THE NUTRITIONAL ASPECTS OF SPIRULINA

Jacques Falquet

Let your food be your medicine.

Hippocrates

Introduction

Spirulina - cyanobacteria has been used as food for centuries by different populations and only rediscovered in recent years. Once classified as the «blue-green algae», it does not strictly speaking belong to the algae, even though for convenience it continues to be referred too in that way. It grows naturally in the alkaline waters of lakes in warm regions. Measuring about 0.1mm across, it generally takes the form of tiny green filaments coiled in spirals of varying tightness and number, depending on the strain.

Its impressive protein content and its rapid growth in entirely mineral environments have attracted the attention of both researchers and industrialists alike.

As part of more detailed analyses, a number of features of particular interest from the nutritional standpoint have been demonstrated: a balanced protein composition, and the presence of rare essential lipids, numerous minerals and even Vitamin B12.

While the interest aroused by other microorganisms has faded due to problems of digestibility or of their acid content, *spirulina* seems to be one of the best solutions for the simple production of a high-quality food supplement. It should also be mentioned that the extreme conditions of salinity and pH in which *spirulina* develops ensure crop hygiene, for very few other microorganisms are capable of surviving in such conditions.

The aim of this paper is to give an overall view of the nutritional properties of *spirulina*. These properties are all the more important because the production of this microorganism is particularly suited to the climatic and economic conditions of regions where malnutrition is rife. Hence the work aimed at improving, testing and disseminating simple and reliable methods for the local production of *spirulina* (**5, 25, 36**).

1. Proteins

1.1 Quantities and composition

The protein content of *spirulina* varies between 50% and 70% of its dry weight. These levels are quite exceptional, even among microorganisms. Moreover, the best sources of vegetable protein achieve only half these levels; for example, soya flour contains “only” 35% crude protein.

However, the protein content varies by 10-15% according to the time of harvesting in relation to daylight. The highest values being obtained at early daylight (**3**).

From a qualitative point of view, *spirulina* proteins are complete, since all the essential amino acids are present, forming 47% of total protein weight (**10**). Among these essential amino acids, the most poorly represented are the sulphur-containing amino acids methionine and cysteine (**3, 10, 17**). Even so, they are present more than 80% of the ideal level defined by the Food and Agricultural Organisation (FAO), calculated on the basis of egg albumin and casein. It also appears that one of the drying methods used industrially - drying on hot drums - reduces methionine content by some 30% compared to spray drying by evaporation (**70**). Lysine is also slightly under-represented according to some authors (**54**), while others consider the level adequate (**17**).

This spectrum of amino acids shows that the biological value of proteins in *spirulina* is very high, and that an optimum product could be achieved by supplementation with a good

source of sulphur-containing amino acids and possibly also lysine and/or histidine. For example cereals such as rice, wheat and millet, or certain oilseeds such as sesame should be excellent supplements. It may be noted that the populations in Chad that eat *spirulina* use it with millet, which is particularly rich in methionine and cysteine (**42**).

1.2 Net protein utilisation (NPU)

The utilisation of ingested proteins is determined by digestibility, i.e. the proportion of protein nitrogen absorbed, and by the amino acid composition (together with other factors, such as age, sex, and the physiological status). The NPU value is determined experimentally by calculating the percentage of nitrogen retained, when the source of proteins under study is the only limiting nutritional factor. This value is generally studied in different situations for example: active growth, adulthood and convalescence. (**72**).

Unlike other microorganisms proposed as protein sources such as yeast (*Chlorella*, *Scenedesmu*s), *spirulina* cells do not have cellulose walls, but a relatively fragile envelope of murein (**3, 10, 13, 27**). This explains the very high digestibility of its proteins (83-90% in ordinary dried *spirulina*, as against 95.1% for pure casein) (**21, 60**).

Thus *spirulina* requires no cooking or special treatment to increase the availability of its proteins. This is a substantial advantage both for simplicity of production and for the preservation of highly valuable constituents such as Vitamins and polyunsaturated fatty acids (see below).

The NPU value of spiralina is estimated at between 53% and 61%, or 85-92% of that of casein (**15, 16, 60**).

1.3 Protein efficiency ratio (PER)

This is the weight gain of an individual, divided by the weight of proteins ingested. Measurements are usually made on growing rats. The reference proteins are lactalbumin or casein (**72**).

The PER value for *spirulina* determined in growing rats is estimated between 1.80 and 2.6 (**27, 60, 61**), as against a PER value for casein of 2.5.

The effect of cereal supplementation with *spirulina* has been estimated in rats, with the following result (**2**):

Table 1. Comparison of protein efficiency ratios, showing the benefit of supplementation

Diet	**Protein efficiency ratio**
Spirulina	1.90
Maize	1.23
Rice	2.20
Wheat	1.15
Rice + *spirulina* (3:1)	2.35
Rice + *spirulina* (1:1)	2.40
Wheat + *spirulina* (3:1)	1.42
Wheat + *spirulina* (1:1)	1.90
Maize + *spirulina* (3:1)	1.80
Maize + *spirulina* (1:1)	1.72
Maize + oats + *spirulina* (3:2:5)	1.90
Maize + rice + *spirulina* (2:2:1)	1.95

The growth rate of rats fed with *spirulina* as the only source of protein is higher than or equal to that of controls. Moreover, after supplementation with essential amino acids, rats fed with *spirulina*, for the same amount of metabolic energy, fix greater or equal quantities of protein as compared to controls. These results indicate good metabolic use of the amino acids in *spirulina*, which is confirmed by the levels of free amino acids found in the blood and muscle of test animals (**70**).

The few studies undertaken on humans tend to show results similar to those obtained with animals, though digestibility seems a little lower (**55, 61, 70**).

2. Lipids

2.1 Total lipids

While several publications (**10, 13, 23, 60**) indicate a lipid content of 5.6-7% of dry weight (in both *S. platensis* and *S. maxima*), other authors (**32**) claim to obtain more than 11% of lipids by using a better extraction system. These total lipids can be separated into a saponifiable fraction (83%) and a non-saponifiable fraction (17%), containing essentially paraffin, pigments, terpene alcohol and sterols (**10, 18, 60**).

The saponifiable fraction consists chiefly of monogalactosyl and digalactosyl diglycerides (23%), sulfoquinovosyl diglyceride (5%) and phosphatidyl glycerol (25.9%). Phosphatidyl choline, phosphatidyl ethanolamine and phosphatidyl inositol are not found in appreciable quantities. Triglycerides are sparse (0.3%). Undefined phospholipids account for a further 4.6%.

2.2 Fatty acids

Human requirements of essential fatty acids are considered to be 1-2% of energy intake for adults and 3% for children (**44, 53a**). It is now well established that essential lipid intake has an influence on the immune system, both humoral and cellular (**33**). Essential fatty acids are at present divided into two groups (omega-3 and omega-6) characterised by the position of the nearest unsaturated point in the terminal methyl group. As omega-3 and omega-6 acids are converted in humans into biochemical derivatives that seem to act as antagonists, some specialists recommend an omega-6/omega-3 ratio of between 4 and 5 (**53**). A detailed analysis of fatty acids in *spirulina* can be found in Hudson & Karis (**32**).

Table 2. Principal fatty acids in two strains of *spirulina*, *S. maxima* and *S. platensis* (**53**)

Distribution of fatty acids in two strains of *spirulina*		
Fatty acids	***Spirulina* maxima** (% of total fatty acids)	***Spirulina* platensis** (% of total fatty acids)
Palmitic (16:0)	63	25.8
Palmitoleic (16:1 omega-6)	2	3.8
Stearic (18:0)	1	1.7
Oleic (18:1 omega-6)	4	16.6
Linoleic (18:2 omega-6)	9	12
Gamma-linolenic (18:3 omega-6)	13	40.1
Alpha-linolenic (18:3 omega-3)	traces	traces

Gamma-linolenic acid represents only 10-20% of fatty acids in *S. maxima*, i.e. 1-2% of dry matter (**23, 32, 49**), compared to 40% in *S. platensis*, or some 4% of dry weight. Thus *spirulina* can be considered one of the best known source of gamma-linolenic acid, after human milk and some little used vegetable oils (evening primrose, borage, blackcurrant seed and particularly hemp oil) (**15**).

The presence of gamma-linolenic acid (18:3 omega-6) is worth stressing in view of its rarity in everyday foods and its presumed high nutrient value. Normally synthesised in humans from linoleic acid (18:2 omega-6) of vegetable origin, gamma-linolenic acid can nevertheless be beneficently directly assimilated even in cases of disorders or shortfall in endogenous synthesis (**44**). The importance of these fatty acids lie in their biochemical evolution: they are the precursors of the prostaglandins, leukotrienes and thromboxanes that serve as chemical mediators of inflammatory and immune reactions.

Other fatty acids are also present, such as linoleic acid (18:2 omega-6). Also noteworthy is the high proportion of palmitic acid (16:0), which forms more than 60% of lipids in *S. maxima*, but only about 25% in *S. platensis*. Table 2 brings out clearly the superiority of *S. platensis* as to lipid content: much less palmitic acid (saturated) and more gamma-linolenic acid (essential).

Sulfolipids such as the sulfoquinovosyl diglycerides (5% of the saponifiable fraction) are now the subject of new research. Following evidence that they are protective against HIV infection of T-helper cells (**28**).

Also worth noting is the absence of fatty acids with uneven carbon numbers (**18**) and the very low level of branched-chain fatty acids (**10**), two types of lipids that cannot be metabolized by higher animals. Lastly, *spirulina* has been recommended as a food supplement in cases of essential fatty acid deficiency (**32**).

2.3 Non-saponifiable lipids

2.3.1 Sterols

While some authors (**10**) stress the absence of sterols, it appears that these products represent 1.5% of the non-polar fraction of *S. maxima* lipids. However, no publication postulates a value for free sterols of more than 0.015% of the dry weight of *spirulina* (**18, 32, 60**). The sterols identified are cholesterol and, in smaller amounts, beta-sitosterol. *S. platensis* also contains small amounts of campesterol and stigmasterol. Some of these sterols could be linked to the antimicrobial activity of *spirulina* (**18**).

2.3.2 Terpenes

Terpene alcohol accounts for 5-10% of the non-saponifiable fraction; it is chiefly alpha- and beta-amyrine, a pentacyclic triterpene. In addition, *S. maxima* contains an unidentified saturated triterpene alcohol (**18**).

2.3.3 Saturated hydrocarbons (paraffins)

Long-chain saturated hydrocarbons represent a substantial fraction - 25% - of the non-saponifiable element in both *S. platensis* and *S. maxima* (**10**). Thus dry *spirulina* contains between 0.1% and 0.3% of saturated hydrocarbons.

Two-thirds of these hydrocarbons consist of n-heptadecane, the remainder, in descending order, of saturated linear hydrocarbons (C15, C16, C18) and three unidentified saturated branched-chain hydrocarbons (**69**).

The presence of paraffins of this kind is not exceptional; for example, certain food yeasts contain between 0.1% and 0.5%. The metabolization of these products, and more particularly the heptadecane, will be discussed in the section dealing with toxicological trials.

3. Carbohydrates

In general, carbohydrates (**57**) constitute 15-25% of the dry weight of *spirulina*. Simple carbohydrates - glucose, fructose and sucrose - are present only in very small quantities; polyols such as glycerol, mannitol and sorbitol also occur.

Virtually all the assimilable carbohydrates consist of polymers such as glucosamine (1.9% of dry weight), rhamnosamine (9.7%) or glycogen (0.5%).

The cell walls of *spirulina* are similar to those of Gram-positive bacteria, since they consist of glucosamines and muramic acid associated with peptides. Although not digestible, these walls are fragile and make the cell content readily accessible to digestive enzymes; this is a major advantage in comparison to organisms with cellulosic cell walls (i.e. yeasts, chlorella).

From the nutrient standpoint, the only carbohydrate that occurs in sufficient quantities to be of interest is mesoinositol phosphate, which is an excellent source of organic phosphorus and inositol (350-850mg/kg dry matter) (**13, 50**). This inositol content is about eight times that of beef and several hundred times that of the vegetables with the highest levels.

However, it should be pointed out that such a high cyclitol phosphate content could have a decalcifying effect in the long term if calcium intake is insufficient. Fortunately this danger is excluded in *spirulina*'s case by its high calcium content, comparable to that of milk (**13, 23**) (see the section on «Minerals and trace elements»). It is worth noting that *spirulina* polysaccharides are believed to have a stimulating effect on DNA repair mechanisms (**52**), which might explain the radio-protective effect mentioned several times in relation to *spirulina* (**56**). Other explanations have been put forward to account for this effect, including the neutralization of the

free radicals generated by irradiation. This rapid neutralisation is thought to be primarily due to beta-carotene. Moreover, the abundant metallothioneins in *spirulina* may be involved in the accelerated excretion of certain radioisotopes as observed during a nutritional study on a group of Belo-Russian children seriously contaminated following the Chernobyl disaster (**43**). Certain polysaccharides are also thought to have immune-stimulating and immune-regulating properties (**4, 24, 73**).

4. Nucleic acids

The nucleic acid (DNA and RNA) content is an important nutritional point, because the biochemical degradation in part of their components (the purines adenine and guanine) ends by producing uric acid. A rise in plasma uric acid can produce kidney stones and gout attacks in the long term. It is generally considered that the long-term maximum acceptable daily intake of nucleic acid is about 4 g/day for an adult (**8**). It should be added that RNA produces three times as much uric acid as DNA for the same purine content, and that increases in the uric acid level depend also on multiple factors such as age, sex, and degree of obesity.

In both *S. platensis* and *S. maxima*, total nucleic acid levels of 4.2-6% of dry matter have been reported (**60, 3**). The proportion of DNA is estimated between a quarter and a third of that in RNA (**15**). These figures should be compared with values for other foods (Table 3). The nucleic acid content of *spirulina* is far lower than that of unicellular organisms in general.

Table 3. Nucleic acid content of some food

Foods	**Total nucleic acids** (% of dry matter)
Beef	1.5
Beef liver	2.2
Spirulina	4-6
Yeast	23

On the basis of a mean nucleic acid content of 5%, and without allowing for the DNA component (which produces one third as much uric acid), the daily limit of 4g represents the

nucleic acid content of 80g of dry *spirulina*. This amount is about eight times the recommended dose of *spirulina* as food supplement. It is reasonable to consider, therefore, that the nucleic acid content of *spirulina* does not pose problems, even over long periods and at high dosage.

5. Vitamins

5.1 Pro-Vitamin A (beta-carotene)

Beta-carotene accounts for 80% of the carotenoids present in *spirulina*, the remainder consisting mainly of physoxanthin and cryptoxanthin (**51**). Each kilogram of dry *spirulina* contains between 700 and 1700mg of beta-carotene and about 100mg of cryptoxanthin; these two carotenoids are convertible into Vitamin A by mammals. For adults Vitamin A requirements are estimated at less than 1mg per day (**24**), one to two grams of *spirulina* are easily sufficient to cover them. Moreover, the absence of retinol (free Vitamin A) rules out a possible risk of overdose, as beta-carotene, unlike Vitamin A, is not cumulatively toxic. The beta-carotene values given above were obtained from samples of *spirulina* dried by spraying, and thus without heating; when hot-drum drying processes are used, the values should be reduced by nearly a third (**10**).

The bioavailability of *spirulina* carotenoids has been demonstrated in both the rat and the chicken (**37, 46, 58**). Clinical studies have also shown excellent utilisation of *spirulina* carotenoids in humans' (**1**). In addition, a study conducted on 5000 Indian pre-school children showed that a single daily dose of one gram of *spirulina* was surprisingly effective against chronic Vitamin A deficiency. After five months, the proportion of children with serious Vitamin A deficiency, i.e. with Bitot's spots on the conjunctiva of the eye fell from 80% to 10% (**65**). This study seems to demonstrate that even very low doses of *spirulina* are sufficient to achieve a considerable reduction in the risks of blindness and neurological damage caused by Vitamin A deficiency in children.

Because of the growing number of indications that carotenoids have a range of effects against cancer, various extracts of *spirulina* have been tested from this viewpoint. A highly

significant preventive and curative effect has been observed in experimentally induced tumours in hamsters. These were epithelial tumours of the cheek induced by dimethyl benzanthracine (DMBA) (**62,63**).

Particular emphasis should be placed on a series of studies in the context of the AIDS pandemic; it has been shown that the transmission of HIV from an infected mother to her child is strongly dependent on Vitamin A deficiency. Thus the more serious a HIV+ pregnant woman's Vitamin A deficiency, the more likely it is that her child will become infected with the AIDS virus (**64**). Hence the availability of foods rich in carotenoids is all the more crucial for continents such as Africa, and the importance of developing local production of *spirulina* is all the greater.

5.2 Vitamin E (tocopherols)

Dry *spirulina* contains 50-190mg/kg of Vitamin E (**13, 23, 50**), a level comparable to that of wheat germ. Daily requirements of Vitamin E are estimated at 15 IU (**29**), or 12mg of free tocopherols. The antioxydant properties of tocopherol for unsaturated fatty acids could explain the good conservation of these substances in dried *spirulina*.

5.3 Water-soluble Vitamins

While *spirulina* is less rich than yeast in the group B Vitamins (except for Vitamin B12), it is nevertheless a good source of these co-factors:

Table 4. The Vitamin content of *spirulina* and adult daily Vitamin requirements

Vitamin	**Content (mg/kg)**	**Daily requirement (mg)** (adult, 24-25 years)
B1	34-50	1.50

B2	30-46	1.80
B6	5-8	2.00
B12	1.5-2.0	0.003
Niacin	130.00	20.00
Folate	0.50	0.40
Pantothenate	4.6-25	6-10
Biotin	0.05	0.1-0.3
C	traces	15-30

5.4 Vitamin B12

It is worth stressing the exceptionally high Vitamin B12 (cobalamin) content, since this Vitamin is by far the most difficult to obtain in a meatless diet because no common food plant contains it. *Spirulina* is four times as rich in B12 compounds as raw liver, long put forward as the best source. However, it should be noted that a controversy surrounds the real bioavailability to humans of the B12 complex in *spirulina*. Some radiochemical tests concerning intrinsic factors would appear to contradict the presence of «active» Vitamin B12 in *spirulina* (**12**). The results are apparently variable depending on the strain of *spirulina*, for the same analytical method is stated to show high levels of «active» B12 in certain strains (**30**).

Vitamin B12 deficiency (pernicious anaemia) derives either from a shortfall in intake (as happens in strict vegetarian diets) or from defective absorption. Moreover, it seems that certain pathological conditions systematically give rise to Vitamin B12 deficiency, as in the case of HIV infections leading to AIDS (**31, 59**).

6. Minerals and trace elements

Table 5. Typical analyses for dry *spirulina*

Minerals	**Content in *spirulina*** (mg/kg)	**Required adult daily dose (47)** (mg/day)
Calcium	1300-14000	1200
Phosphorus	6700-9000	1000
Magnesium	2000-2900	250-350
Iron	580-1800	18
Zinc	21-40	15
Copper	8-10	1.5-3
Chrome	2.8	0.5-2
Manganese	25-37	5
Sodium	4500	500
Potassium	6400-15400	3500

The minerals of particular interest in *spirulina* are iron, calcium, phosphorus and potassium.

The very high iron content should be doubly stressed because iron deficiencies (anaemias) are very widespread, particularly in pregnant women and children, and good sources in food are rare. As a comparison, whole cereals, which are ranked as one of the best sources of iron, contain only 150-250 mg/kg. In addition, iron supplements given in the form of ferrous sulfate can pose a toxicity problem and often cause diarrhoea. Cereals, meanwhile, are rich in phytic acids and phosphatic polymers, which sharply limits the bioavailability of the iron they contain. In the case of *spirulina*, iron bioavailability has been demonstrated both in rats and in humans (**35**).

Calcium, phosphorus and magnesium occur in *spirulina* in quantities comparable to those found in milk. The relative amounts of these elements are balanced which rules out the risk of decalcification through an excess of phosphorus. It may be noted that regions with soils poor in magnesium are common and cause deficiency syndromes, including cardiovascular and nervous disorders, in the local populations.

The high potassium content is also worth underlining, because many nutritionists attack

the very low potassium/sodium ratio available in the majority of food sources.

There is unfortunately very little information on the level in *spirulina* of one important trace element, and that is iodine. However, there are data that indicate that it is possible by selection or adaptation to obtain *spirulina* strains capable of fixing iodine (**66**).

7. Microflora associated with *spirulina* crop environments and preparations

The microflora associated with *spirulina* crops is generally scarce and non-pathogenic (**70**). In fact, the high alcalinity of the crop environment (pH 8.5-11.0) is an excellent barrier against contamination, whether by bacteria, yeast, fungi or algae. Further certain substances secreted by or contained in *spirulina* have a bactericidal, or at least bacteristatic, effect (see section 2.3.1 on sterols). Thus *spirulina* can be used as poultices to treat gangrenous wounds in Africa.

In a synthetic environment, there are usually $3x10^4$ to $6x10^5$ microorganisms per millilitre of culture medium (**60, 71**).

After harvesting and drying, *spirulina* contains no more than 10^3 to 10^6 re-viable organisms per gram. This number falls steadily with storage time: even in preparations made from natural growths (which are much more contaminated than cultivated products, in particular because of traditional drying methods on the ground), no coliform bacteria or streptococci are detectable after a month's storage.

Bacteriological analyses of *spirulina* produced industrially in Mexico (**60**) or the United States (**23**) confirm the complete absence of pathogens such as salmonella, shigella and staphylococci. No contamination by dysenteric amoebas has been demonstrated, neither in natural sources (Lake Chad) nor in experimental ponds (**34**).

The conservation of dried *spirulina* preparations seems to pose no problem because the product appears to be fully resistant to moulds. Thus *Aspergillus flavus* and aflatoxin (secreted by this fungus) have never been detected in batches of *spirulina* (**34**). Industrial *spirulina*

contains fewer than 100 viable mould spores per gram (**23**).

8. Toxicological studies

8.1 Investigations on toxic minerals

In several studies, toxic substances such as lead, mercury and arsenic (**60, 50**) and fluorine (**60**) have not been detectable; however, a more detailed study shows that *spirulina* harvested in its natural environment can contain relatively high levels of arsenic and especially fluorides. While these special properties are certainly the result of the geological make-up of the areas concerned, the factors governing the accumulation of these elements in contaminated sites still remain to be determined. It may be noted that experiments on rats fed with natural *spirulina* as their only protein source have shown no toxic effect from these minerals (**8**).

These problems appear to be non-existent in *spirulina* grown in an artificial environment, since the values observed are below the relevant norms (IUPAC, 1974; WHO and FAO, 1972).
The average levels are:

Arsenic	0.06 - 2 ppm
Selenium *	0.01 - 0.04 ppm
Cadmium	0.01 - 0.1 ppm
Mercury	0.01 - 0.2 ppm
Lead	0.6 - 5.1 ppm
Fluorine **	112 - 630 ppm

*Selenium and fluoride could have been dealt with in the section on «Minerals and trace elements» in view of their essential role in human food. However, they represent a greater danger in the event of overdose than the trace elements discussed.

Only one publication gives this level (8**), which has subsequently been refuted (**14**).

8.2 Investigations on organic, mutagenic and teratogenic toxic substances

The possible toxic properties of the paraffins referred to above have been studied in rats and pigs (**69**). On them a study was carried out concerning the retention of heptadecane (a major constituent of *spirulina* paraffins) when they were fed with *spirulina* as the only protein source. In the rat, there is a process of accumulation, which stabilises at around the fourth month at a final level that depends on the animal's lipid level. In pigs, heptadecane appears to be much more readily metabolised and retention of this hydrocarbon is very slight. In the light of what is known of hydrocarbon toxicity, no acute or chronic toxicity is to be expected (**69**).

3,4-Benzopyrene has been measured in *spirulina* because it serves as a good indicator of the presence of aromatic polycyclic hydrocarbons, which are powerful mutagens and cancinogens. The quantities observed (2-3ppb) are well below those found in most common vegetables (**14, 7**).

Teratogenicity has been found to be 0 for three species at four different stages of gestation, with *spirulina* concentrations of 10%, 20% and 30% of the diet. Similarly, no mutagenic effect or subacute or chronic toxicity was detected (**14, 8**). The mutagenicity of urine from animals fed on *spirulina* has been tested on bacteria (Ames test) without negative results (**15**).

8.3 Contamination by neurotoxic or hepatotoxic cyanobacteria

It has long been known that certain cyanobacteria produce powerful toxins acting on the nervous system (e.g. anatoxin-A from *Anabaena flos-aquae*) or the liver (e.g. microcystine from *Microcystis aeruginosa*). To our knowledge, no contamination by microorganisms has been demonstrated in *spirulina*, a fact that appears to be related to its very specific growth environment. While the problem has apparently never arisen in artificial crops, it is known that certain lakes in Chad that produce *spirulina* (*S. platensis*) are periodically invaded by other cyanobacteria such as *Anabaenopsis circularis or Microcystis aeruginosa* (**42**). It is reasonable to assume, however, that the seasonal character of this contamination reflects changes in the composition of the environment (sharp fall in salinity and pH following the rainfalls), which

would not occur in cultivated crops.

On the other hand, it should be pointed out that while *spirulina* itself is not in question, the same cannot necessarily be said of certain freshwater algae or cyanobacteria harvested without real controls and without any of the toxicological guarantees surrounding *spirulina* (**12**). Yet such products, derived from the genus *Aphanizomenon* and even from the genus *Anabaena*, can be found on the North American market if not elsewhere (**39**).

9. Nutritional trials in human subjects

The most convincing trials are of course those conducted among populations, like the Kanembous of Chad, which traditionally eat *spirulina*. Its consumption is regular but at a fairly low level, 10-12 grams per person per day, except pregnant women who eat considerably more (**20**). Thus it is chiefly a food supplement; the nutritional benefits have not been brought out by the quantitative studies undertaken so far (**20**), and the effects of essential amino acids as a food complement and intake of the other constituents of *spirulina* still have to be determined. It would be of particular interest to know whether these populations suffer from nutritional deficiencies, and to compare them with neighbouring populations who do not eat *spirulina*.

Clinical studies are still rare in the literature and generally relate to small numbers of subjects. However, two studies covering large numbers of individuals merit attention:

- The Indian experiment on pro-Vitamin A referred to above, which covered 5000 young children (**65**);
- A second large-scale study, now in progress in Bangui (Central African Republic), relates to the efficacy of *spirulina* in the treatment of protein-energy disorders. This study, which involves several hundred children with severe malnutrition, seems already to give very solid backing to the hopes placed in *spirulina*, especially against kwashiorkor (**22**).

Among the studies on small numbers of subjects, the following studies may be noted.

The nitrogen balance was studied in 10 children aged 5-10 months hospitalised for severe malnutrition (**55**). They were given in turn 2-3 grams of protein per kilogram of body weight in the form of *spirulina*, cow's milk or soya during four-day periods. Nitrogen absorption was 60% for *spirulina* and 70% for soya, but for retention the proportions were reversed: 40% for *spirulina* and 30% for soya. Thus the relative retention of *spirulina* was as high as that of cow's milk, indicating excellent protein utilisation despite average digestibility.

At the Hôpital Bichat in France, absorption of *spirulina* proteins was found to be good; the tests were carried out on undernourished children and adults who were given massive doses of *spirulina* (80-90 grams/day). Despite these very large doses, no noteworthy increase in blood uric acid was demonstrated (**60**).

A study on 28 children suffering from manifest protein-energy diseases was carried out from January to November 1989 in Zaire (**9**). The parameters measured during this study show the generally positive effects of *spirulina* on patients' nutritional status, regardless of the inevitable hazards associated with studies in the field.

Lastly, a Chinese study on 27 children aged from 2 to 6 years concluded that *spirulina* is «a real source of health for children», after analysis of the impact of a daily portion of 1.5 grams of *spirulina* on the health status of the children concerned (**45**).

10. Therapeutic value of *spirulina*: studies, prospects and questions

Although the therapeutic properties of *spirulina* lie outside the scope of this review, it is useful to mention here some of the work linking this product to the treatment of various pathological conditions. We shall not go further into the therapeutic applications already referred to above:

- Iron deficiency anaemia (see «minerals and trace elements»)
- Pernicious anaemia (see «Vitamin B12")

- Vitamin A deficiency (see «pro-Vitamin A»)
- Inhibition of mother-child transmission of HIV (see «pro-Vitamin A»)
- Inhibition of infection of T4 helper cells by HIV (see «fatty acids»)
- Protein-energy disorders (see «nutritional trials in human subjects»)
- Cancer prevention through provision of carotenoids (see «pro-Vitamin A»)
- Radiological protection (see «carbohydrates»)
- Strengthening immune defences (see «carbohydrates»)

A critical review of the various therapeutic studies of *spirulina* has been published (**6**). The works referenced include studies linking *spirulina* consumption with a positive effect on blood cholesterol levels in humans' (**48**). A protective effect on the kidneys has been detected, apparently associated with the phycocyanin present in *spirulina*. This study was carried out on rats treated with two known nephrotoxic substances: p-aminophenol (an analgesic) and cisplatin (a tumour inhibitor) (**26**).

Lastly, it is worth mentioning the possible relationship between the carotenoid content of *spirulina* and the many accounts (not verified clinically) attesting to its effectiveness in the treatment of certain skin conditions such as psoriasis, acne and even herpes.

As to lines of therapeutic research involving *spirulina*, mention should be made of the recent identification of a strongly antibacterial and antimycotic substance isolated from *S. platensis* (Funteu F, 1996; in press). At a symposium held in South Africa in 1996, a team from Harvard Medical School presented the results of a study on the antiviral activity of an aqueous extract of S. platensis (**3b**). These results demonstrate excellent *in vitro* inhibition of HIV-1 virus both in human T-cell lines and in human monocytes. The therapeutic index of the extract is reported to be over 100 and concentrations as low as 5-10 μg/ml evidently reduce the production of virus and/or syncytium by about 50%.

Such a profusion of therapeutic applications - genuine or supposed - is bound to leave *spirulina* with the image of a *miracle potion*. The fact remains that a *simple* natural food supplement, endowed with the riches of this product, could well improve a good number of pathological conditions. This is specially so in a world population that is tending to divide itself

into the *underfed* in the developing countries and the *badly fed* in the industrialised countries.

References

1. Annapurna V. et al. (1991), “Bioavailability of *spirulina* carotenes in pre-school children.” J. Clin. Biochem Nutrition. 10 145-151.
2. Anusuya D. m. & Venkataraman L. V. (1983), “Supplementary value of the proteins of the blue green algae *Spirulina* platensis to rice and wheat proteins.” Nutrition Rep. International, 28:1029-1035.
3. Association française pour l'a1gologie appliquée (AFAA) (1982), “Actes du premier symposium sur la spiruline *Spirulina* Platensis (Gom.) Geitler de l'AFAA.”

3.a Aychunie S., et al. (1996), “Inhibition of HIV-1 replication by an aqueous extract of *Spirulina* platensis (Arthospira platensis).” International Association of Applied Algology, 7th International Conference. 16 April 1996, Knysna, South Africa.

4. Baojiang G. et al. (1994), “Study on effect and mechanism of polysaccharides of *spirulina* on body immune function improvement.” Second Asia Pacific Conference on Algal Biotech. University of Malaysia. pp 33-38.
5. Becker E.W. (1993), “Development of *spirulina* Research in a Developing Country – India.” Bull. Inst. Océano, Monaco, Special # 12, 49-57.
6. Belay A. & Ota Y. (1993), “Current knowledge on potential health benefits of *spirulina*” Journal of Applied Physiology, 5:235-241.
7. Borifs G. & Tulliez J. (1975), “Détermination du 3-4-benzopyrène dans les algues spirulines produites et traitées suivant différents procédés.” Ann. Nutr. Aliment. 29, 573-575.
8. Boudène C., Collas E. & Jenkins C. (1975), “Recherche et dosage de divers toxiques minéraux dans les algues spirulines de différentes origines, et évaluation de la toxicité a long terme chez le rat d'un lot d'algues spirulines de provenance mexicaine.” Ann. Nutr. Aliment.29, 577-587.
9. Bucaille P. (1990), “Intérêt et efficacité de l'algue spiruline dans l'alimentation des enfants presentant une malnutrition protéino-énergétique en milieu tropical” PhD Thesis, University Paul Sabatier Toulouse III, 10 Oct. 1990.
10. Bujard-E, U. Braco-U, Mauron-J, Mottu-F, Nabholz-A, Wuhrmann-JJ & Clément-G (1970), “Composition and Nutritive Value of Blue Green Algae (*Spirulina*) and their Possible Use in Food Formulations.” 3rd. International Congress of Food Science and Technology, Washington 1970.
11. Campbell J., Stevens S.E. & Balkwill D.L. (1982), “Accumulation of Poly-hydroxybutyrate in *Spirulina* platensis.” J. Bacteriol. 149, 361-363.
12. Carmichael W. (1994), “The Toxins of Cyanobacteria” Sci. Am. Jan. 1994, 64-72.
13. Challem-JJ, Passwater-RA, & Mindell-EM (1981), “*Spirulina*” Keats Publishing, Inc. New Canaan, Connecticut.

14. Chamorro-Cevallos-G. (1980), "Toxicological Research on the Alga *Spirulina*." United Nations Organisation for Industrial Development, 24 Oct. 1980.

15. Ciferri O. (1983), "*Spirulina*, the Edible Microorganism." Microbiol. Rev. 47, 551-578.

16. Ciferri O. & Tiboni O. (1985), "The Biochemistry and Industrial Potential of *Spirulina*." Annual Rev. Microbiology 39, 503-526.

17. Clément G., Giddey C. & Menzi R. (1967), "Amino Acid Composition and Nutritive Value of the Alga *Spirulina* Maxima." J. Sci. Fd. Agric. 18, 497-501.

18. Clément G. (1975), "Production et constituants caractéristiques des algues *Spirulina* platensis et maxima." Ann. Nutr. Aliment. 29, 477-487.

19. Contreras A., Herbert D.C., Grubbs B.G. & Cameron I.L. (1979), "Blue-Green Alga, *Spirulina*, as the Sole Dietary Source of Protein in Sexually Maturing Rats." Nutr. Rep. Int. 19, No 6, 749-763.

20. Delpeuch F., Joseph A. & Cavelier C. (1975), "Consomation alimentaire et apport nutritionnel des algues bleues (Oscillatoris platensis) chez quelques populations du Kanem (Tchad)." Ann. Nutr. Aliment. 29, 497-515.

21. Dillon J.C. & Phan P.A. (1993), "*Spirulina* as a source of proteins in human nutrition" Bull. Inst. Océano, Monaco, Special # 12, 103-107.

22. Dupire J. et al. (1996), to be published.

23. Earthrise Farms *Spirulina*, (1986), "Product Typical Analysis", San Rafael, USA.

24. Evets L., et al. (1994), "Means to normalise the levels of immunoglobulin E, using the food supplement *Spirulina*." Grodenski State Medical University Russian Federation Committee of Patents and Trade. Patent (19) RU (11) 2005486. Jan. 15, 1994. Russia.

25. Fox R.D. (1980), "Algoculture: la spiruline" Edisud 1980

26. Fukino H., et al. (1990), "Effect of *spirulina* on the renal toxicity induced by inorganic mercury and cisplatin" Eisei Kagaku, 36:5.

27. Furst-PT (1978), "*Spirulina*", Human Nature, 1(3), 60-65.

28. Gustafson K., et al. August 16, (1989), "AIDS- Antiviral sulfolipids from cyanobacteria (blue-green algae)" Journal of the National Cancer Institute, 81(16) 1254. USA.

29. Guyton A.C. (1986), "Textbook of Medical Physiology", 7th. edition W.B. Saunders Company.

30. Hau R, (1995), "Vitamin B12 in der Mikroalge *Spirulina* platensis" FIT fürs LEBEN 1, 29.

31. Harriman-GR; Smith-PD; Horne-MK; Fox-CH; Koenig-S; Lack-EE; Lane-HC & Fauci-AS (1989), "Vitamin B12 malabsorption in patients with acquired immunodeficiency syndrome", Arch-Intern-Med. 149(9): 2039-41.

32. Hudson-BJF & Karis-IG (1974), "The Lipids of the Alga *Spirulina*", J. Sci. Fd. Agric. 25, 759-763.

33. Hwang D. (1989), "Essential fatty acids and immune response" FASEB J. 3:2052-2061.

34. Jacquet J. (1975), “Microflore des préparations de spirulines.” Ann. Nutr. Aliment. 29, 589-601.

35. Johnson P. & Shubert E. (1986), “Availability of iron to rats from *spirulina*, a blue-green algae.” Nutrition Research 6, 85-94.

36. Jourdan J.P. (1996), “Cultivez votre spiruline” Antenna Technology (to be published).

37. Kapoor-R & Mehta-U (1993), “Utilization of beta-carotene from *Spirulina* platensis by rats.” Plant-Foods-Hum-Nutr. Jan. 1993, 43(1): 1-7.

38. Kapsiotis-G, Béhar-M, DeMayer-EM, Teply-LJ & Venkatachalam-PS. (1972), “Acceptable Limits of Nucleic Acid in SCP for Various Age Groups and Diet Patterns” PAG Bulletin, 5(3),18-26.

39. Kay R.A. (1991), “Microalgae as Food and Supplement.” Critical Reviews in Food Science and Nutr. 30(6):555-573. Pub. by CRC Press.USA.

40. Lehninger A.L. (1975), “Biochemistry, the Molecular basis of Cell Structure and Function.” Worth Publishers, Inc.

41. Leitzmann C. (1993), “Vitamin B12 aktueller Stand der Forschung.” FIT fürs LEBEN 6, 12-15.

42. Léonard-J & Compère-P (1967), “*Spirulina* platensis (Gom.) Geitler, algue bleue de grande valeur alimentaire par sa richesse en protéines.” Bull. Nat. Plantentuin Belg. 37 (1),Suppl.23 p.

43. Loseva L.P. & I.V.Dardynskaya (1993), “*Spirulina*- natural sorbent of radionucleides.” Research Institute of Radiation Medicine, Minsk, Belarus. 6th Int'l Congress of Applied Algology, Czech Republic.

44. Manuel Merck (1994), 2e ed. française, editions d'Après, Paris.

45. Miao Jian Ren (1987), “*Spirulina* in Jiangxi China”. Academy of Agricultural Science. Presented at Soc. Appl. Algology, Lille France Sep. 1987.

46. Mitchell-GV; Grundel-E; Jenkins-M & Blakely-SR (1990), “Effects of graded dietary levels of *Spirulina* maxima on Vitamins A and E in male rats.” J-Nutr. 1990 Oct; 120(10): 1235-40

47. National Research Council (1980), “Recommended Dietary Allowance” 9th ed. Washington, DC: National Academy Press.

48. Nayaka N., et al. (1988), “Cholesterol lowering effect of *spirulina*.” Nutrition Reports International 37(6), 1329-1337.

49. Nichols-BW & Wood-BJ (1968), “The Occurrence and Biosynthesis of Gamma-Linolenic Acid in a Blue-Green Alga, *Spirulina* Platensis, Lipids.” January 1968, 3(1), 46-50.

50. Nippon Ink & Chemicals (1977), “*Spirulina*”.

51. Palla-JC & Busson-F (1969), “Etude des caroténoïdes de *Spirulina* platensis (Gom.) Geitler (Cyanophycées).” C.R. Acad. Sc. Paris, t.269 p.l704-1707.

52. Pang-QS; Guo-BJ & Ruan-JH (1988), “Enhancement of endonuclease activity and repair DNA synthesis by polysaccharide of *Spirulina* platensis.” I-Chuan-Hsueh-Pao. 1988; 15(5): 374-81.

53. Pascaud M. (1993), “The essential polyunsaturated fatty acids of *spirulina* and our immune response.” Bull. Inst. Océano, Monaco, n°spécial 12, 49-57.

53a. Pascaud M. & Brouard C. (1991), “Acides gras polyinsaturés essentiels w6 w3. Besoins nutritionnels, équilibres alimentaires.” Cah. Nutr. Diet. XXV 13:185-190.

54. Protein Advisory Group of U.N. (1974), “Recent Developments in *Spirulina*.” PAG Bulletin, 3(4), 4-7.

55. Proteus, Inc. (1975), “Clinical experimentation with *Spirulina*.” National Institute of Nutrition, Mexico City, 1975. (Translated by Proteus, Inc.)

56. Qishen P., Kolman et al. (1989), “Radioprotective effect of extract from *spirulina* in mouse bone marrow cells studied by using the micronucleus test.” Toxicology Letters 48: 165-169.

57. Quillet M. (1975), “Recherches sur les substances glucidiques élaborées par les spirulines.” Ann. Nutr. Aliment. 29, 553-561.

58. Ross-E & Dominy-W (1990), “The nutritional value of dehydrated, blue-green algae (*Spirulina* platensis) for poultry.” Poult-Sci. 1990 May; 69(5): 794-800.

59. Rule-SA; Hooker-M; Costello-C; Luck-W & Hoffbrand-AV (1994), “Serum Vitamin B12 and transcobalamin levels in early HIV disease.” Am-J-Hematol. 47(3): 167-71.

60. Santillan-C (1974), “Cultivation of *Spirulina* for human consumption and for animal feed.” International Congress of Food Science and Technology. Madrid (Spain) September 1974.

61. Sautier C. & Trémolières J. (1975), “Valeur alimentaire des algues spirulines chez l'homme.” Ann. Nutr. Aliment. 29, 517-533.

62. Schwartz-J & Shklar-G (1987), “Regression of experimental hamster cancer by beta carotene and algae extracts.” J-Oral-Maxillofac-Surg. 1987 Jun; 45(6): 510-5.

63. Schwartz J., Shklar G., et al. (1988), “Prevention of experimental oral cancer by extracts of *spirulina*-dunaliella algae.” Nutr. Cancer 11, 127-134.

64. Semba-RD; Miotti-PG; Chiphangwi-JD; Saah-AJ; Canner-JK; Dallabetta-GA & Hoover-DR (1994), “Maternal Vitamin A deficiency and mother-to-child transmission of HIV-1.” Lancet. 343(8913): 1593-7.

65. Seshadri C.V. (1993), “Large scale nutritional supplementation with *spirulina* alga.” All India Coordinated Project on *Spirulina*. Shri Amm Murugappa Chettiar Research Center (MCRC) Madras, India.

66. Singh-Y & Kumar-HD (1994), “Adaptation of a strain of *Spirulina* platensis to grow in cobalt- and iodine-enriched media.” J-Appl-Bacteriol 76(2): 149-54

67. Soeder C.J., Muller-Wecker H., Pabst W. & Kraut H. (1970), “Bases de travail pour l'emploi de microalgues dans l'alimentation et dans la diététique.” Ann. Hyg. L. Fr.-Med. et Nut.- 1970. T.6, No 4, p. 49-56.

68. Takeuchi T., et al. (1978), “Clinical experiences of administration of *spirulina* to patients with hypochronic anemia.” Tokyo Medical and Dental Univ.1978, Japan.

69. Tulliez J., Bories G., Février C. & Boudène C. (1975), “Les hydrocarbures des algues spirulines: nature, étude du devenir de l'heptadécane chez le rat et le porc.” Ann. Nutr. Aliment. 29, 563-571.

70. Vermorel M., Toullec G., Dumond D. & Pion R. (1975), “Valeur énergétique et protéique des algues bleues spirulines supplémentées en acides aminés: utilisation digestive et métabolique par le rat en croissance.” Ann. Nutr. Aliment. 29, 535-552.

71. Wu J.F et Pond W.G. (1981), “Amino Acid Composition of *Spirulina* Maxima, a Blue-Green Alga, Grown on the Effluent of Different Fermented Animal Wastes.” Bull. Environm. Contam. Toxicol. 27, 151 - 159.

72. World Health Organization (1973), “Energy and Protein Requirement.” World Health Org. technical. Report Serial, No. 522, Geneva.

73. Zhang Cheng-Wu, et al. (1994), “Effects of polysaccharide and phycocyanin from *spirulina* on peripheral blood and hematopoietic system of bone marrow in mice.” Proc. of Second Asia Pacific Conf. on Algal Biotech. Univ. of Malaysia.

****

ANTENNA Technologies