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Algae as an Approach to Combat Malnutrition in Developing Countries

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Algae are being increasingly used in our food. Their use is, however, not an entirely new phenomenon as some species have been beneficially consumed in diverse cultures for centuries. Algae's wealth of nutrients has also led researchers to investigate new approaches for combating malnutrition in developing countries. One approach is based on the small-scale production of the microalga "*Spirulina*" and has proved to have considerable potential as a tool for development. Significant work has been done to develop its production and distribution in order to reach malnourished populations. However, although this approach has been successful, support for it by large international organisations is weak, and they do not include it in their development efforts. This might nevertheless change as evidence is accumulated in successful field trials.

1 Algae in Human Food

For centuries, coastal populations have taken advantage of the availability of algae to supplement their food supply, also using it as fertilizer and as animal feed. Traces of algae have been found in the ashes of prehistoric dwellings, which suggests that mankind turned to algae as a source of sustenance at an early time. Algae have been a traditional and timeless food source in the coastal regions of East Asia. In Japan, China and Korea, for instance, they are well anchored in food habits, and their daily consumption keeps algae farms busy. In North America and Europe, consumption is more limited and recent, where production is largely limited to the field of extracted by-products such as alginates and agars. These are used as food additives in a variety of food products for their gelling or thickening properties. However, research is zooming ahead into using algae to develop novel food products, taking advantage of the fact that the functionality of

their compounds goes beyond their basic nutritive value (Cornish et al. 2010). The combined presence of major nutrients – such as vitamins, minerals, antioxidants, rare essential amino acids and fatty acids – has contributed to this trend (MacArtain et al. 2007; Marfaing et al. 2010).

Microalgae have gained particular popularity as a dietary supplement in industrialized countries, where the intake of calories is high but that of micronutrients tends to be low. Human consumption is today by far the largest commercial application of microalgal biomass production (Tramoy 2011). Spirulina, Chlorella and Dunaliella belong to the most commonly found species. In addition to their nutritional value, microalgae bear many potential benefits for human health as is reflected in the impressive amount of research that has been conducted on the pharmacological properties of their specific metabolites. Most of these benefits have yet to be clinically proven, but the fact remains that a simple natural food such as algae may well improve a good number of health conditions (Gerschwin et al. 2007).

2 Meet Spirulina!

Among microalgae, Spirulina is the genus that has gained the most interest as a food supplement.[3] It possesses a complete range of micronutrients and contains an extraordinarily high level of protein (50 % to 70 %). Additionally, it contains all the important vitamins (with the exception of vitamin C) and has high levels of essential micronutrients such as β-carotene, vitamin B12, iron and trace minerals. Moreover, thanks to the absence of a cell wall (unlike other microalgae), it provides an easily digestible product and does not require processing (Falquet et al. 2006). Spirulina is successful in treating some of the most severe forms of malnutrition, such as vitamin A, protein, iron and zinc deficiencies. This is also the reason why it has been traditionally consumed in several regions of the world for centuries. One such group is, for instance, the population in the Kanembu region of Lake Chad, who have notably avoided malnutrition for centuries despite their poor diets, especially in times of famine. This singular food was rediscovered in Chad in the 1950s by a European scientific mission, who described dried green cakes sold in markets and produced from the abundance of Spirulina growing naturally in the lake (Habib et al. 2008).

The rationale for the use of *Spirulina* as a solution to malnutrition brings together several complementary perspectives. Firstly, Spirulina, as a natural product, provides a comprehensive solution to malnutrition as it contains most critical micronutrients. It has frequently been demonstrated to be a truly effective solution. Just one to two grams per day is sufficient to correct a child's malnutrition within a few weeks. In addition, recent studies have shown that Spirulina not only improves children's physical and cognitive development, but also helps people affected by HIV/AIDS to feel better in their daily life and gain weight. Spirulina is also a very cost-effective solution, considering the ratio of production costs compared to its nutritional value. It can be easily cultivated in pool systems with relatively little upfront investment. An installation costs only between 10 € and 20 € per square meter, and a pool of 200 square meters produces enough Spirulina for 1,200 children per year. Finally, just as its traditional use in Chad suggests, Spirulina also sets the foundation for an approach that can create employment and income, establish a sustainable supply chain and therefore generate a long-term impact (Heierli et al. 2007).

3 Small-scale Production as a Development Tool

It is clear that the nutritional virtues of Spirulina are not its only advantages. Producing it locally potentially makes it more appealing than an imported foodstuff. Besides using local resources, product development that is based on local needs will also enhance a product's acceptance among the target beneficiaries. As such, Spirulina farms provide a solution not only to overcome malnutrition, but also to counter unemployment. Teaching locals to produce Spirulina will benefit them in the eyes of their peers as they acquire expertise in production.

Several organisations, such as Antenna Technologies, have created the capacity for developing small-scale Spirulina production, acting as facilitators to encourage local production. This small-scale production is orientated towards easier dis-

tribution to cover both rural and urban communities where the staple diet is poor. Antenna Technologies has developed a method using ponds, which allows local people to grow their own microalgae independently. The key lies in transmitting know-how to target populations so that they can grow and market the microalgae product themselves.

Establishing a Spirulina farm means ensuring that several criteria related to climate (temperatures, light intensity), access to water, competence of local staff, and availability of agricultural fertilizers and bicarbonate are met. The production technology is rather simple and requires little up-front investment. Cultivation may be carried out in unlined ditches or in concrete ponds. Stirring may be provided by a simple device driven by wind energy or by hand. The mature Spirulina is harvested by simple cloth-filtration. After washing the Spirulina in fresh water, it can be directly mixed with the staple diet, without processing or cooking. If needed, Spirulina can also be preserved by immediate drying, with no significant loss in quality or nutritional value (Jourdan 2006).

The major challenge for small-scale Spirulina farms lies in reaching financial sustainability. Once on site, research is carried out to improve productivity, competitiveness and quality. It is in particular related to replacing imported inputs with local products, using cheap construction materials, improving stirring and working conditions, using recycling systems for the growth medium, and improving drying and packaging (Hug et al. 2011).

Small-scale farms in developing countries are fully aware of Spirulina's potential to improve the nutrition of the population, and most are also motivated to develop into commercial businesses. As a consequence, Spirulina farmers in developing countries have mastered the production methods, from sowing to packaging during the past decade. The technical problems encountered ten years ago have almost entirely disappeared, and the quality of Spirulina in developing countries has greatly improved. In several African countries, good manufacturing practices (GMPs) and official quality control systems have been established (Charpy et al. 2008, Birot 2009).

Establishing a Spirulina farm as a local business also requires the creation of an effective distribution network and of an appropriate strategy to teach the local population about the nutritional benefits of Spirulina. One of the most important features of local Spirulina production is to involve local women in the production process and in creating a business for them. These women not only distribute the product but also educate peers about its nutritional values, and thus provide a service to the community. Combining local production with its distribution is a key for achieving an efficient and long-lasting impact. Hence Spirulina not only emerges as a remedy for malnutrition, but also as a true tool for development (Heierli et al. 2007).

Fig. 1: Small-scale Spirulina farm in a developing country*

* Spirulina farm in Sékong, Laos, established 2011 with support from Antenna. Small-scale Spirulina production is a relatively simple and straightforward process. It essentially consists of managing water and fertilizer levels, stirring, harvesting and drying.

Source: Antenna 2011

4 Spirulina as a Business to Combat Malnutrition

Having the beneficiaries contribute as customers is part of the paradigm of a sustainable long-term strategy to combat malnutrition. This implies the necessity of making it so affordable that even the poor can contribute to the production cost of Spirulina-enriched products. As a public health solution, Spirulina must be marketed as a tangible product plus as a service in the form of information about its usefulness. In this sense, the product has to include an outreach strategy: the product should not only be easily consumed but also be distributed in such a way that it reaches the populations who need it most (Heierli et al. 2007).

The business model identifies children and lactating women as the primary target group. As malnutrition can inflict its most severe impact on young children, it is important to reach this target group through their mothers, who can be relied on to convey the message of nutrition from peer to peer. Such an approach is especially relevant in countries where promotion through the conventional media is not suitable because of its low coverage and the high illiteracy rates. Sales activities may indirectly contribute to the fight against malnutrition as the additional income from being part of the value chain can result in improved food intake by both women and their children. Women therefore not only represent sales channels but are also beneficiaries (Heierli et al. 2007).

Product development requires a deep understanding of the needs of the customers and the local circumstances in order to develop a functional solution that incorporates critical features into the design of the product. In its raw form, Spirulina may only be sold to those who are already convinced of its value. For a wider market, a more attractive product is needed. In order to reach targets such as malnourished children, product development is therefore an area that deserves much attention. The product needs to be easy to chew and distribute and to be produced locally with simple technology. There are several examples of specifically designed products meeting these requirements. The Spirulina enriched "chikkies" found in India are an excellent example of such product development, based on local needs and local resources. A chikki is a kind of energy biscuit based on peanuts and belongs to the most popular snacks for children in India. Spirulina chikkies were hence very well accepted (Heierli et al. 2007). Another recently marketed product in India takes the form of a candy. This product represents another example of such a link to successfully reach poor and malnourished children. Its retail price (1 INR = 0.02 €) lies within the price range for a regular snack that poor children in India can afford. It is therefore competitive, affordable and also represents a business opportunity for sales women (Antenna 2011).

5 Food Aid and Development Policies

The use of small-scale Spirulina production as an approach to combat malnutrition is mainly being promoted by NGOs and local health institutions in developing countries. Their work is being urged on by numerous positive field experiences and endorsed by the growing evidence from clinical studies (see the next section). In spite of this, large international organizations and UN agencies such as the WHO, the WFP and UNICEF still do not clearly recommend it or promote its use. To date, these agencies have taken only non-committal positions on the use of Spirulina in the fight against malnutrition. The fact that Spirulina in this context is neither a medicine nor a foodstuff may have represented a hurdle. Should Spirulina be assessed from the perspective of malnutrition as a public health matter (then under the responsibility of the WHO), as a food security matter (FAO) or rather as an issue about the condition of children (UNICEF)? In the end, none of these institutions truly takes a stand.

This situation may soon change, since several countries, such as Burkina Faso or Senegal, have implemented governmental plans to develop the cultivation of Spirulina. Moreover, in 2005, several African and South American countries put forward a draft resolution demanding a clear stance from the UN General Assembly in favour of the production and use of Spirulina.[4] Under this mandate, the FAO prepared a review on the subject in 2008 (Habib et al. 2008).[5] Although the review covers the issue of malnutrition only superficially, it nevertheless recognizes the potential of Spirulina in this field. In its re-

port, the FAO made two recommendations in this regard (Habib et al. 2008, p. 26):

1. "International organizations working with Spirulina should consider preparing a practical guide to small-scale Spirulina production. This small-scale production should be oriented towards: 1) providing nutritional supplements for widespread use in rural and urban communities where the staple diet is poor or inadequate; 2) allowing diversification from traditional crops in cases where land or water resources are limited."
2. "There is […] a role for both national governments – as well as intergovernmental organizations – to re-evaluate the potential of *spirulina* (emphasis by the author) to fulfill both their own food security needs as well as a tool for their overseas development […] ."

The first recommendation is widely followed today, since the NGOs working with Spirulina have continued their efforts to develop and promote it. In recent years, considerable progress has been achieved in this domain in dozens of countries. Antenna Technologies, for instance, is involved in Spirulina programmes in more than ten African and Asian countries. Regarding the second FAO recommendation, a lot of work still needs to be done. In its latest guidelines regarding the choice of foods and ingredients for moderately malnourished children, the WHO concluded (for the first time) that Spirulina could play a role in treating children with moderate malnutrition and recommended further investigation of this subject (Michaelsen et al. 2009).[6] This has been a slow progression fed by a large number of successful field initiatives and accumulating evidence.

6 The Evidence on Spirulina in Malnutrition

The need to increase acceptance among policymakers calls for more systematic research on the role of Spirulina in the context of malnutrition. Here is a survey of some of the most recent clinical trials conducted with Spirulina, in particular with children and vulnerable populations (such as HIV/AIDS individuals), that helps provide compelling evidence.

- In India, a randomized clinical trial with 60 schoolgirls addressed not only the purely nutritional effects of a small intake of Spirulina (1 g/day), but also the possible indirect effects on their cognitive development (Sachdeva et al. 2004). This study led to positive and statistically significant results both on the haematological condition of the pupils and on their intellectual performance. It ends with a recommendation to the Indian government that it supply Spirulina free in schools, particularly in deprived regions.
- In Burkina Faso, a comparative study on the nutritional recovery of 170 children (of which half were HIV positive) demonstrates the benefits of Spirulina in the treatment of child malnutrition, as well as its particularly positive impact on the nutritional rehabilitation of HIV-infected children (Simpore et al. 2005). Another work by the same authors compared the nutritional benefits of diets composed of Spirulina or of misola[7] (Simpore et al. 2006). The study was on 550 severely malnourished children under the age of 5. An increase in body weight was observed in all children, especially those whose diet was made up of both Spirulina and misola. The authors concluded that Spirulina and/or misola added to traditional food constitute good diets for severely malnourished children. The diet with Spirulina and misola yielded the best results, because it combines misola's high caloric value with Spirulina's high protein and micronutrient content.
- In the Central African Republic, a 6-month randomized trial was carried out with adults infected and affected by HIV (Yamani et al. 2009). A total of 160 patients were divided into two groups. Patients in the first group received 10 grams of Spirulina per day, while patients in the second group received a placebo. This study showed a significant improvement on the main endpoints (e.g. weight, arm girth, number of infectious episodes, CD4 count). However, no clear conclusions could be drawn from a clinical standpoint because of methodological problems reported by the authors.
- In Cameroon, a randomized single-blind study of 52 malnourished HIV adults compared a group given a supplement of Spirulina to another given one of soya beans (Azabji-Kenfack

et al. 2011). This work showed significant improvements in anthropometric, biological and immunological parameters in HIV-positive malnourished patients receiving Spirulina. The authors concluded that there is sufficient evidence to regularly provide Spirulina to such patients.

These recent clinical trials regarding malnutrition show that Spirulina is associated with a positive impact on children's nutritional status as well as on other critical health outcomes. However, these trials still suffer from the same weaknesses as earlier studies, namely regarding their statistical power (due to, for example, the small study populations and short follow-up periods), and are subject to some criticism regarding their methodology. A systematic review from 2008 that analysed the previous studies also came to this conclusion, recommending that a large double-blind clinical trial be conducted to provide more conclusive results (Halidou Doudou et al. 2008). Such a trial would obviously be desirable, but one must keep in mind the difficulty of conducting such studies in developing countries and even more in finding sponsors. Despite several attempts to raise funds for this purpose, nothing has materialised. Nevertheless, there are numerous positive results, combined with successful field experience over the years, which should start to provoke reactions from decision makers.

7 Conclusion

In developing countries, malnutrition poses a heavy burden with devastating socio-economic consequences. Although there are many strategies for fighting malnutrition, a solution must be local in order for it to be sustainable and avoid an economy of dependence. In this connection, an approach utilising algae and involving the growing and processing of a simple microorganism as a source of alternative food supplements might represent one of the most promising approaches in the long term. Producing Spirulina and distributing it by developing special products may not be cheaper than the classic feeding approaches to malnutrition, however it presents advantages in terms of local ownership and microeconomics. Much work is involved in building up viable local production units. Similarly, the broad set of required activities – from the marketing of Spirulina products to the involvement of women in feeding programmes – adds dimensions which are given less emphasis in common feeding schemes. The aims of combating malnutrition, on the one hand, and relying on social entrepreneurship to ensure sustainability, on the other, represent unique challenges. But in a world confronted by severe economic crises, which make the funds for development more uncertain, such efforts seem more necessary than ever.

Notes

1) The Antenna Technologies Foundation is an international organization headquartered in Geneva (Switzerland), whose goals are to identify, develop and favour the diffusion of efficient technologies that are suitable for populations with limited resources in developing countries. In order to fight malnutrition, Antenna Technologies has developed tools and trainings especially adapted to the local production of Spirulina in a sustainable way. Today, Antenna Technologies is involved in Spirulina programmes in more than ten countries in Africa and Asia. http://www.antenna.ch, http://www.antenna-france.org, http://www.antennaindia.org
2) We would like to thank Christopher Morgan, Michael Briner and Fanny Lansaque for their valuable suggestions on the manuscript.
3) Most of the information presented in this paper was taken from following sources: Hug, Weid 2011 and Heierli, Weid 2007. These sources and additional documentation about malnutrition and Spirulina can be found at: http://www.antenna.ch/en/research/malnutrition/documents.
4) The UN draft resolution on Spirulina submitted during the 60th session of the UN General Assembly (2005) about "The use of Spirulina to combat hunger and malnutrition and help achieve sustainable development", available at: http://www.un.org/ga/60/second/draftproposals.htm.
5) The FAO Review on Spirulina (2008) can be downloaded from the following address: ftp://ftp.fao.org/docrep/fao/011/i0424e/i0424e00.pdf.
6) Conclusions and recommendations on microalgae and Spirulina in the WHO guidelines on foods and ingredients for moderately malnourished children from 6 months to 5 years of age: "Microalgae may be good sources of micronutrients and high-quality protein, but availability might be low due to the cellulose content. Spirulina, a cyanobacterium, seems to have protein and micronutrients with a better bioavailability and has a high content of n-6

PUFAs. Some studies suggest that Spirulina could have a role in treating children with moderate malnutrition, but this should be investigated further." (Michaelsen et al. 2009, p. S378–S379):

7) Misola is a common nutritional complement composed of millet (60 %), soy (20 %), peanuts (10 %), sugar (9 %) and salt (1 %), which is widely used for malnourished children in West Africa.

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