of the total body content and bone mass (WHO/FAO, 2004). Secondly, it is often considered as a limiting growth nutrient (Michaelsen *et al.*, 2009) as growth is related to DNA replication, RNA transcription, endocrine function and metabolic pathways which are dependent of enzymatic reactions (Hotz and Brown, 2004). Zinc is also involved in genetic expression and other regulatory functions such as programmed cell death, known as apoptosisand synaptic signaling, when neurons pass electrical or chemical signals to other neurons or cells (Hotz and Brown, 2004).

Zinc also plays an important role in immune competence, and affects cellular and humoral immunity in both specific and non-specific immune function (WHO/FAO, 2004). Zinc affects the epithelial barrier's integrity and enhances white blood cell function and cytokine production (Hotz and Brown, 2004). These effects are related to glucocorticoids release, a decreased thymulin activity (Hotz and Brown, 2004) and antioxidant properties (Michaelsen *et al.*, 2009). Zinc supplementation may boost immune function and help combating infections.

Risk in case of deficiency

Zinc deficiency is dangerous and its expression depends on age. Zinc deficiency is not expressed in the same way depending on the age of patients. Up to 2 months, it has been shown that infants lacking zinc may suffer from diarrhea (Hotz and Brown, 2004) and reduced diarrheal morbidity was observed when children had zinc supplementation. Later on, children's neuro-behavioral function can be affected by zinc deficiency. Children may subsequently present cognitive function and memory impairments, behavioral problems and neuronal atrophy (Penland, 2000). In addition, skin, gastrointestinal and hair-loss problems have been observed (Van Wouwe, 1989). In school-aged children, conjunctivitis, growth retardation and recurrent infections may happen (Hotz and Brown, 2004) as well as delayed sexual maturation (WHO/FAO, 2004). The positive role of zinc supplementation in relation to respiratory infections was illustrated by a study in India, Jamaica, Peru and Vietnam: the incidence of pneumonia was reduced by 41% when children were supplemented with zinc. At a later age, elderly people may also suffer from zinc-deficiency related pathologies such as chronic non-healing leg ulcers and recurrent infections (Hotz and Brown, 2004).

A CONSEQUENCE OF ZINC DEFICIENCY

Acrodermatitis enteropathica is an inborn error of metabolism which results in zinc malabsorption and severe zinc deficiency. This skin disease is characterized by erythematous patches usually around the mouth, scalp, hands, feet and anus. These lesions may be infected by bacteria, lead to hair loss, diarrhea and be fatal. As patients' zinc concentration in urine, serum and hair are hals of normal levels, this disease has to be treated by dietary zinc supplementation (Van Wouwe, 1989).

Source: www.dermaamin.com

Dietary requirements

Small fish species fully consumed are rich in zinc. A number of small fish species are very rich in zinc (Thilsted, 2012). For instance, the Mekong flying barb (*Esomus longimanus; trey changwa plieng*) in Cambodia (Figure 11) is cheap and consumed by poor people (Roos *et al.*, 2007 b). In general, zinc bioavailability is maximal in aquatic animals (fish and seafood) (McManus and Newton, 2011).

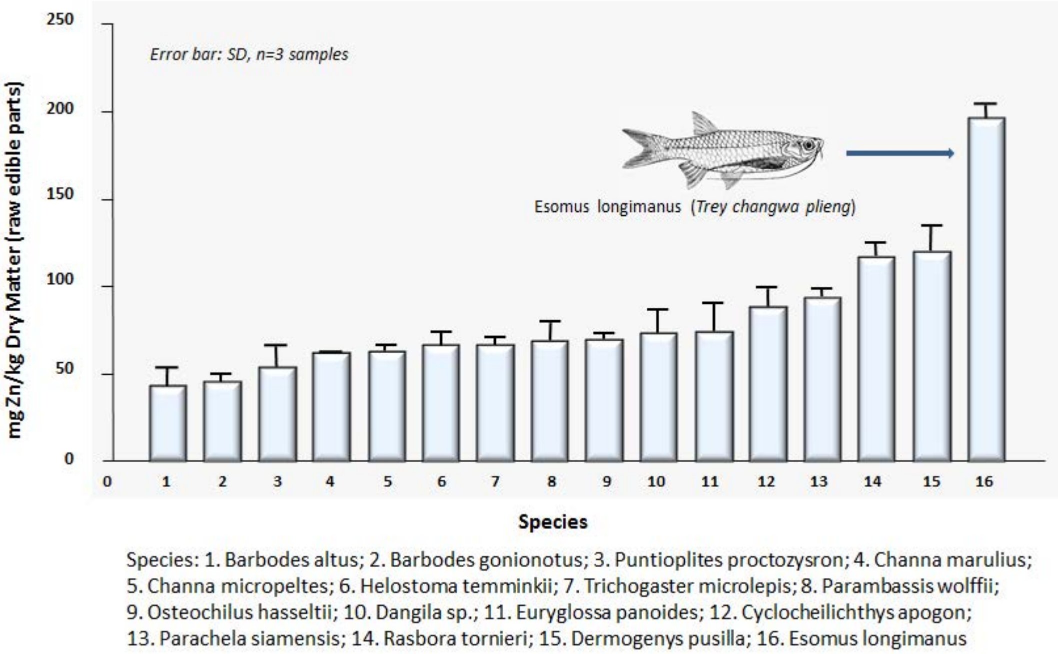

Figure 11: Zinc content in common Cambodian fish species (WorldFish). Source: Thilsted 2010

However, zinc bioavailability is reduced by rice consumption. Rice contains inhibitors of zinc absorption such as phytic acid (Kawarazuka, 2010). In Cambodia, the diet is low in zinc availability because of the consumption of rice. Children, pregnant women and elderly people are more at risk of zinc deficiency. The daily requirement for women in the third semester of pregnancy and during lactation represents more than twice the daily requirement for women who are not pregnant (FAO/WHO, 2004). Elderly people who have a lower absorptive efficiency also need a higher intake (Michaelsen *et al.*, 2009).

4.1.4 Calcium

Calcium is an essential mineral for the body and its skeleton. Calcium is involved in neuromuscular functions (especially the heart), blood clotting, most metabolic processes and above all in the skeleton's rigidity (FAO/WHO, 2004).

In Cambodia, fish is the most important source of calcium since dairy products are little consumed outside urban areas. Calcium consumption varies a lot depending on countries; in developing countries, especially in Asia, calcium intakes are the lowest observed (FAO/WHO, 2004). This is explained by a very small consumption of dairy products (Mogensen, 2001; Kawarazuka, 2010). Many small indigenous species fully consumed (i.e. with bones) are a rich source of calcium that balance the limited calcium input through dairy products (Roos *et al.*, 2007 c). Small fish constitute up to 86% of the total calcium intake from fish and other aquatic animals (Mogensen, 2001) as large bones from large fishes are not eaten. A study led on humans and rats has shown that the bioavailability of calcium from the bones of whole small fish is as high as that from milk (Hansen *et al.*, 1998; Larsen *et al.*, 2000; Figure 12). A survey in Bangladesh has shown that puti (*Puntius ticto*) and chanda (*Chanda ranga*) consumption provides >800 mg/100 g of edible parts, i.e. eight times more calcium than milk (Hansen *et al.*, 1998; Larsen *et al.*, 2000).

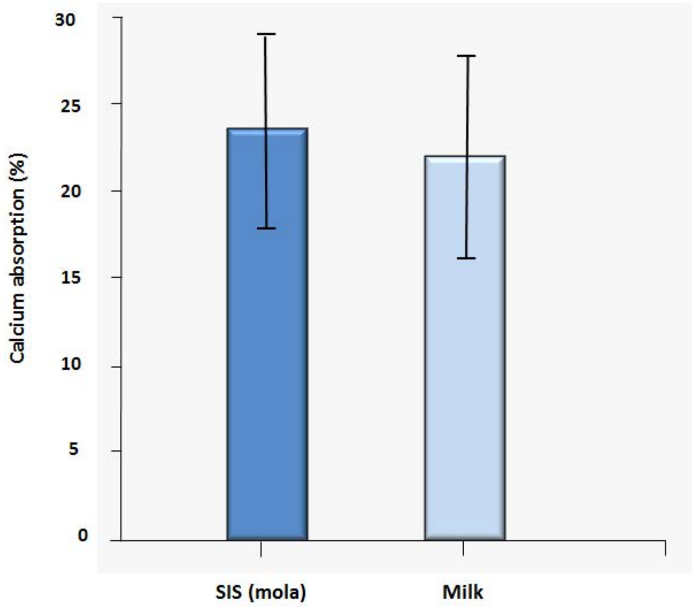

Figure 12: Calcium absorption from small fish and from milk. Source: Thilsted *et al.*, 2010

Benefits for the human body

In the human body, calcium is incorporated into collagen fibrils of the skeleton by a form of calcium phosphate [$CaHPO^4$] (FAO/WHO, 2004). However, a constant concentration of ionized calcium is needed to enable calcium to play its non-structural roles. In fact, if the supply of calcium falls short of requirement, resorption will occur and the skeleton and teeth will be at risk (FAO/WHO, 2004).

Risk in case of deficiency

Calcium is stored in bones, thus deficiency leads to decalcification and affects the skeleton. Calcium deficiency in Cambodia is not a major problem (Mogensen, 2001). However, in case of deficiency, the most common illness observed is osteoporosis (WHO/FAO, 2004). This disease is characterized by a low bone density (Figure 13) and is mostly due to the extra urinary calcium lost by post-menopausal women. Osteoporosis happens when the formation of new bone can't compensate the resorption of existing calcified tissues. In case of osteoporosis, bone loss is about 0.5–1.0% per year (WHO/FAO, 2004) and increases the risk of fragility fractures (McManus and Newton, 2011).

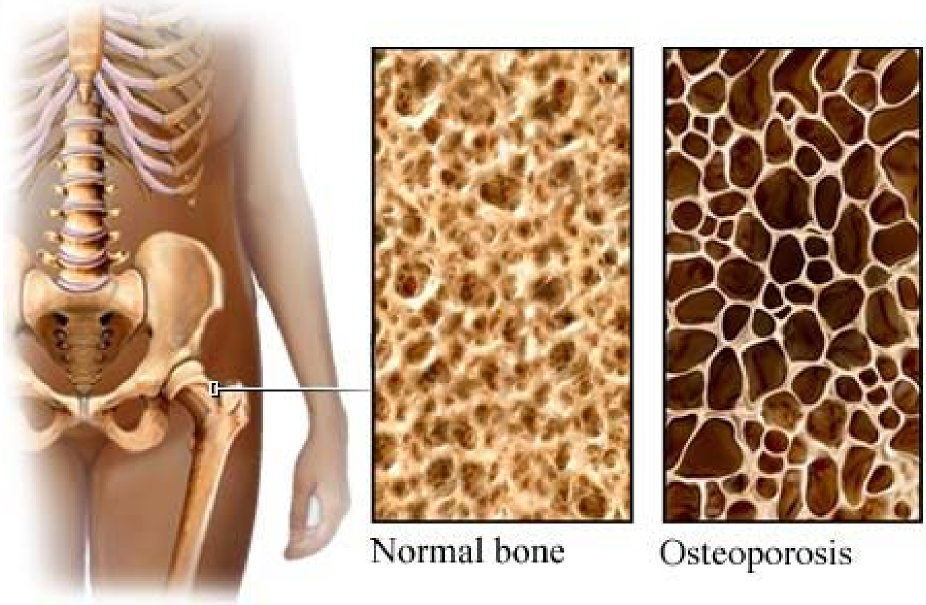

Figure 13 : Normal bone and osteoporosis. Source: www.theosteoporosiscenter.com

Children's teeth in rural Cambodia are in poor condition because of calcium deficiency, but also due to poor oral hygiene and health (Chu *et al.*, 2008). In pregnant women with low intake, calcium deficiency also leads to hypertension, pre-term birth and pre-eclampsia (Hofmeyr, 2011). The latter is a disease that can occur after 20 weeks gestation and leads to proteinuria (an excess of proteins in the urine), oedema and finally to maternal or fetal death (Idogun, 2007). A reduced risk of these pathologies was observed when women were supplemented in calcium (Idogun, 2007; Hofmeyr, 2011). Thus, infants, children, adolescents, childbearing women and elderly people are the groups most exposed to the consequences of calcium deficiency.

Dietary requirements

Calcium absorption is influenced by several physiological factors. Fibers and phytate inhibit calcium absorption and, depending on the Vitamin D and hormone status, bioavailability of the mineral may vary (Mogensen, 2001). Although staple food contains phytate, the exposure to sunlight in Cambodia may guarantee a good Vitamin D status. Thus, calcium availability is considered high (Mogensen, 2001). Women and men from 18 to 65 should consume 1 000 mg/day; however, pregnant and lactating women need more, with a requirement reaching 1 200 mg/day (FAO/WHO, 2004). Calcium absorption decreases after 65 years and for women after menopause urinary calcium increases. These two different mechanisms lead to a loss of calcium requiring a daily intake of 1 300 mg/day (FAO/WHO, 2004).

4.1.5 Iodine

Dietary iodine is an inorganic salt form of iodine (Zicker and Schoenherr, 2012). In most diets, iodine status may be improved by seafood consumption, especially shellfish and fish (Gunnarsdottir *et al*., 2010; McManus and Newton, 2011) (Table 5). Iodine content of plants is generally low, as it reflects often poor concentration of iodine in the soil. However, it is possible to combat deficiency by consuming iodized salt (Michaelsen *et al.*, 2009). After absorption, iodine enters the thyroid through the sodium-iodine symporter (NIS *et al.*, 2011). This active transport protein is part of the thyroid gland and especially of its follicular cells (Zicker and Schoenherr, 2012). Seventy to eighty percent of all the iodine in the body is found in the thyroid (Zicker and Schoenherr, 2012).

Table 5: Iodine content in food types Source: Zicker and Schoenherr, 2012

Species	Content (µg/kg)
Marine fish	1455.9
Freshwater fish	102.8
Leafy vegetables	88.8
Other vegetables	80.1
Meat	68.4
Cereals	55.0
Fresh fruits	30.6
Water	6.4

Benefits for the human body

Iodine is a key component of thyroid hormones. Among vertebrates, the only known function of iodine is to form thyroid hormones (FAO/WHO, 2004). In the thyroid gland, iodine is covalently bound by the thyroperoxidase enzyme to tyrosine residues to create mono- and di-iodotyrosines (Esfandiari, 2010). The molecules created combine and become triiodothyronine (T3) and thyroxine (T4) **(Figure 14)**. T4 and T3 hormones are then released into the bloodstream, where they are involved in development, facilitate normal growth and multiple metabolism activities throughout life, especially during pregnancy and infancy (Michaelsen *et al.*, 2009; Esfandiari, 2010; McManus and Newton, 2011; Gunnarsdottir and Dahl, 2012; Zicker and Schoenherr, 2012).

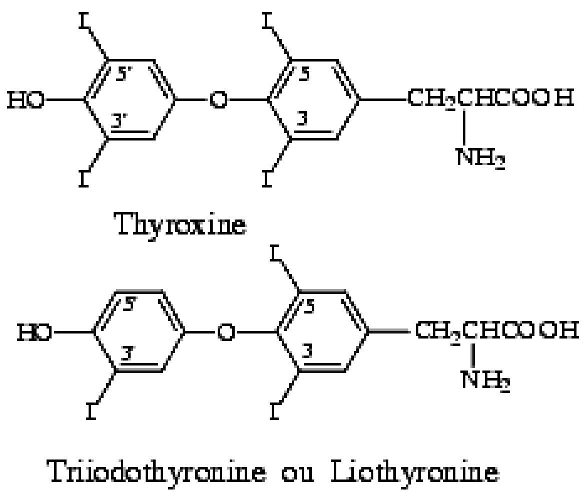

Figure 14 : Thyroxine T4 and triiodothyronine T3 hormones. Source: www.pharmacorama.com

Risk in case of deficiency

A lack of iodine can lead to different physical and mental pathologies (McManus and Newton, 2011). Physically, chronic iodine deficiency (i.e. less than 5 µg/day during months to years) can lead to goiter, a swelling of the neck resulting from an enlargement of the thyroid gland (Esfandiari, 2010; Zicker and Schoenherr, 2012) (Figure 15). Goiter is considered endemic when ≥10% of the population suffers from that pathology, usually due to a low content of iodine in soil and plants, and to a lack of diversified food items (McManus and Newton, 2011).

Poor iodine status also results in mild mental impairment. Cretinism is an irreversible mental retardation related to neonatal hypothyroidism or to congenital issues. Most of the time this disease is correlated to maternal deficiency during pregnancy (Michaelsen *et al.*, 2009; Esfandiari, 2010). However, young children may recover by iodine supplementation (Michaelsen *et al.*, 2009). Reproductive failure (Gunnarsdottir and Dahl, 2012), prenatal death and infant mortality (Michaelsen *et al.*, 2009), abnormalities of hearing, gait and posture and short stature (Esfandiari, 2010) can also be related to iodine deficiency.

Figure 15: Man suffering from goiter. Source: http://bugswong.smugmug.com

Dietary requirements

During pregnancy and especially during the lactating period, iodine is concentrated in mammary glands to feed the newborn. It is recommended that childbearing women get an iodine supplement from 50 µg/day to 150 mg/day (FAO/WHO, 2004; Esfandiari, 2010).

4.2 SECONDARY NUTRIENTS AND MICRONUTRIENTS FOUND IN FISH

Fish also contains other substances of interest that are not widely available in rural Cambodia.

4.2.1 Micronutrients

Micronutrients are fundamental nutrients for humans. They are required in small quantities and involved in physiological functions throughout life. This food group includes minerals and vitamins.

Minerals

Phosphorus

Phosphorus is part of phospholipids and thus is a component of cell membranes (Michaelsen *et al.*, 2009). This mineral is also part of the adenosine triphosphate (ATP), which is the essential form of energy in the body (Soetan *et al.*, 2010). Phosphorus, like calcium, is also involved in bone and teeth mineralization (Michaelsen *et al.*, 2009; Soetan *et al.*, 2010).

Fish, especially soft-boned fish eaten whole, is an excellent source of highly available phosphorus (Michaelsen *et al.*, 2009). Rice also contains phosphorus but the latter in the form of phytate, quite resistant to digestion and thus phosphorus absorption is minimal. Malnourished children are frequently suffering from hypophosphatemia (low phosphate levels in the body), which can lead to rickets-like bone changes and increases the risk of mortality (Michaelsen *et al.*, 2009). In adults, phosphorus deficiency may cause osteomalacia, a softening of the bones (Soetan *et al.*, 2010). Pregnancy and lactation don't affect the recommended intakes (DRI, 1997).

Potassium

Potassium is an essential mineral involved in all body cells. It has a very important role, together with sodium, in electrolyte regulation (Bellows and Moore, 2013; IFIC, 2011). In nerves, the sodium-potassium pump generates a gradient of ions building up a chemical and electrical gradient responsible. The latter allows the propagation of the nerve signal. Moreover, potassium is affecting muscle control, blood pressure and mineral balance (Bellows and Moore, 2013; IFIC, 2011). This mineral reduces the risk of cardiovascular diseases, especially thanks to its role in reducing hypertension (IFIC, 2011). In Cambodia, potassium deficiency is not common and mainly happens in case of excessive fluid loss (diarrhea) and low-calorie diets (Bellows and Moore, 2013). The symptoms include muscle cramps, loss of appetite, nausea, fatigue, and weakness (Bellows and Moore, 2013). Potassium deficiency among children has a negative influence on growth (Michaelsen *et al.*, 2009). Breastfeeding mothers should get an extra potassium intake (Bellows and Moore, 2013).

Selenium

Selenium cannot be synthetized by human tissues but is found in proteins from plant or animal source foods (DRI, 2000). This compound is abundant and readily available in fish (McManus and Newton, 2011). Selenium is an antioxidant preventing cellular damage and is also involved in thyroid regulation and immune functions (McManus and Newton, 2011). A deficiency may lead to illnesses such as Keshan disease, a cardiomyopathy which occurs only in selenium-deficient children, or Kashin-Beck disease, which affects cartilages among preadolescent or adolescent people especially in low-selenium areas of Asia (DRI, 2000). In populations endangered by methylmercury contamination, selenium also moderates the detrimental effects of mercury (McManus and Newton, 2011). A study of elderly consumers showed that selenium may also have a positive action against brain ageing (Berr *et al.*, 2009). Women require an extra in take after the third trimester of pregnancy and during the lactation period (FAO/WHO, 2004).

Vitamins

Vitamins are vital organic compounds needed by the organism in limited amounts that cannot be synthesized by the human body. These micronutrients help maintain optimal health; they have hormone-like regulatory functions, can be antioxydants or enzyme cofactors (Bellows and Moore, 2014).

Water-soluble vitamins

Water-soluble vitamins can't be stocked in the human body (Bellows and Moore, 2014). They are eliminated in urine and easily catabolized so the human body requires a daily supply (Bellows and Moore, 2014).

The Vitamin B-complex group

This group of vitamins is composed of eight vitamins that help the body to obtain energy from food (Bellows and Moore, 2014). They are especially important for normal appetite, skin, blood cell formation, nervous system, and eyesight (Bellows and Moore, 2014). In this report, we focus on vitamins B_6 and B_{12}, which are found in fish.

Vitamin B_6

Vitamin B_6, also known as pyridoxine, pyridoxal or pyridoxamine, is involved in protein metabolism for red blood cell formation and in insulin and hemoglobin synthesis (Bellows and Moore, 2014). A lack of Vitamin B_6 leads to several diseases such as skin problems, angular cheilitis (inflammation of the lips and mouth leading to cracks), kidney stones and nausea; it may also cause mental confusion in infants (Bellows and Moore, 2014). The recommended dietary intakes for Vitamin B_6 increase with age, and additional intake is required during pregnancy and lactation (FAO/WHO 2001).

Vitamin B_{12}

Vitamin B_{12} also known as cobalamin, has an important role in the brain and nervous system (McManus and Newton, 2011; Bellows and Moore, 2014) and is also involved in DNA, red blood cellssynthesis, and both fatty acid and amino acid metabolism.

In case of deficiency, individuals may suffer from neurological disorders such as dementia, depression and memory impairment (McManus and Newton, 2011) but also anemia and fatigue (Bellows and Moore, 2014). The population at risk is composed of people having a vegan diet, i.e. completely free of animal products (FAO/WHO, 2004). Fish and shellfish, especially clams, octopus and fish roe provide great amounts of vitamin B_{12} (McManus and Newton, 2011). Pregnant and lactating women should get an extra intake.

Fat-soluble vitamins

The fat-soluble vitamins group is composed of vitamins A, D, E, and K. They are dissolved in fat and thus stored in the liver (Bellows and Moore, 2014). This part of the report will focus on vitamins D, E and K since the case of Vitamin A has been detailed above.

Vitamin D

Fish and seafood are good sources of Vitamin D, which is concentrated in the marine food chain but can also be obtained from sunlight (McManus and Newton, 2011). Vitamin D status is considered good in Cambodia thanks to high sun exposure (Mogensen, 2001). Vitamin D allows calcium absorption and is involved in both calcium and phosphorus regulation in bones (e.g.: women consuming seafood have a higher bone density). Vitamin D is also involved in muscle strength and contraction, nerve conduction, cell differentiation, thyroid function, immunity, rennin and insulin production and skin condition (FAO/WHO, 2004; McManus and Newton, 2011). Vitamin D may also lower the risk of some cancers and cure skin diseases such as psoriasis.

In case of deficiency, growth retardation, rickets and a higher risk of tuberculosis are observed (Mogensen, 2001). Estimating recommended dietary intakes of Vitamin D is difficult and lacks precision as exposure to sunlight has to be considered.

Vitamin E

Vitamin E is found in fish in small quantity, with an average concentration of 12 µg/100 g (Murray and Burt, 2001). Vitamin E is an antioxidant group of 8 vitamins which are only found in the diet (FAO/WHO, 2004; McManus and Newton, 2011). Their main role in the body is to maintain skin integrity by protecting long chain polyunsaturated fatty acids, cholesterol (low density lipoprotein) and other components of cell membrane from oxidation (FAO/WHO, 2004). In addition, they protect Vitamins A and C from oxidation (Ekweagwu, 2008), and are involved in the nervous system, heart and circulatory system (McManus and Newton, 2011). Deficiencies lead to central nervous system impairments such as peripheral neuropathy that affects sensory neurons, spinocerebellar ataxia (a progressive, degenerative and often fatal neurodegenerative disorder), skeletal myopathy, and pigmented retinopathy (damage to the retina of the eye). The lack of Vitamin E also results in cardiovascular diseases, diabetes, and cataracts. Dietary requirements increase until 14 then remain stable until death even during pregnancy, but an extra allowance is recommended for lactating mothers (DRI 2000).

4.2.2 Others

Peptide derivatives

Carnosine and creatine

Carnosine is a proteic component derived from alanine and histidine (Boldyrev *et al.*, 2013) whereas creatine is a derivative of glycine, arginine and methionine. These two proteic components cannot be found in a vegetarian diet but are concentrated in muscles and brain tissues (Kohen *et al.*, 1988). Carnosine in less concentrated in fish than in meat. This peptide lowers the production of atherosclerotic plaque (Rashid *et al.*, 2007), has an antioxidant activity in the brain and muscles (Kohen *et al.*, 1988) and may even rejuvenate some senescent cells (Hipkiss, 2005). Creatine is also beneficial in the human body, as this peptide is involved in muscle contraction, provides energy to muscles cells and interacts with the adenosine triphosphate (Cooper *et al.*, 2012). The human body synthesizes half of its needs, the other half is provided by meat and fish intake.

4.3 CONCLUSION

The present review shows clearly that poor children and women are more vulnerable to morbidity and mortality caused by nutritional deficiencies. Fish consumption increases bioavailable nutrients and micronutrient absorption, which contribute to counter deficiencies. Iron, zinc, calcium, Vitamin A, iodine and secondary micronutrients provided by fish consumption are involved in reducing diseases and malnutrition. Thus, the role of fish supplementing the carbohydrate-based diet in Cambodia is not limited to its protein or omega-3 fatty acid high content but also contributes to public health and human well-being. However, malnutrition is still a scourge in the country and the following chapter will focus on elements that may explain this recurring problem.

5 WHY DO RURAL CAMBODIANS SUFFER FROM MALNUTRITION?

Food security has four major components: availability of food, access to food, quality or nutritional adequacy of food and utilization of food (Bose and Dey, 2007). The three main indicators of undernutrition are stunting (low height for age), wasting (low weight for height) and underweight individuals[1]. In this chapter, we review the factors maintaining high malnutrition rates in Cambodia and underline the fact that fish is not enough. We conclude with recommendations for future studies.

5.1 FOOD INSECURITY AND MALNUTRITION IN CAMBODIA

Fish substantially contributes to food security in Asia, providing quality proteins, essential fatty acid and combating micronutrients deficiencies (Kawarazuka and Béné, 2010). However, despite rapid economic growth and the central role of fish in the Cambodian diet, the population remains burdened by poor health and malnutrition; deficiencies in Vitamin A, iron, calcium, riboflavin, iodine and zinc deficiencies are especially widespread (Roos *et al.*, 2007c; SCN, 2004;).

In rural Cambodia, 5 to 15% of households can be considered food insecure, and about 30% of them report decreasing food consumption to cope with shocks (Nam So and Bunthang Touch, 2011; Mousset *et al.*, 2016). Between 2008 and 2012, severe underweight, moderate to severe stunting and wasting were respectively affecting 6.7%, 39.9% and 10.9% of the population whereas only 1.6% of the population was overweight (UNICEF, 2013).

At a national level, nutrition security, reflecting the nutritional deficiencies detailed above, is more a problem than food shortage (Results, 2014). The difficulty to access micronutrients of interest is caused by the combination of many different food and non-food factors which influence nutritional status (Haseen, 2010) and which are described below.

5.2 THE MULTIPLE CAUSES OF MALNUTRITION

5.2.1 Malnutrition, poverty and food affordability

Poor nutrition is often related to a lack of money (Wallace *et al.*, 2014), and fish catches are used for income generation instead of being consumed. Thus, a study in Lao PDR shows that poor villagers sell a higher percentage of their fish catch than wealthier ones (Garaway, 2005). The money earned is used to secure caloric intake from staple food (Kawarazuka, 2010), and food items are prioritized in

[1] Stunting refers to height-for-age (chronic malnutrition), wasting to weight-for-height (acute malnutrition) and underweight to weight-for-age (underweight). *"Stunting reflects long-term, cumulative effects of inadequate nutrition and health. Wasting represents the failure to receive adequate nutrition during the period immediately before the assessment or recent episodes of illness. Being underweight could mean that the child is stunted, wasted or both"***.** Source: HKI, 2002.

CHILDREN'S AND WOMEN'S UNDERNUTRITION IN RURAL CAMBODIA

The most nutritionally vulnerable population groups are i) pregnant and lactating women, whose bodies have to cope with infants or children needs, and ii) preschool-aged children (World Bank, 2008; Nam So and Bunthang Touch, 2011).

In poor Cambodian rural households, little more than rice is given to children, but deficiencies may often be invisible and lead to hidden hunger (Results, 2014). Malnutrition kills more than 6,400 children per year in Cambodia (UNICEF Australia, 2014) and school-aged children are the most energy deficient (IFReDI, 2013). Despite a general decrease over the past decades, among children under age 5 years old, 42% in rural areas and 28% in urban areas are stunted; it has also been estimated that 28% of children are underweight and 11% are wasting (NIS *et al.*, 2011). Furthermore 55% of them are anemic (Wallace *et al.*, 2014) particularly between 6 and 17 months as 80% of children suffer from anemia (NIS *et al.*, 2011).

A malnourished child. Source: UNICEF

Among women between 15 and 49 years old, 19% are too thin (NIS *et al.*, 2011). Their average energy intake is also low, and only 17% of women get their recommended intake (Wallace *et al.*, 2014). Food restrictions are common and tend to affect women's food security: 97% of them don't meet their daily-recommended nutrient intakes of iron in Kandal Province (Wallace *et al.*, 2014). Although the prevalence of anemia decreases slightly, more than 40% of women remain anemic (NIS *et al.*, 2011), with iron deficiency causing 30% of this anemia (Theary *et al.*, 2013). The vitamin A status is also low as prevalence of night-blindness is 8% among pregnant women (Onley, 2009). In Kandal, the daily recommended intake of Vitamin A is not met by 70% of these women (Wallace *et al.*, 2014).

relation to their cost (Wallace *et al.*, 2014). As a result, poorer households reduce their consumption of high-quality food such as meat, fruits and vegetables (Figure 16). Thus, nutritional status is affected by economic constraints resulting in daily meal reductions, smaller portion sizes and cheaper foods (Onley *et al.*, 2009; World Food Programme *et al.*, 2009). Children with poor nutritional status also often enroll in school later, and only a third of them go on to secondary school (Results, 2014), which reinforces the vicious circle.

Figure 16: Rural boy eating rice and one egg, because fish and vegetables were too expensive.
Source: C. Vilain, September 2014, Takeo Province, Cambodia.

5.2.2 Synergy between poor health and malnutrition

A negative synergy exists between poor nutritious status and infections, since the latter cause loss of appetite, gastrointestinal malabsorption of ingested nutrients, and metabolic wastage of available nutrients (Chen *et al.*, 1981). The highest prevalence of malnutrition in Southeast Asia is found in Cambodia (Andersen *et al.*, 2008) because of the high prevalence of infectious diseases such as diarrhea and and acute respiratory diseases such as pneumonia (Andersen *et al.*, 2008; Nam So and Bunthang Touch, 2011). Infestation by hookworm, whipworm and roundworm are also widespread in Cambodia; they are responsible for iron loss, which can cause anemia (WHO, 2001), and decreased Vitamin A absorption, leading to inflammation and diarrhea (Wallace *et al.*, 2014; FAO/WHO, 2004). In addition, a weakened immune system due to malnutrition doubles the risk to contract tuberculosis, and undernourished patients are more likely not to complete treatment (Results, 2014).

5.2.3 Malnutrition, beliefs and culture

Poor dietary intakes are also due to a lack of nutritional education and mistaken beliefs (Dyg 2006; Haseen, 2010; Wallace *et al.*, 2014). Poor people are often uninformed about conditions for a healthy lifestyle and risks in case of deficiencies, and religious fatalism can predominate over self-care (Grenier and Mitra, 1995). It is commonly believed in rural Cambodia that women should change their food habits during pregnancy (e.g. avoidance of “hot foods”) in a way that reduces nutritional diversity (Karim *et al.* 2002; Wallace *et al.* 2014). Pregnant women in conservative families also tend to “eat down”, i.e restrict their food intake, in order to have a small fetus and thus an easier delivery (Mogensen, 2001; Karim *et al.*, 2002). During breastfeeding, certain fish species are banned, and the nutritious fish paste is avoided (Wallace *et al.*, 2014). Furthermore, for cultural reasons, infants are not fed with the mother’s colostrum, which increases vulnerability to illness (Mogensen, 2001).

5.2.4 Rice and other malnutrition factors

Micronutrient absorption from fish can be inhibited by other foods, in particular rice. The combination of foods eaten together with fish is a determinant for bioavailability, as there are significant interactions between nutrient phytochemical compounds (Dyg, 2006). The strongest anti-nutritional factor of the Cambodian diet is phytate. This substance is found in high proportion in rice; it forms insoluble complexes with many nutrients and subsequently inhibits the absorption of proteins, iron, zinc, and calcium (Mogensen, 2001; Michaelsen *et al.*, 2009). Tannins found in tea inhibit the absorption of iron, which explains why only 30% of the iron consumption is bioavailable (Wallace *et al.* ,2014).

5.2.5 The role of processing and cooking in malnutrition

Even after processing or cooking, protein and fat are stable, whereas some micronutrients are sensitive to heat, sunlight or water (Kawarazuka, 2010); therefore, fish processing and cooking methods can affect the amount of micronutrients actually usable.

Processing methods lead to a loss of micronutrients especially Vitamin A. Fish and other aquatic animals are often processed to extend their consumption to the lean season (Kawarazuka, 2010). Processing includes drying, salting, smoking and fermentation (Michaelsen *et al.*, 2009). Sun-drying maintains the nutritional value for protein, fat and minerals (iron, zinc and calcium), but destroys nearly all Vitamin A (Roos *et al.*, 2007 c; Michaelsen *et al.*, 2009). Steaming and oven-drying result in the destruction of 50% of that Vitamin A. This vitamin is also largely lost by fermentation (Mogensen, 2001; Michaelsen *et al.*, 2009).

Micronutrients can be lost by cleaning or discarding. Before cooking, fish is cleaned (Figure 17) and head and guts are often removed for aesthetic, sapidity and minimal contamination reasons (Kawarazuka, 2010). However, head, viscera and bones are the parts of fish most concentrated in micronutrients. Thus, the calcium, iron and zinc content of the Mekong flying barb (*Esomus longimanus*, called *trey changwa plieng* in Khmer) is respectively 58, 25, and 53% more important in raw cleaned samples analyzed with the head intact, than in those with the head discarded (Roos *et al.*, 2007 b).

Figure 17 : Cleaning of fish. Source: C. Vilain, September 2014, Takeo Province, Cambodia.

Cooking methods affect the content of micronutrients in fish. Fishes are most often boiled in soups or fried (Figure 18). However, boiling affects the iron content of fish (Roos *et al.*, 2007 d) and frying decreases the concentration of fatty acids such as EPA and DHA (Thorseng, 2007; Chung *et al.*, 2008; Vannice and Rasmussen, 2014).

Figure 18 : Traditional fish soup. Source: C. Vilain, September 2014, Takeo Province, Cambodia.

5.2.6 The sex bias in malnutrition

In case of food scarcity in families, women and elderly people give up some of their food to men and older children who work more (Mogensen, 2001). A study focused on intra-family food distribution in Bangladesh showed that sex-biased attitudes cause higher female than male mortality rates, especially among children (Chen *et al.*, 1981). In Cambodia, males consume bigger daily portions (180.4 g) than females (166 g), but this may be related to the body weight, as this quantity accounts for 18 to 19% of total intake for both genders (IFReDI, 2013).

5.3 CONCLUSION

Despite record fish consumption, multiple nutritional requirements are not met in the Cambodian diet and malnutrition remains a public health problem as a result of both inadequate nutrition intake and unsatisfactory health, both factors related to human and environmental resources, economic systems and cultural factors (Nam So and Bunthang Touch, 2011). This particularly affects rural communities (Kawarazuka, 2010), and production for the household's own consumption is the most direct way to increase food intake and thus reinforce food security (World Bank, 2008). In this case, aquaculture and selection of highly nutritious and low production cost fish and other aquatic species should be encouraged (Amilhat *et al.*, 2005).

6 OVERALL CONCLUSION

This bibliographic review highlighted the benefits of fish consumption, especially in rural Cambodia. Fish as a good source of omega-3 fatty acids and micronutrients was described (Michaelsen *et al.*, 2009). The emphasis was put on bioavailable micronutrients, whereas nutritionists usually focus on macronutrients, energy and protein (Thilsted *et al.*, 2014). The roles of essential minerals such as calcium, iron, zinc or iodine and vitamins such as Vitamins A and D, but also secondary micronutrients, were highlighted and the risks in case of deficiency were detailed. Results show that smaller fish have higher mineral content than large fish and that they are consumed more often by rural groups. They also show that children and women are more sensitive to deficiencies.

As fish stocks globally decrease, innovative fish production technologies and other approaches to enhance the nutritional contribution of fish steadily increase (Roos *et al.*, 2006; Thilsted *et al.*, 2014). Small-scale farming and pond aquaculture show promising results in countries such as Bangladesh and Malawi (Roos *et al.*, 2006), and there is a growing interest in aquaculture and household production in Cambodia (Dyg, 2006). Highlighting the role of nutrient-dense small fishes like the Mekong flying barb (*Esomus longimanus*, called *trey changwa plieng* in Khmer) can contribute to improving nutritional status of individuals but also empowering women and communities (Iqbal *et al.*, 1998; Roos *et al.*, 2006).

The present review also highlighted the need for further studies, in particular about:

- bioavailability of micronutrients in fish;
- consequences of reduced fish supply on food and nutrition security;
- contribution of vegetal food other than rice to micronutrient intake;
- risks of food combination in terms of loss of micronutrients from fish;
- cooking and processing methods and their impact on fish nutrients and micronutrient content; and
- influence of climatic factors and climate change on fish consumption and nutrition.

The volatility in food prices today threatens the poor whose diet has become even less diversified and more dependent on starchy staples (Thilsted *et al.*, 2014). In that context, the challenge in Cambodia is to enable people to access nutritious food, to encourage diversity in the diet and strengthen health services in order to improve lower nutrition insecurity. Fish is an irreplaceable animal source in the Cambodian diet. However, this staple food alone is not able to ensure nutrition security in the population.

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