SPIRULINA AS A FOOD COMPLEMENT TO SUPPORT HEALTH AND COGNITIVE DEVELOPMENT

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INTRODUCTION

Brain development and cognitive abilities for the entire life are strongly determined by the nutritional status of both the child and his/her mother during the perinatal period. Micronutrients, proteins and essential fatty acids (EFA) are essential for the proper growth and structure of the brain as well as for the activity of multiple enzymes required in metabolic and signaling pathways. Malnutrition –that is, deficiencies in micronutrients- can be seen as a "silent hunger" in which cognitive development is affected. During gestation, breastfeeding and the two first years of life, particularly, certain nutrient deficiencies have dramatic effects on brain development (1,37). Nutrition clearly determines the future learning, working and thinking performance of children.

While we present a rapid review some of the scientific knowledge about the impact of nutrition on brain development and functioning, we remind some qualities of the microalgae *Spirulina*, very rich in nutrients that are essential for children growth and health. Because of the demonstration of the impact of malnutrition on brain functions, it could represent a minimal but necessary, potentially efficient food complement. In November 2005, the United Nations General Assembly recognized the merits of *Spirulina* productions and their "*potential to enhance food security in environmentally compatible ways"*, *"based on academic research and reports from the Food and Agriculture of the United Nations and the World Health Organization*". [1]

NUTRIENT DEFICIENCIES IN INDIA : SOME FIGURES

In India, the undernourished child population 0 – 6 years is estimated to be 85 millions. Officially, only 34 millions children are getting access to supplementary nutrition, but actual coverage is much less. In spite of the widely recognized hunger and malnutrition situation well documented trough an impressive documentation efforts, no action plan is giving priority to eliminate hunger or micronutrient deficiencies.

In Year 2000, Comptroller & Auditor General Report found one-fifth of rural households facing hunger and forty percent of all households did not get two square meals a day[2]. National Family Health Survey (NFHS-2) admitted that almost half of children under three years of age (47%) are underweight, and 46% are stunted. In India, the impact of calorie and protein supplementation has shown nearly no improvement for the BPL (below poverty line) population. Also, ICMR (Indian Council of Medical Research) published various studies related to micronutrients; particularly in three basic public health areas :

- The overall prevalence of anemia among pregnant women and children under 2 years is estimated to be over 80 %.
- Vitamin A status among children is estimated to be below 50% of RDA (recommended daily allowance) in most parts of the country.
- Iodine deficiency disorders (IDD) are indicated by a recent ICMR study (2001) with an average prevalence of 4.7%, but recent studies in Delhi slums indicate a prevalence of 23% and in Bombay slums prevalence was 56% with a visible goiter rate of 11%. In spite of positive declining trend in recent years, cretinism according to Ministry of Health and Family Welfare (2002) is still widespread in some Eastern district.[3]

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[*] ***abbreviations*** *: RDA : Recommended daily allowance; EFA : Essential fatty acids; BPL Below poverty line; IDD : Iodine deficiency disorders; IDA : Iron Deficiency Anemia; Hb : hemoglobin; DNA : Deoxyribonucleic acid; RNA : Ribonucleic acid; IDA : iron deficiency anemia; PEM : Protein-Energy Malnutrition*

[1] *Revised draft resolution* A./C.2/60/L.14/Rev.1

[2] *Right to food (Supreme Court Orders) Human Rights Law Network, New Delhi 2005.*

[3] *Indian Pediatrics, vol. 41, 2004.*

Various nutritional deficiencies like vitamin B, vitamin C, vitamin D are related to nutritional deprivation. For instance, children from 1 – 3 years would consume in most States less than 50% of the vitamin RDA. Other micronutrient deficiencies (Zinc, Folic Acid, etc.) are not sufficiently documented to express it with concrete figures, but they are recognized not to be adequate.[4]

According to the National Nutrition Monitoring Bureau (NNMB), slum children are the worst off in nutritional profiles. A National Nutrition Policy and a National Plan of Action (1995) have clearly defined the objectives to reduce the micronutrient deficiencies in children and lactating women. Unfortunately, 10 years later, the goals are not achieved.

Reduction of hunger and malnutrition needs a clear analysis of its causes. The available food in calorie resources in India are not only sufficient, but there is a huge export of 20 million tones of grain from India at almost BPL (below poverty line) prices. Figures from 2002 – 2003 show that the whole India midday meal scheme could almost be covered if this export grain would be allocated to the hungry children. We also have to mention the existence of the Public Distribution System, a unique facility to organize food security for the poorest BPL .
Unfortunately the scheme is not working properly what has been well documented in the Supreme Court Orders. Many States are refusing to distribute ration cards to urban destitute or to organize proper identification of the BPL families. This happens in spite of the Supreme Court Order, under the excuse of the difficulties to select and identify the BPL population.

NUTRITIONAL NEEDS FOR MENTAL DEVELOPMENT DURING LATE PREGNANCY AND THE FIRST TWO YEARS OF LIFE

During the last three months of gestation and early infancy, the brain is a site of high activity, where cells divide and differentiate into neurons and accessory cells. During this period of growth, proteins, lipids and energy supply is needed. Micronutrients, which serve as cofactors for many metabolic and signaling processes, are essential as well. These nutrients are normally brought prenatally by placental transfer to the fetus, and postnatally by breastfeeding.

IRON

It is to keep in mind that iron is always prioritized to red blood cells over any other organ, including the brain (2) : iron deficiency can be pathologic even before iron deficiency anemia (IDA). In other words, iron homeostasis mechanisms are made in a way which first, ensures production of red blood cells. Particularly, iron deficiency induces irreversible effects on the brain of children if occurring during pregnancy or the first year of life.

One of the most important feature of iron is its role in **energy utilization** in the respiratory chain of mitochondria. Studies in the rat model by De Ungria and colleagues demonstrated that iron deficiency was associated with a decreased energy metabolism in the hippocampus, a region involved in cognition and memory (3). This might explain the observations that iron deficiency in human neonates are associated with electrophysiological evidence of reduced recognition memory at birth (4). Second, iron is essential for **myelin production** because it is a co-factor for lipid biosynthesis. As a consequence, IDA has been shown to be associated with myelin defects and slower transmission trough the auditory and visual systems (5). This phenomenon is not reversible and persists despite treatment for IDA with iron supplementation. Finally, iron plays a role in the metabolism of monoamines, which constitute a group of **neurotransmitters** and neuromodulators, particularly dopamine (6).

In several studies, **iron** deficiencies and moderate anemia occurring during infancy were shown to affect cognitive performance at school. These studies were controlled for socio-economical background of children (7, 8). In addition, iron supplementation is not always able to revert the low cognitive abilities of those children : mental development seems to occur in a “window-period” during life, inside which damages can be irreversible.

One gram of *Spirulina* dry extracts contains about 0.6 to 1.8mg of iron (9). It is much more than the highest content found in cereals (max. 0.25mg/g). In addition, the bioavailability of iron from *Spirulina* has been shown to be high (10), as opposed to cereals, which

[4] *Micronutrient Profile of Indian Population, ICMR, Dr. Todeja, 2003 (?)*

contain high phytate levels, which have a negative effect on the intestinal assimilation of cations. With such characteristics, *Spirulina* is an excellent dietary source of iron.

Iodine

Iodine is necessary for the synthesis of thyroid hormones, themselves being involved in the proper development and functioning of the brain (11). Goiter is a compensatory hypertrophy of thyroid occurring in case of iodine deficiency. Hypothyroidism can also result from such a deficiency, and if occurring early in life, it first induces anorexia and constipations, and later on it induces cretinism, an irreversible form of mental retardation associated with growth retardation. Light to moderate iodine deficiencies can also induce mental impairments if occurring later in life.

Unfortunately, there is no detectable iodine in *Spirulina*. An adult roughly needs 200 μg of iodine per day, and slightly higher doses during pregnancy and lactation (250 μg). In contrast, iodine toxicity is very low, so that the World Health Organization considers daily intakes up to 1 mg as safe. About a billion humans suffer from iodine deficiency. China (300 million people), Latin America (200 million), and Africa and India (100 million) are the main regions where iodine is seriously lacking, as other regions in Europe or Indonesia. Main sources of iodine are seafood – mainly algae and fish (100 μg of iodine are brought by 100 mg of sea fish) - and salt supplemented with iodine.

Vitamin A

Vitamin A is a lipid-soluble vitamin whose precursor is pro-vitamin A, or β-carotene. Its most known characteristic is its role in vision. Vitamin A is the precursor of retinal, which is associated with visual pigments such as rhodopsin. Deficiencies in vitamin A have been first associated with associated with night blindness. Early symptoms are defects in adaptive night vision; if left untreated (by supplementation), symptoms of xerophtalmia appear : corneal opacity or necrosis, and total blindness.
If occurring early in pregnancy, vitamin A deficiencies can induce serious or lethal malformations, affecting the nervous system (*spina bifida*), the face or the limbs. Vitamin A plays also a role in the integrity of skin and the mucosa of the respiratory tract : vitamin A deficiencies induce detachment of the epithelium, and therefore a decrease in the capacity to eliminate respiratory mucus, the consequence of which being an increased susceptibility to infections.

Spirulina contains high levels of β-carotene (about a milligram per gram of Spirulina powder). It has been successfully used in a trial to treat children suffering from chronic vitamin A deficiencies : 1g of Spirulina per day reduced the incidence of visual symptoms on these children from 80% to 10% (38).

Zinc

Zinc is found in all human tissues but it is found at high concentrations in the brain. It is essential for the activity of a large number of metalloenzymes : the cellular functions are as wide as RNA and DNA synthesis, cellular growth, differentiation and metabolism. Early development –when cell activity is the highest- may be particularly sensitive to zinc deficiency. In some studies, it has been associated with reduced neuronal growth and brain volume. In addition, zinc deficiency has been shown to compromise activity, cognitive development and attention (12,15). In some studies, zinc levels have also been correlated with reading ability and academic performances. Finally, zinc supplementation studies have shown an effect on reasoning abilities … autres???? (12).

One gram of *Spirulina* contains about 0.02 to 0.04 mg of zinc. The absence of phytates in *Spirulina* allows a much higher availability of zinc. However, zinc levels brought by 10g of *Spirulina* remain much too low to reach recommended intakes (15 – 20 mg/day, WHO). Because of the almost ubiquitous role of zinc in biochemical processes, and in order to reach WHO recommendations, we currently develop zinc-enriched culture protocols in order to obtain *Spirulina* extracts containing 0.2 to 2 mg/g.

Other micronutrients

Vitamin B1 (thiamin) plays a role in aldehyde transfer. The typical syndrome associated with its deficiency is Beriberi, which includes weight loss, heart problems and neurological dysfunction. **B1, B2, B6, B12 vitamins** and **folic acid** have been shown to be needed for

the synthesis of several neurotransmitters (13). The only source of **vitamin B12** are animal products : infants breastfed by mothers who do not consume animal products, and people who do not consume them are at risk for vitamin B12 deficiencies. Vitamin B12 deficiencies typically induce pernicious anemia, but in addition, they have been associated with neurological defects. Studies on children with vitamin B12 deficiencies reported a slower perception, memory or reasoning, lower academic performance and delinquent behaviors (14,15). **Vitamin E** (α-tocopherol) is a fat-soluble vitamin. It is a strong anti-oxidant : it interacts and neutralizes reactive oxygen species such as hydroxyl radicals before they can oxidize unsaturated membrane lipids and damage cell structures. Therefore, vitamin E plays an essential role in maintaining cell integrity, a crucial parameter for neuron structure and function. Vitamin E deficiency can lead to night blindness (ref).

Table 1 : Approximate composition of various vitamins (mg) of Spirulina (dry extract) :

Vitamin	Amount (mg) per 10 g of Spirulina	Recommended intake per day (mg)
Vitamin B1	0.34 - 0.50	1.50
Vitamin B2	0.40	1.80
Vitamin B6	0.05 – 0.08	2.0
Vitamin B12	0.015 *	0.003
Niacin	1.3	20.0
Folate	0.005	0.4
Panthotenate	0.046 – 0.25	6 - 10
Biotin	0.0005	0.1 – 0.3
Vitamin E	0.5 – 1.9	12

ESSENTIAL FATTY ACIDS (EFA)

EFA are polyunsaturated fatty acids. Two groups exist : n-3 and n-6 families of EFA. Linolenic acid, the precursor of the n-3 family, gives rise to DHA (docosahexaenoic acid) while linoleic acid (LA) is the precursor of various types of n-6 fatty acids such as arachidonic acid (ARA). Both DHA and ARA are found in cell membranes, but their concentration is particularly high in the central nervous system.

The first degree of importance of EFA is that they affect the **structural composition** of neurons. In neuronal membranes, EFA affect membrane fluidity, membrane thickness, membrane microenvironment; they interact with membrane proteins, and n-3 deficiencies are associated with alterations in receptors, transport, and cellular interactions. For example, it has been shown that DHA supports the function of rhodopsin in vision, allowing a greater mobility of rhodopsin in the membrane bilayer (16). Animal studies showed that n-3 fatty acid deficiencies during pregnancy are accompanied by abnormal retinal responses to light in newborns (17,18). Restriction of n-3 fatty acid intake during the prenatal period have long-term effects on retinal fatty acid composition and function and can not be reversed by early n-3 fatty acid repletion (19). The importance of the integrity and physical properties of neuronal cell membranes (20) is also illustrated by learning and behavioral defects observed in animal studies of n-3 fatty acid dietary deficiencies (21). Second, n-3 and n-6 polyunsaturated fatty acids are involved in the differentiation of precursors cells into neurons. Third, the polyunsaturated fatty acid DHA can affect levels of various neurotransmitters, in specific regions of the brain (13). Dopamine, particularly, plays a role in cognition in early childhood as a modulator of attention and motivation, as well as in visual processes (22).

The best source of EFA for infants is breast milk. While the total EFA content is a parameter to consider to assess the quality of breast milk, another parameter is the ratio n-6 / n-3. FAO and WHO recommend this dietary ratio to be between 5/1 to 15/1. Therefore, the diet of pregnant and lactating mothers has to be sufficient both for n-3 and n-6 EFA, n-3 fatty acids usually being the limiting product. Communities should be informed about the importance of EFA in heath :

- Fat diets containing <u>both n-3 and n-6 EFA</u> are for example : breast milk, fish, soybean, linseed, sesame, canola oil.
- Fat diets containing <u>n-6 but no n-3 EFA</u> are : *Spirulina platensis* (40% of total fatty acids, about 3% of total weight in dry extracts (9)), corn, sunflower, safflower, olive oils, and seeds from other plants such as *Moringa oleifera*.

PROTEIN-ENERGY

* *however, there is still a controversy with regard to these high levels of vitamin B12 : within this amount, the fraction of active vitamin B12 is still under investigation.*

Protein-energy malnutrition (PEM) should be categorized as “undernutrition” rather than “malnutrition”. It is caused by insufficient intake of proteins and/or calories (lipids and carbohydrates). Roughly, two forms of PEM exist : marasmus, due to a deficiency in both proteins and calories intakes, and kwashiorkor, which results from a deficiency in proteins only. The psychomotor, cognitive and behavioral defects associated with kwashiorkor have been reviewed by Carol Thompson and Ernesto Pollitt (23) : “*apathy, irritability, anorexia, and withdrawal*”, while neurological symptoms are “*hypotonia, poorly developed motor skills, and occasionally, cortical and subcortical atrophy*”. Regarding the marasmic condition, behavioral and neurological data reflect “*a reduced activity, hypotonia, cortical atrophy, and reduced brain weight*”. In several studies, malnourished children have been found less responsive to environmental stimuli than children with normal weight; this has been attributed to a decreased attention. Rehabilitation from malnutrition could not attenuate this defect.

Spirulina is a food complement, which has to be added to regular meals in amounts varying from 1 to 5g. By itself, it can not bring the amount of proteins necessary for the development of children (estimated at about 10 to 15g per day in the first year of life), but it contains substantial amounts of essential amino acids. Dry weight of *Spirulina* is composed of about 60% of proteins, with small variations depending on culture conditions. This exceptional level of proteins is far above those found in other organisms. Most importantly, the quality of these proteins is complete, since all of the 20 amino acids –including “essential” amino acids, which mammals can not synthesize- are represented (table 2, (9)). An additional feature of proteins found in *Spirulina* is their high accessibility and ability to be digested and absorbed in the intestine. Finally, animal studies on weight gain using dietary *Spirulina* food demonstrated a high proteinic efficiency, with a mean value of 1.90 (9).

Table 2 : *Spirulina* essential amino acids content (mg) in 1 gram of extract. The percentage of child daily requirements covered by 1g of *Spirulina* are displayed.

Essential amino acids	*Spirulina* content , in mg per g	Percentage of requirements (child 0 – 12 months)	Percentage of requirements (child 1 - 5 years)
Histidin	1	0.3 – 0.5 %	0.1 – 0.3 %
Isoleucin	35	5 – 8 %	5 – 8 %
Leucin	54	3 – 5 %	1 – 3 %
Lysin	29	3 – 4 %	1 – 2 %
Methionin	14	2 – 4 %	1 – 2 %
Phenylalanin	28	2 – 3 %	1 – 2 %
Threonin	32	4 – 6 %	1 – 3 %
Tryptophan	9	5 – 8 %	2 – 5 %
Valin	40	4 – 7 %	2 – 4 %

Cognitive development and stunting of children : lessons from observational studies and supplementation trials

Single micronutrient deficiencies are associated with specific pathologies. However, it is well known that a deficiency in one single nutrient is rare in clinical practice : children usually suffer from multiple micronutrient deficiencies, one consequence of which being **stunting**. Stunting is a consequence of chronic malnutrition in early life either prenatally, postnatally, or both **SEULEMENT?? AUTRES RAISONS LIEES AU STUNTING??**. About a third of children in developing countries are stunted (24). They have smaller head size, poor neuromotor development manifesting as clumsiness or incoordination, lack of vigor and enthusiasm, poor scholastic performance and absenteeism in school (13). In a study realized on more than two thousands Filipino children in 1999, Mendez et al. have shown the negative consequences on malnutrition on cognition and schooling. Stunting between birth and the age of 2 years was chosen as the discrimination factor between children. Severe or moderate stunting resulted in lower scores in cognitive tests at ages 8 and 11, as compared to non-stunted children (25). It is to note that the timing of stunting also affected test scores, earlier stunting resulting in lower results.

In another study, Walker et al. (26) have shown that food supplementation (milk-based based formula) induced benefits on development in stunted children, but they have shown that this effect was not long-lasting up to 11 years of age. However, this study has highlighted the importance of **psychosocial stimulation** on cognition : the benefits brought by early social stimulation (designed to improve mother-child interactions) for stunted children have been shown to be long lasting, even without any food supplementation : at 17-18 years of age, children have caught up cognitive scores obtained by non-stunted children. From this study, the child’s environment appears as important as nutrition to allow an optimal development of children.

Infections and cognitive development

Biomedical research provided the evidence that both malnutrition and undernutrition are associated with an increased susceptibility to infections, as well as cancer, auto-immune and neurodegenerative diseases. The immune system needs a complete intake of nutrients to efficiently fight pathogens, undesirable cells or to distinguish correctly the “self” from the “non-self”.

Infectious diseases, themselves, have been linked to behavior and cognitive development. Several studies have demonstrated a positive correlation between cognition defects and malaria (27-29), cerebral meningitis (29), intestinal parasites (30), or HIV/AIDS (31,32). The two major reasons are a direct effect of these pathogenic events on brain functions, and school absenteeism due to sickness and recovering time. Given the importance of nutrition in the efficiency of the immune system in the fight against various pathogens, for which a number of reviews decrypt the underlying mechanisms (33), access to highly nutritive foods can help mental development of children by the reinforcement of immunity.

Food fortification with *Spirulina* as a response to chronic malnutrition : studies and evidences

In many countries, supplementation policies may have limited effects because populations suffer from several –sometimes many- deficiencies. They may also be inefficient if provided out of the “time window” of early brain development. Supplementation policies bringing several nutrients may have a better impact on health. Furthermore, given the impact of infectious diseases on mental and cognitive development of children (27-33), it is likely that micronutrient supplementation would further enable children’s cognition through a reinforcement of immunity. Finally, the study of Walker et al. (26) illustrates the need for strengthening physical and psychosocial stimulation of infants. This parameter has even been recently included into recommendations by the World Health Organization (WHO) (34). From the literature, the combination of enhanced stimulation and appropriate nutrition is expected to have a strong and long-lasting effect on children’s cognition and behavior.

In poor settings, complementation of traditional meals with the microalgae *Spirulina*, which contains high levels of essential micronutrients such as iron, vitamin A, B1 and B2, as well as macronutrients such as EFA and proteins, is a promising source for food fortification. Vitamin A and iron, associated together, may efficiently reduce the incidence of a large number of mental diseases –or disabilities- attributable to nutrient deficiencies. The presence of EFA in *Spirulina* is interesting, although n-3 fatty acids are lacking; other dietary sources of iodine (sea fish, sea algae) or n-3 fatty acids (fish, vegetable oils such as soybean, sesame, canola) need to be made available. Animal sources of nutrients (milk, meat) also contain large amounts of essential nutrients (iron, zinc, proteins) and should be made more available, in many countries where it is still lacking.

The complementation of meals with *Spirulina* could be a solid and cost-effective option to provide to the most vulnerable populations a solid basis of physical and mental health. In one of the projects started by *Antenna Technologies* in R.D.Congo, a mixture of 3 cereals mixed with *Spirulina*, water and sugar is currently provided to 2500 children suffering from mild or severe malnutrition. This meal, named SOSPISOMA (Sorghum, *Spirulina*, Soya, Corn), is more efficient to rehabilitate children than the meal provided without *Spirulina* complementation (Zaccharie Kasongo, personal communication). In Burkina Faso, Jacques Simpore *et al.* (35) have shown that daily supplementation with *Spirulina*, added to traditional for eight weeks, was efficient in rehabilitating undernourished children. Finally, the experience from our partners on the field is worth to report : Sr Valérie Kingombe from a dispensary in Goma/Himbi (RDC) reported that “*People living with HIV/AIDS are the first beneficiaries of* Spirulina *because they recovered physical strength due to an enhanced appetite” , “several people suffering from diabetes recovered their strength”, “a young patient suffering from tuberculosis became more healthy”.* These are some of the multiple evidences that we regularly collect, and which we aim to further validate in a scientific way.

Recommendations ; conclusion

Back to the situation in India, the disastrous burden of child malnutrition, undernutrition and low birth weight children will require time to be overcome. Even if all the States have enough food to provide to the BPL population, and particularly to children and lactating women, the political will to implement adequate schemes through a midday meal program is not demonstrated and is not operational. These are the main reasons why NGOs are urgently requested :

- to reduce the mass scale nutrition insecurity by asking the Union of India to ensure that the Supreme Court Orders are implemented.
- to act politically in obtaining adequate funds available from the States to combat child malnutrition.
- to improve status of children 0 –6 years by providing supplementary food and particularly micronutrients.
- to provide pregnant and lactating women with adequate food and micronutrients.
- to facilitate to all Anganwadi Centers (AWCS) access to *Spirulina*. Many of the Centers are not operational like in Bihar, Uttaar Pradesh, Jharkhand. Supreme Court gave the following directions to all State Governments/Union Territories :

According to the norms of Government of India, one Center AWCS should be provided for one thousand population. It seems that only 600,000 out of 1,400,000 have been sanctioned. The Order (August 2004) also directed the Government of India to revise the supply of nutritious food worth 1 rupee to 2 rupees per child per day. [5]

There is no point to recognize the importance of eliminating micronutrient malnutrition without promoting the evidence of optimal breastfeeding and infant feeding practices. Whatever micronutrient policy or health care system is implemented, breastfeeding practices has to be made integral part of all nutrition interventions.

The concept of these interventions – breastfeeding and improvement in nutritional status with micronutrient supply – should be community based. In India, we should use of the great advantage of achieving the distribution through existing services like ICDS and AWCS or mobile creches (ciiy working women on construction sites). Such centers should first be approached to include a balanced mix with *Spirulina*. These centers can also be a platform for nutrition education and demonstration. It needs qualified NGOs to collaborate in these nutrition training and pedagogy. We can not forget to mention the most difficult handicap to achieve such a role in slums : safe drinking water and the difficult improvement of environmental sanitation and hygiene.

We do not envisage *Spirulina* otherwise than as a food complement. In our programs it is added to traditional meals as a source of essential nutrients such as iron or vitamin A, which often lack in available food, even though populations often have “enough” to eat. Nonetheless, success against malnutrition not only depends on supplementation programs such as *Spirulina* production, but local autonomy and proper structural agriculture policies, as well. Strengths of *Spirulina*-based complementation programs are that first, *Spirulina* brings a “cocktail” of essential nutrients. Second, for several reasons, manly due to improvements of health and well-being, it is very well accepted by the populations. Third, *Spirulina* production can be local, needs a low-cost technology which necessitates warm temperatures and light, and therefore which is adapted to tropical countries. A minimum of knowledge is required to manage a production, whereas adaptations or improvements are possible.

Although the effects on cognition have not been investigated yet, we expect that consumption of *Spirulina*-enriched meals by young infants and pregnant/lactating mothers to 1- decrease the incidence of mental diseases due to severe micronutrients deficiencies 2- improve children’s performances at school 3- enhance cognition of adults as workers and citizen. While its positive effects on immunity and physical growth start to be well documented, clinical and scientific studies are necessary to further investigate the benefits of *Spirulina* on cognition.

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