

A sustainable response to malnutrition in hot regions: the local production of spirulina

1.1 “Chemical” fortification of staple foods: an emergency solution

The bulk of severe food deficiencies comes from the lack of three elements: vitamin A, iron and iodine. The required daily intake of these substances is very small, and hence the idea of adding them directly to certain foods (such as flour, oil, sugar or salt) seems an adequate and inexpensive response to deficiency problems (UNICEF, Annual Report 1996, pages 49-51).

While that approach is perfectly justified in an emergency setting, it does not provide a lasting solution because it depends on the importation of pharmaceutical or chemical products. Account must also be taken of the real technical difficulties associated with the precise, uniform and stable mixing of minute proportions of these compounds in very large tonnages of food commodities. That approach also implies strong centralization of certain basic resources (in the case of flours or oils, for example), since the technologies needed for the preparation of “enriched” foods cannot be introduced at each production site, still less where the products are consumed. That is not without consequences for local economies, for it will often be much more practical (and cheaper) to enrich imported foods or those produced by a small number of large growers than to collect the output of myriads of small local producers. It follows that in some cases these “enriched” foods run the risk in some cases of competing with local products. In any case, access to these products will be very problematical for isolated villages, not forgetting that the problem of storage and conservation of foods is in itself a headache in hot countries. How then to be sure that the commodities carefully “fortified” and painstakingly transported to the villages will not deteriorate in storage, as happens almost always with an enormous proportion of local commodities?

1.2 Diversification of agricultural production: not so easy!

Another suggestion in the fight against malnutrition, the local production of foodstuffs rich in micronutrients, has been proposed for many years: encouragement for the production and consumption of fruits and vegetables is certainly an excellent initiative. Unfortunately, this approach is difficult because of a series of practical problems:

- These agricultural products are generally seasonal and their conservation, when it is possible, destroys some fragile micronutrients (such as provitamin A). To this “internal” deterioration can be added the storage difficulties mentioned above and thus the losses relating to insect or rodent infestations; not forgetting the deterioration and dangers of poisoning relating to the development of bacteria or moulds in poorly stored products.
- These agricultural products require favourable soils, specific climatic conditions, much water and time. The quality of soils deteriorates daily from the combination of factors such as overgrazing, wind and water erosion, desertification or poor irrigation management. Added to these is the immense (political) problem of access to land and to water.
- The control of plant diseases and of insects is a major problem. One has only to think of invasions by locusts to realize to what extent months of investment in work and water remain at the mercy of a single day of misfortune. Some parasitic plants can themselves ravage huge areas of farmland in a short time: in Africa, for example, *striga* infests some agricultural areas almost irreversibly, blocking any attempt to grow cereals there.
- The nutritional content of everyday foods is often known, but the real bioavailability of these nutrients, i.e. the human capacity to *assimilate* them from these foods, remains very controversial or unknown. In most cases, these bioavailabilities vary enormously according to the mode of conservation, the preparation of the foods, even the conditions in which plants have grown. In the case of plants, the main barrier to the assimilation of their nutrients by humans is the cellulose wall that covers every plant cell. As this cellulose is completely indigestible for humans, only intensive mechanical grinding (hence lengthy chewing) can give us access to the contents of plant cells. The only alternative to grinding is cooking, which has the effect of bursting the cellulose walls, but which also entails heavy losses of heat-sensitive nutrients (especially essential fatty acids and a good number of vitamins). It is interesting to note that recent studies have shown that the carotene in raw carrots is so inaccessible that it is still preferable to eat this vegetable after cooking, since the small amount of carotene that resists this treatment is assimilable. Thus it seems that to the difficulty and cost of producing vegetables, the cost of the energy necessary to transform them into assimilable foods has to be added.

As a general rule, when a region produces only a limited range of foods, it is because the local conditions lend themselves to only a small number of crops. That is the case over vast regions with poor soils, desert climates or brackish water. Moreover, even when the material conditions to make diversification possible exist, the introduction of new crops inevitably encounters a number of obstacles: new techniques, new knowledge, acceptability in the diet, etc.

All these potential obstacles mean that the introduction of a single new farm crop would theoretically call for a thorough and costly study for each local situation.

1.3 High tech versus malnutrition?

A new technology has joined the ranks in the fight against malnutrition: genetic engineering. The recent announcement of the development of genetically modified varieties of rice, one with a high provitamin A content and another able to accumulate iron, has aroused keen interest. However, this achievement raises many questions: does not the arrival on the market of seeds of a small number of “super-varieties” pose the risk of accelerating an already very serious process of genetic erosion? Will these “super-varieties” be cultivable everywhere? Will they stand up to varying local conditions as well as the traditional cultivars? What is more, will these new seeds be freely accessible to small peasant farmers?

Finally, the bioavailability of the micronutrients added by these new technologies to cereals remains to be established. In the case of iron, the question is justified because whole wheats are rich in iron, but unfortunately it is poorly assimilated by humans. For carotene, the cooking that rice needs could also pose a problem.

Generally speaking, the biotechnological approach enables the process of obtaining new varieties to be tremendously accelerated; on the other hand, it does nothing to speed up the acquisition of experience of these plants “in the field”: in any event many years are needed to explore the advantages and disadvantages of each of them. How can one predict, for example, whether rice containing carotene will be preferred to any other rice by such and such a harmful insect? Whether it will be more (or less) sensitive to such and such a dangerous mould when in storage? Whether it will require the presence or absence of certain elements in the soils where it is grown? Until experience has helped to make these new varieties better known *in real situations*,

it would be difficult to justify encouraging poor populations to grow them, when they have no means of reacting if something unexpected happens, especially if they have meanwhile abandoned their traditional varieties. It is therefore imperative for this lengthy gathering of experience to be done under controlled conditions that are as diverse as possible, by those who work on producing new varieties: in a sense, the “burden of proof” falls on them.

Given the extent of this preliminary work, it is essential to emphasize solutions based on traditional resources, since the implications of their exploitation are in the main known, at least in some settings. Prospecting for local traditional resources continues to provide us with new weapons against malnutrition; and then the next step is to study the possibility of disseminating them beyond their traditional areas of use.

2. Spirulina, a realistic and widely applicable response

2.1 A traditional food rediscovered

In the 1950s, a strange traditional food was rediscovered in Chad by a European scientific mission. It took the form of dried flat cakes tinted green with a blue tinge, which were found in the markets of the Kanem region under the name of “dihé”. The study showed that this “dihé” came from masses of a unique micro-organism harvested on the surface of highly alkaline ponds and dried on the sand of the banks. This micro-organism, capable of photosynthesis and reproducing itself rapidly, was called “spirulina” because of its spiral filament-like appearance under the microscope (its scientific name is *Arthrospira platensis*; it is a cyanobacterium).

Analysis of the nutritional properties of spirulina showed first and foremost an exceptionally high protein content, of the order of 60-70% of its dry weight; it also showed the excellent quality of these proteins (balanced essential amino acid content). These first data were enough to launch many research projects for industrial purposes in the 1970s, because micro-organisms (yeasts, chlorella, spirulina, some bacteria and moulds) seemed at that time to be the most direct route to inexpensive proteins - the famous “single cell proteins”. While finally no micro-organism fulfilled its promise of cheap protein, spirulina continued to give rise to research and even increasing production, for this cyanobacterium had many other assets, both nutritional and technical.

2.2 Nutritional and technical characteristics of spirulina

· Toxicological safety

Exhaustive toxicological studies, as well as nutritional studies in humans, combined with the fact that spirulina is traditionally consumed in Chad and Mexico, prove unequivocally the total harmlessness of this foodstuff. Very few food products have been so carefully evaluated from the toxicological angle. To that should be added several studies showing the very high degree of genetic homogeneity in various spirulinas (formally *Arthrospira sp.*) cultivated or harvested throughout the world. Mention should also be made of the total absence, after more than 30

years of industrial or small-scale production, of food accidents directly or indirectly attributable to the production or consumption of spirulina.

It should also be emphasized that there are no known serious side-effects after overdoses of spirulina, even massive ones; only a benign accumulation of carotenoids in the skin may appear in some extreme cases (“suntan pill” effect).

- Nutritional value of spirulina

Having no cell walls, spirulina is perfectly digestible raw or simply dried. Its nutritional value goes well beyond its protein content: it is one of the richest known sources of provitamin A and assimilable iron, while also containing high levels of the rare vitamin B12, gamma-linolenic acid (GLA) and other essential fatty acids. Many nutritional tests have proved the bioavailability of these micronutrients. Produced in an adequate culture medium, spirulina also becomes an excellent source of zinc: trials carried out by Antenna Technology in 1998 show that it is easy to obtain a spirulina of which 2-4 g are enough to cover simultaneously the essential daily requirements for zinc, iron and vitamin A in the child.

These experiments in modifying the nutritional content of spirulina by a suitable culture medium are extremely promising: in certain cases the spirulina, by easily assimilating the minerals provided, makes them available to humans (who would not have been able to use them directly). Moreover, some minerals (including zinc), while essential in small doses, become dangerous if the dosage is wrong (incidentally, that is one of the problems of chemical fortification of foods: an error can have serious consequences). In the case of spirulina cultivated in the presence of zinc, an error in dosage will have the immediate effect of killing, not people, but the spirulina! Thus growing spirulina serves not only to make minerals available to humans that would not necessarily have been available otherwise, but also as a safety net in case of mistakes in the dosage of a potentially toxic element. This protective effect has been successfully tested in the case of zinc and of copper, and for a combination of these two elements; tests are planned for selenium and chrome.

- Production yields

As the growth rate of this photosynthetic micro-organism is very fast, it yields up to 20 times as much protein per hectare as soya. This productivity also derives from the fact that spirulina is eatable in its entirety: thus all the energy and the inputs used in its production are put to use; in a classic agricultural crop, only a small proportion of the plant cultivated (or animal raised) is in fact consumable.

The problem of agricultural inputs (fertilizer, energy, water, etc.) is absolutely crucial: no sustainable crop can ignore this problem. In the case of spirulina, Antenna Technology has demonstrated the feasibility of production requiring only the recycling of natural fertilizers. Although highly desirable in the long term, this type of technique, combined with the novelty of “spirulina as a product”, would risk reducing its acceptability. Antenna Technology has therefore resolutely determined to utilize classic farm fertilizers, at least during the first stage of projects for the production of spirulina. This choice has several advantages: better control of the composition of the culture medium, greater ease of culture, and smaller deposits of insoluble matter at the bottom of culture tanks. It should also be added that the use of soluble fertilizers in spirulina production is all the more justified since the tanks form real virtually closed intensive cultures and the rate of uptake of these products is extremely high. Unlike a classical agricultural crop, there is no loss here that pollutes through soil leaching, no involuntary fertilizing of the weeds in fields: practically everything that is added to the culture medium is utilized by the spirulina, and only by the spirulina! This efficiency of fertilizing in the case of spirulina explains the low share of the cost of fertilizers in the final cost of the spirulina (the main part being the cost of labour and the amortization of land and installations).

Productivities of 5-10 g of spirulina (dry weight) per square metre per day are usual; these values represent steady averages (thus the annual yield, in climates that allow it, is 18-36 tons of dry product per hectare). To be fully understood, this yield needs to be reduced to the daily doses used in the human diet: no more than a few grams of dry spirulina suffice to improve radically the daily nutritional intake of a young child. This means that each square metre of spirulina cultivation is enough to provide continual nutritional assistance to 2-3 children (throughout the year in hot regions). What agricultural crop could claim as much?

- Safety of production and resistance to contaminants

Growing as it does in a culture medium that is entirely mineral and highly alkaline (classically at a pH of 10 and up to pH = >11), spirulina is virtually immune from problems of contamination by other organisms. This decisive advantage enables it to be cultivated without risk, even in systems with very low technology and in tropical climates.

In addition to this intrinsic resistance, the harvesting process (by filtration) retains only particles about 50-100µ in size. The highly characteristic morphology of spirulina filaments, and their particular pigmentation, considerably simplify routine checks: relatively rudimentary equipment is sufficient for an acceptable level of quality control.

Direct consumption of the spirulina paste taken from the pond is highly desirable: in addition to the factors of simplicity and economy, the acceptability of the product is also increased (no taste or smell) compared to the dried product. "Immediate" consumption of this kind is the best way of ensuring the bacteriological safety of the product, since it minimizes the time spent away from the protection of the culture medium.

The drying stage, which is essential if the product is to be transported far or conserved more than a few hours, is the only tricky stage in terms of the final product. Antenna Technology has developed several simple and effective methods to control the critical parameters in the drying of spirulina, i.e. the speed of drying, the maximum permitted temperature, and protection against light and dust.

2.3 Promoting the production and consumption of spirulina in developing countries

In order to offer a lasting solution, applicable in a very wide range of settings, Antenna Technology has therefore given priority to the development of the exceptional dietary supplement that is spirulina. This edible aquatic micro-organism has excellent potential as a new agricultural crop for the developing countries. Through its rich content in micronutrients such as iron, zinc, provitamin A and essential fatty acids, spirulina should be considered as a food supplement (or a "nutrition booster") rather than just a food. In fact, very low doses (1-5 g/day) of spirulina are a decisive nutritional input for a young child. This status of supplement rather than food greatly simplifies the problems of acceptability, while limiting the area and the work necessary for its production.

2.4 Introducing a food supplement as a new agricultural crop

Several aspects of the production of spirulina are particularly well adapted to the agricultural realities of hot, even desert, countries. The choice of a photosynthetic micro-organism that develops in an aquatic environment avoids the problems of both soil quality and plant parasites or diseases. Contrary to what might be thought, the water consumption of such a crop is far less than that of any other classical agricultural crop. Because of its extremely high productivity and the small quantities of spirulina needed per person, the area used for production is also very small. Lastly, many climates permit the continuous production of spirulina all the year round. If the spirulina is consumed locally, no conservation method is needed; moreover, the fresh spirulina can be consumed immediately, without transformation or cooking, and hence without need for an additional input of energy.

All these factors go to support the exploitation of small areas, and degraded or infertile soils. The low water consumption and the possibility of using brackish water (containing salt or natron that is useless in classical agriculture further increase the interest of spirulina production in arid regions. Finally, both the crop itself and the stages leading to its consumption are remarkably economical in energy.

· Simple and reliable culture methods

Antenna Technology has developed and field-tested various simple systems permitting production on different scales (from family microproduction to semi-industrial installations).

In the case of artisanal installations on a small and medium scale (a daily output of 50 g to 3000 g of dry spirulina), all the materials and most of the equipment necessary are generally available locally. The inputs are essentially classic agricultural fertilizers, water and (optionally) electricity. To these should be added soda or bicarbonate of soda, products that are generally easy to find (and replaceable by wood ash).

As part of the training for the cultivation of spirulina, Antenna Technology proposes the installation of a "learning module". A simple manual and samples of live spirulina can be supplied on written request. This learning module makes it possible to test the feasibility of spirulina production in real conditions, without taking much time and for a very modest investment (of the order of US\$ 100-200, depending on the country). It consists of a 4 square metre production tank equipped with a very low-power (7 watts) electrical agitator and a semitransparent cover. The necessary equipment, the mineral salts and the control and harvesting tools have been selected to be easily accessible locally. The size of this module was chosen to allow a realistic trial at low cost that includes all the stages in the production process, from seeding the tank to maintaining it during culture, and from harvesting the spirulina to eating it, and even drying it. Normal operation should ensure a production of between 20 and 40 g of dry spirulina per day, enough greatly to improve the nutrition of about 15 children (depending on their ages). In addition to its training role, this learning module can be reconverted into an "emergency reserve" as part of spirulina production on a larger scale.

2.5 An essential prerequisite: information

Unfortunately, the value of a product such as spirulina is not always strikingly obvious to those who might need it the most! Many cultures have known for centuries the crucial importance of food for health. They have often developed practices designed to take the best nutritional advantage of their local resources (e.g. by preparing cereals and legumes together in the same traditional dish, or by adding ashes or lime to various cereal cakes, which makes their vitamin B1 assimilable). It is certainly difficult to imagine why and how such and such a nutritional innovation

was adopted over the course of history. Anyone who has worked in nutrition knows how keen the resistance to change can be in this field. And yet countless cases demonstrate that some dietary changes can be rapidly and massively adopted, for better or worse, in both industrialized and traditional societies. In the majority of cases, the key element in the adoption of a new product or a new recipe is the information that accompanies it: official message, medical advice, word of mouth, advertising, marketing, etc. One may not like it, but there is little doubt that in dietary habits advertising and marketing have proved by far the best ways of making a product known (at least in the short term). As far as spirulina is concerned, advertising and marketing would only reach the populations who need it most if they were backed by a multinational company trying to sell spirulina the way some companies sell bouillon cubes.

As we are dealing here with the local *self-production of spirulina*, the only means of information that can be envisaged involve government channels, mutual aid organizations, NGOs, or local associations. For these partners, Antenna Technology is developing information tools on the value of spirulina, the means of producing it, and ways of consuming it.

2.6 Experience shows the acceptability of spirulina

As any change in eating habits is tricky, Antenna's approach is to make spirulina known through nutritional tests done in the locality. In the case of diseases due to malnutrition, the effect of a spirulina supplement is clearly visible in a few weeks: this direct proof of its effectiveness is worth any number of speeches. Once convinced of the value of spirulina, the mothers of the children treated often themselves find the best way of incorporating this product into their meals. However, these demonstrations are linked to emergency situations, situations where the phenomenon of malnutrition is clearly identifiable and understandable by those who are its victims.

When malnutrition is less acute or is simply a risk to be prevented, the acceptability of a new commodity depends almost as much on its presentation as on the accompanying information. In the case of spirulina, the fresh product is distinct from the dry product. In its fresh state, spirulina appears as a thick paste coloured the green of spinach, without taste or smell. It is readily consumed as a spreadable paste that can be spiced or mixed with other ingredients: it can then be used as a garnish for toasts, chapattis, tortillas, millet cakes, etc. It can also be very easily stirred into soups, sauces and porridges, bearing in mind its powerful colouring effect.

Dried spirulina is a little more tricky to use, because of its smell reminiscent of alga or fungus. In this form, it should be mixed with soups, sauces or porridges. In some regions, the powder is stirred into fruit juices, although most people associate spirulina more with savoury or spicy flavours.

However, there are ways of associating the long-term conservation of spirulina with excellent acceptability: that is by preparing dry biscuits (savoury or sweet) with a 15-30% spirulina content (dry weight). The preparation of such biscuits is extremely simple and needs no cooking; on the other hand, it should preferably be done in the immediate proximity of the place of production of the spirulina. These biscuits are obtained by mixing the fresh spirulina paste with crumbs (crushed dry bread or any other crushed dry cake), a little salt and spices. The mass obtained is flattened, cut with a knife and dried away from the sun. For sweet biscuits, fresh spirulina is mixed with broken biscuits reduced to powder. Experience shows that such biscuits need no advertising with children.

2.7 Spirulina: a marketable product - locally

A simple drying procedure and adequate packaging enable spirulina or products enriched with spirulina to be stored over a lengthy period of time. These high-value products can therefore be transported and sold both in local markets and, in principle, in international markets. Antenna Technology's initiative is aimed above all at local autonomy in food; from this point of view, the export of spirulina to international markets would in most cases be a mistake on two counts. On the one hand, it would deprive the local population of a direct means of improving its nutritional status; on the other, it might result in difficulties of profitability. Indeed, independent quality control, which is essential to enter industrialized countries' markets, will probably be beyond the reach of small production units. Moreover, international prices for spirulina in bulk are in the midst of readjustment because of the vary large production units coming on stream, particularly in China. All small and medium-scale production projects should therefore guard against the temptation to amortize their installations rapidly by exporting their output. It has to be underlined that the profitability of installations for the production of spirulina will depend, at least to begin with, on the creation of a local, regional or national market for this new product. It is therefore essential for the transfer of technologies and the necessary knowledge for the creation of new spirulina production units to be accompanied, or even preceded, by the wide dissemination of nutritional information. The local production of spirulina makes sense only when its value is recognized. Accordingly, local training in nutrition should be supported so that information on spirulina can be properly evaluated and properly integrated into broader programmes dealing with overall nutritional education.

Prospects

Antenna Technology is fully convinced that the transfer of knowledge and technologies relating to the local production of spirulina has excellent potential in the fight against malnutrition. The exploitation of this potential

depends, however, on the information and the nutritional education that must necessarily accompany it. First of all, it is essential to make the real implications of malnutrition better known. Apart from the direct and easily detectable effects of dietary deficiencies and malnutrition in all its forms, more and more is now known about subtle effects such as growth retardation, certain mental disorders or immune dysfunction. As research into malnutrition advances, *indirect* and yet very serious effects appear more and more frequently. In view of the many advantages of the local and economical production of a crop capable of improving the daily nutritional intake of populations in the hot regions, Antenna Technology suggests that the self-production of spirulina should become a high priority for the developing countries.

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