SPIRULINA CULTIVATION IN CHINA

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Abstract This paper reviews and discusses the development and many problems of *Spirulina* cultivation in China, points out the advantages and disadvantages of open photobioreactor system, and predicts that seawater *Spirulina* cultivation will be a new trend to be strengthened and emphasized due to its special physiological characteristics, easier management, lower fertilizer cost, and higher resistance to contaminants and rare pollution of chemicals.

Key words: *Spirulina*, cultivation, open photobioreactor, closed photobioreactor

INTRODUCTION

Discovery, cultivation and industrialization of *Spirulina* (Cyanophyta) are some of the most important achievements in the field of algal cultivation studies in the world since the 1960s in view of its abundant nutrients, special bioactive substances, and successful cultivation in its open photobioreactor system (Richmond, 1986, Vonshak et al., 1988). It took only a little more than 10 years for the raw product to go from the field, pass through laboratory studies, and on to the local and world markets as very high value commercial products. In the last few years, *Spirulina* has very rapidly become more and more popular in the possibly biggest market of the world, China. *Spirulina* products, mainly in the form of tablets or capsules, form a very competitive market, as more and more consumers are benefited from its nutritive and medicinal values. Most consumers generally consider *Spirulina* as health medicine, not solely as nutrient food. Hundreds of tons of dried *Spirulina* powder are exported every year by some *Spirulina* enterprises founded in the last five years. Basic studies on its cultivation and application in all aspects have been widely carried out in many universities and institutes (Hu, 1996; Li et al., 1996). The achievements in, principal problems of, and prospects for, *Spirulina* cultivation in China are reviewed and discussed below.

DEVELOPMENT AND PRESENT CONDITION OF *SPIRULINA* CULTIVATION IN CHINA

In the early 1980s, the high protein content of *Spirulina* attracted the great interest of some Chinese phycologists. *Spirulina* species introduced from foreign laboratories or isolated in China, include *Spirulina platensis*, *S. maxima*, *S. sabsalsa*, *S. major*, *etc.* (Tseng, 1995; Wu et al., 1985). Two main species cultivated at present, *S. platensis* and *S. maxima*, were originally from Africa's Chad Lake and Mexico's Texcoco Lake. *S. platensis* is more widely cultivated as it is more stable in growth and more easily controlled in production.

In the early stage of *Spirulina* introduction to China, experiments on its "seed" selection, culture condition, physiological and biochemical characteristics were widely conducted, and were further strengthened by a key program of the National 7th Five-year Plan (1986 – 1990) on production of algal proteins (Tseng, 1995). Many strains were isolated and selected from the above two main species to see if they could adapt to different environments. The SCS strain of *S. platensis*, grows particularly well in seawater medium in tropic climate, and *S. maxima* SW1 strain shows good adaptation to lower temperature (Wu et al., 1988). *Spirulina* outdoor mass cultivation on about 100 m^2 scale was carried out in the provinces of Shandong (Qingdao), Hubei (Wuhan), Jiangsu (Nanjing), Jiangxi, Guangdong (Guangzhou, Huilai and Zhanjiang) and Hainan (Sanya) during 1984 – 1989 (Tseng, 1995).

In the later 1980s, an important experiment on large-scale (3000 m^2) cultivation of *Spirulina* in seawater medium with a fully mechanized process of agitation, harvesting and spray-drying was initiated in Huilai, Guangdong Province, by the South China Sea Institute of Oceanology, CAS and sponsored by the National Key Program (Wu et al., 1993). This project was the first large-scale experiment on *Spirulina* cultivation in seawater medium not only in China, but also in the world. A solid foundation for initiation of commercial cultivation of *Spirulina* in seawater medium was thus laid. The first plant for *Spirulina* cultivation on commercial scale in seawater medium was set up in 1993 in Sanya, Hainan Province (Wu et al, 1996). A few freshwater *Spirulina* plants were also set up (Tseng, 1995).

Table 1 Estimation on development of industrialized cultivation of *Spirulina*

(data collected and estimated by the authors, up to Aug., 1997)

Year	Number of *Spirulina* plants	Total area of culture ponds (× 10000 m^2)	Designed capacity (t, dryweight)	Real total yield (t, dryweight)
1992	3	2 – 3	40	15
1993	10	10	150	20 – 30
1994	20	20 – 30	300	50 – 80
1995	80	80 – 100	1200	150 – 250
1996	100 – 120	100 – 150	1500	300 – 500
1997(August)	100 – 120	100 – 150	1500	50 – 100

In the last few years, the development of *Spirulina* enterprises has become uncontrollable. So many enterprises bloomed that nobody knows exactly how many were or will be set up, and how large they will be in their total scale and yield (Li , 1996). It is said that the production capacity of all plants sums up to 1000 tons, or even 2000 tons, but in fact, the actual annual production is no more than 500 tons in the recent three years. Enterprises are widely distributed in China (from the southern end of Hainan Province to Liaoning Province in the north, and from Yunnan and Sichuan Provinces in the west to Zhejiang Province in the east) and straddle tropical, subtropical and temperate regions. Actually, the southern part of China with tropical or subtropical climate, and occa-

sional rain and unpolluted environment, locations such as Sanya or Donfang, Hainan Province are best for the cultivation (in terms of quantity and quality) of *Spirulina* (Tseng, 1995). Quite a few *Spirulina* cultivation enterprises in China do not pay sufficient attention to the importance of environmental factors in *Spirulina* cultivation. As a result, most enterprises have a considerably low annual yield, averaging at 3 – 5 $g/(m^2 \cdot d)$. The product quality is different from one enterprise to another, and is unstable even in the same one. The main quality problems in most enterprises are: comparatively low content of proteins; high content of heavy metals surpassing the National Standard for health; loss of bioactives due to over-heating in drying process or unsuitable culture management, contamination by amoebae, rotifers and other algae (*Chlorella*, etc.), resulting in bad odour or taste, and low quality and yield. The reasons are complicated, and are partly due to immature techniques and lack of biological or related knowledge, partly due to poor management and administration, partly due to environmental factors and partly due to lack of marketing knowledge (Hu, 1996; Li, 1996), which will be further discussed in the following section.

PROBLEMS IN OPEN PHOTOBIOREACTOR SYSTEM FOR *SPIRULINA* CULTIVATION

At present the Chinese *Spirulina* industry uses the open photobioreactor system in which the *Spirulina* is generally cultivated in the open and a few covered raceway ponds, stirred and circulated by paddle wheels with controllable speed. There are quite a few problems involved. The most important of all is that some investors themselves and their technicians do not have the necessary knowledge of microalgal cultivation; they thought that the production of *Spirulina* was very simple, just consisting of building the necessary cultivation ponds, adding water to the ponds, sowing the "seeds" and needed nutrients to the water, occasional stirring of the culture, and that after a few days, the culture solution will turn deep blue green, and be ready for harvesting. They do not realize that the culture should be pure in species and not be infected by protozoans, rotifers and other organisms, or the result will be total failure of the culture. Some culture ponds were located in cloudy places or where it rains most of the time, temperature was too low for active growth of the algae, or near industrial region or highway bringing in chemical pollutants such as Pb or Hg to the culture.

SEAWATER MEDIUM CULTURED *SPIRULINA*: FROM LABORATORY TO FACTORY AND TO THE MARKET

Since the early stage of *Spirulina* studies, sufficient attention has been paid to seawater cultivation of *Spirulina* (Cheng, 1996; Vonshak et al., 1988). At present, in China there is only one strain of *Spirulina* (*S. platensis* SCS strain) that has been successfully and stably cultured on industrial scale in seawater based medium (Wu et al., 1996).

The SCS strain was isolated and selected from freshwater *S. platensis* originally from Chad Lake and was adapted to seawater-based medium. Experiments on mass culture were conducted in

Zhanjiang (1988 - 1987), Sanya (1988 - 1990), and Huilai (1986 - 1989), and further experiments on large-scale industrial cultivation were carried out in Huilai (1989 - 1990). The first commercial seawater *Spirulina* plant was set up at the Tropic Sanya area in 1992. Up to now, the total area of seawater *Spirulina* cultivation is about 40000 m^2 for production capacity of above 80 tons. The yield of seawater *Spirulina* varied from 10 to 12 g/(m^2·day) during our experimental cultivation, and 7 - 10 g/(m^2·day) during the large scale commercial production. Commercial products of seawater *Spirulina* including algal powder, tablet, natural blue colorant phycocyanin, and highly purified phycobiliproteins have been developed. The former two products are already in the market (Wu, et al., 1996, 1985, 1988, 1992a, 1992b, 1993; Xiang et al., 1991, 1994, 1995).

In our studies in both experiments and in commercial production, the advantages of cultivating *Spirulina* in seawater medium (compared to freshwater medium) are: (1) lower fertilizer cost; (2) saving precious farm land by using waste sea beach; (3) the medium after harvest can be repeatly used; (4) the pH of the seawater medium constantly remains at 9 - 10 and need not be adjusted; (5) seawater culture is not easily polluted by heavy metals and contaminants. Hence the yield and quality are both improved (Wu et al., 1992a, 1993).

The most important advantage of cultivation of *Spirulina* in seawater medium is the avoidance of heavy metal pollutants and biological contaminants. Problems of pollution or contamination in freshwater cultivation of *Spirulina* production are difficult to avoid but they rarely occur in seawater cultivation. Its particular, the physiological characteristics, such as very high resistance to heat stress (up to 40℃ or even higher) and light stress (100000 Lx or more) lead to the higher photosynthetic efficiency of *Spirulina*.

Table. 2 Comparison between products of seawater *Spirulina* SCS and freshwater *Spirulina* in main bioactives

Bioactives	Content (% dryweight)	
	SCS[a)]	Freshwater *Spirulina*[b)]
Inositol	2 - 2.5%	0.04 - 0.1%
Phycocyanin	14 - 18%	3 - 7%
Chlorophyll	1.0 - 2.5%	0.8 - 1.0%
GLA	2 - 3%	1 - 2%
Solub. polysacch..	7 - 8%	2 - 3%[a)]
Iodine	0.01	trace[a)]
Selenium	0.00005 - 0.0002	trace[a)]

a) Analyzed by the authors and their co-workers, b) DIC, 1985; 1991

PROSPECTS

The following suggestions are proposed for the development of food grade *Spirulina* cultivation in China: (a) Each enterprise should have technicians well trained in microalgal cultivation; (b) Each enterprise should select and use strains or "seeds" with high resistance to environmental stress, particularly to high DO concentration and high temperature, which are the main limiting factors for

Spirulina growth both in open and closed photobioreators (Marquez et al., 1995; Richmond, 1986; Singh et al., 1993; Tredici et al., 1993); (c) Each enterprise should take suitable and effective precaution against contamination and environmental pollution; (d)It is necessary for any enterprise, trying to develop a closed photobioreactor system, to simplify the structure and lower the cost of the solid system (Li et al., 1996; Miu, 1996; Tredici et al.,1993); (e) Each enterprise should apply on-line automatic analysis of culture condition, for example, DO, CO_2, nitrogen elements etc. in open ponds, in which the sensors should be of lower cost, better stability and higher sensitivity.

The *Spirulina* industry will definitely flourish in China in spite of its present chaotic condition. China is a big country in urgent need of raising the protein content of food. With good technicians and good management, China's *Spirulina* for human consumption should unquestionably increase enormously in quantity and improve in quality. The day will soon come when China becomes the most important country in *Spirulina* production.

Spirulina for human consumption is not the sole object of the Chinese *Spirulina* industry. In fact at the start of the 7th National Five-year Program, *Spirulina* was not intended for human consumption. It was initiated to develop *Spirulina* as one of the three algae grown for animal feed. At the conclusion of the national Five-year Program, it was found that *Spirulina* was the best alga for cultivation for animal feed. In fact in the early eighties *Spirulina* was already under cultivation for animal feed in Jiangxi Province. In the early nineties, people realized the value of *Spirulina* to human health and started to cultivate *Spirulina* for human consumption. At present, *Spirulina* tablets and other forms such as drinks or even noodles can be obtained in many places in China.

There are, therefore, two goals of *Spirulina* production: production for human consumption, as food and or medicine; production for animal feed. For production of the food grade *Spirulina*, more research should be done, experienced technicians should be employed and good location should be selected. For production of the feed grade *Spirulina*, anywhere in China should be encouraged, and production in open bioreactors will be sufficient, and can be effected just by the present methods. We believe that China will need not hundreds but thousands of *Spirulina* production enterprises for making the necessary feeds. We should say again, that *Spirulina* production for human consumption and for animal feed will be a big industry in China, undoubtedly, the biggest in the whole world.

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