

Spirulina (*Arthrospira*) industry in Inner Mongolia of China: current status and prospects

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Abstract This paper outlines an investigation on current situation of *Spirulina* (*Arthrospira*) industry in Inner Mongolia, an internal region of China with temperate continental climate. More than 20 *Spirulina* plants have been established in Inner Mongolia since 2001, most of which are located at Wulan Town in the Ordos Plateau. By the end of 2009, the total annual production of *Spirulina* in the Ordos Plateau surpassed 700 t (dw), which account for ca. 80% of the total productivity of Inner Mongolia, and ca. 20% of China. Besides abundant solar radiation and enough freshwater favorable for *Spirulina* production, the three technical strategies contribute to the prosperity and success of *Spirulina* industry in the region: (1) reducing the cost or investment by overall advantages of rich local natural resources with low cost for *Spirulina* production, such as alkaline lakes, coal, electricity, and sandy land; (2) controlling the culture temperature and to avoid contamination by building plastic greenhouses on raceway ponds, (3) reducing investment by simplifying the construction of the ponds and the greenhouses. As the result, the growth period of *Spirulina* has been prolonged from about 120 to about 165 days, the cost of *Spirulina* has decreased by 25–30%, and the quality of products has been enhanced

substantially. Inner Mongolia is expected to become the largest base for *Spirulina* production not only in China, but also in the world in the near future.

Keywords *Spirulina* production · Alkaline lake · Temperate climate · Plastic greenhouse · Inner Mongolia

Introduction

Spirulina (*Arthrospira*), a blue-green alga containing unusual high amounts of balanced proteins and a wide range of abundant nutraceuticals, is one of the most promising microalgae in the market since the success of its commercial production in open raceway ponds in the 1980s (Voushak and Richmond 1988). *Spirulina* cultivation plants have sprung up in China since the early 1990s. By the mid 1990s, China has become the biggest country in *Spirulina* production in the world (Li and Qi 1997; Wu et al. 1998). Total production of *Spirulina* in China was about 2,500 t (dw) in 2006 (Hu 2007). According to our observation and investigation, up to 2009, 3,500 t (dw) of *Spirulina* have been produced.

Inner Mongolia has a mid temperate climate with an annual average temperature of 6.4°C which greatly limits the growth of *Spirulina* (Qiao et al. 2001). Although there were several reports examining the feasibility of industrial production of *Spirulina* in temperate climates earlier (Jiménez et al. 2003), most *Spirulina* plants at present are located at tropical and sub-tropic area in the world since *Spirulina* is thermophilic with optimal growth temperature between 35 and 38°C (Li and Qi 1997; Belay 1997; Wu et al. 1998).

Consequently, it is of significance that large-scale commercial production in Inner Mongolia has been achieved.

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This paper analyses how the *Spirulina* industry was established successfully in Inner Mongolia, and discusses the prospects of local *Spirulina* industry. Suggestions for sustainable development of commercial production of *Spirulina* in this region in the future are made.

History and present status

Local species of *Spirulina* were discovered in alkaline lakes in the Ordos Plateau of Inner Mongolia in 1995, and at least three species, including *Spirulina* (*Arthrospira*) *platensis* and two other novel species of *Arthrospira* were discovered and isolated (Li et al. 2003; Hu 2007). In 1997, a pilot-scale experiment was conducted to probe the feasibility of commercial production of local *Spirulina* species in Inner Mongolia (Qiao et al. 2001), but no further progress was reported. In 2001, the first commercial *Spirulina* plant with open raceway ponds was established in Ordos Plateau (Hu 2007).

In the early stage (2001–2003) of *Spirulina* production in Ordos Plateau, the culture in open raceway ponds was affected by the low temperatures and sand storm which resulted in low quality and productivity of products. The majority of *Spirulina* produced in this stage was sold with low profit as low-grade animal feeds. Because of the technical improvement in *Spirulina* production after 2003, the total annual production of *Spirulina* increased rapidly. The total annual production of *Spirulina*, as well as total ponds area in Ordos in the past 4 years is presented in Fig. 1. The major manufacture plants in Ordos City and their production data in 2008 are listed in Table 1. It shows that the productivity of *Spirulina* in Ordos during production period is close to or even higher than that of sub-tropic or tropic areas in China (Li et al. 2003; Wu et al. 1998).

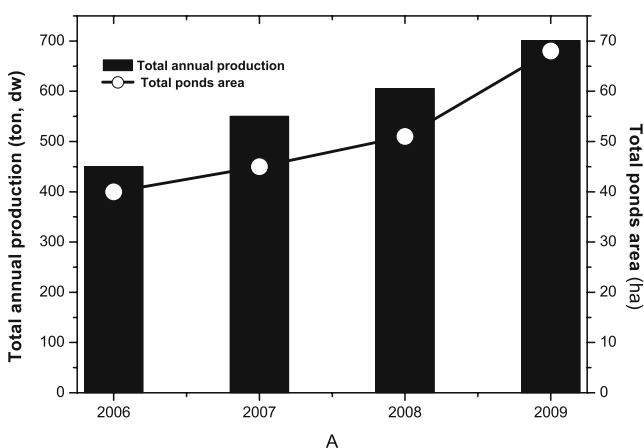


Fig. 1 Total annual production of *Spirulina* and total pond area in the last 4 years in Ordos city

Up to now, more than 20 companies have produced *Spirulina* in different areas of Inner Mongolia, including Ordos City, Alxa Meng and Bayannaoer Meng. Most *Spirulina* plants in Inner Mongolia are located at Wulan Town in the Ordos Plateau, southwest Inner Mongolia. Total ponds area of at least 13 companies, covering more than 70 ha, is used for large-scale cultivation of *Spirulina*. Based on our investigation, in 2009, the total annual production of *Spirulina* exceeded 700 t (dw) in Ordos, about 80% of *Spirulina* produced in Inner Mongolia and about 20% of that in China.

It has been indicated that several native *Spirulina* (*Arthrospira*) species isolated in Inner Mongolia have potential for commercial production (Li et al. 2003; Hu 2007). However, according to our investigation, another two common foreign species, *S. platensis* from Lake Chad, Africa, and *S. maxima* from lake Texcoco, Mexico, both of which are thermophilic, are used widely in present commercial production in Inner Mongolia.

Since both the quality and productivity have been enhanced in recent years, most of *Spirulina* produced in Inner Mongolia is sold as food, food additive, high-grade animal feeds, and bioactive substances with phycocyanin and polysaccharides involved. The alga powder as human food or animal feed was the main product sold earlier, however recently, with an increasing need for *Spirulina* tablets as health foods whether from China or overseas, many *Spirulina* plants in Inner Mongolia have begun to produce *Spirulina* tablets, bringing more unit profit than alga powder. Meanwhile, some high-value products, such as phycocyanin, polysaccharides and polypeptides extracted from *Spirulina*, have been developed, but the market is very limited. One company produces and sells fresh biomass of *Spirulina* in the form of oral liquid (Table 1).

In fact, Inner Mongolia has become one of the most important bases for commercial production of *Spirulina* in China. Compared with other places in China, the cost of *Spirulina* production in this region has decreased by 25–30%, which has become the main impetus for development of *Spirulina* industry.

What has happened in recent years for *Spirulina* production in Inner Mongolia? The following information and discussion about the advantages, disadvantages, and technical strategies for *Spirulina* production in Inner Mongolia attempts to answer this question.

The advantages, disadvantages, and strategies

First of all, due to a large number of alkaline lakes are located in Inner Mongolia, bicarbonate with a very low price can be used for *Spirulina* cultivation. In Ordos plateau alone, there are 65 alkaline lakes in over a 1-km² area, with

Table 1 Main *Spirulina* plants in Ordos and their production profile in 2008

Company	Ponds area (ha)	Annual production (Ton, dw)	Productivity ($\text{gm}^{-2} \text{d}^{-1}$) ^a	Products sold
Shuangfengbao Greenalgae Co., Ltd.	9.30	132	8.61	Alga powder as food and animal feeds
Luyuan microalgae Co., Ltd.	6.20	57	5.57	Alga powder, oral liquid, phycocyanin, polysaccharides
Erdos Jiali <i>Spirulina</i> Co., Ltd.	6.50	83	7.74	Alga powder, tablets, polypeptide
Luweibao <i>Spirulina</i> Bioeng. Co., Ltd.	4.75	58	7.41	Alga powder, tablets, capsule
Mengjian <i>Spirulina</i> Industry Co., Ltd.	3.00	39	7.88	Alga powder as food and animal feeds
Bulonghu Bioeng. Develop. Co., Ltd.	4.09	38	5.64	Alga powder, capsule
Derong algal Industry Co., Ltd.	3.80	57	9.09	Alga powder, tablets,
Lufeng Bioeng. Co., Ltd.	2.84	28	5.97	Alga powder, tablets,
Weida <i>Spirulina</i> Industry Co., Ltd.	4.52	65	8.72	Alga powder, tablets
Huayitai <i>Spirulina</i> Co., Ltd	5.50	48	5.29	Alga powder, tablets

^a The productivity was calculated on the basis of average annual production period, 165 days

a total area of all alkaline lakes of 189 km² (Qiao et al. 2001). Generally, according to our analysis and recorded data, high concentration of alkali exists in most alkaline lakes in the forms of carbonate and bicarbonate. In some lakes, alkali concentration is over 260 mM. An important technical strategy in many plants is to utilize alkaline mother liquor which provides bicarbonate for *Spirulina* growth. Through application of the new strategy, the cost of bicarbonate, calculated on the basis of solid form, has decreased to 19–43 US\$ per ton, much lower than that of commercial bicarbonate (food grade), at about 190 US\$ per ton.

Secondly, the short rainy season, long daylight hours and the abundant solar energy in this region are optimal natural conditions for *Spirulina* production. The average annual precipitation is between 280 and 360 mm and average annual daylight sunshine is 3,000 h. Total annual solar radiation is 5,730–5,930 MJ m⁻² in this region, which will provide plenty of solar energy for growth of *Spirulina*.

Thirdly, with rich coal resources, the price of electricity supplied by coal-fired power plants for *Spirulina* production in Inner Mongolia is much lower than other places in China. Moreover, coal could be used in spray-drying, which could save 50–80% of the drying cost of *Spirulina*, compared with other places in coastal or middle region of China. Encircled by the Great Bend of the Yellow River, the Ordos plateau provides plenty of clean surface and underground fresh water.

Finally, since the climate of western Inner Mongolia like Ordos Plateau is semi-arid, the sandy land around alkaline lakes, mostly desert, is very cheap. Therefore, due to the land price, along with simplified construction of culture ponds which are underlain by plastic liner after the ground is leveled, compacted, and shaped as the structure of raceway ponds with the help of simple and cheap

framework, the cost of investment to construct a *Spirulina* plant has decreased significantly compared with other places in the developed eastern coastal region of China.

However, considering specific disadvantages for *Spirulina* production in this region, some special measures are taken. The average annual temperature is 6.4°C with a long period of frost days. Low temperature is the key obstacle for *Spirulina* cultivation. There would be only a period of ~120 days for *Spirulina* growing in open raceway ponds in this region if no measures are taken to control the culture temperature. Meanwhile, since strong wind and sandstorms often occur here, sand, dust and possibly microbes will contaminate *Spirulina* cultures in open ponds and reduce the quality of the product. In order to overcome these problems, one of the most important strategies in *Spirulina* cultivation in this region is to build plastic greenhouses over the raceway ponds (Fig. 2, 3). The plastic greenhouse is made of a cheap framework (mixture of steel and bamboo or wood) and transparent plastic membrane. The plastic greenhouse enhances the culture temperature significantly (Fig. 4) and prolongs the growth period up to an average of 165 days with a maximum of up to 180 days. The maximum daily temperature of the culture is over 30°C and up to 42°C from May to September, and over 20°C and up to 39°C except for a several days in April or October.

With the help of the thermo-proof plastic greenhouse, the diurnal variation of culture temperature is 3–5°C in most days of growth period, which are optimal for *Spirulina* production. However, in the early stage (April) of the year, “seeds” management (incubation and expansion) is very important for *Spirulina* production of the whole season and is constrained easily by extra low temperature during cloudy or rainy days in April (Fig. 4). In some plants, temperature of “seeds” culture in night is maintained by an

Fig. 2 A typical *Spirulina* plant with plastic greenhouse at Wulan Town, Ordos City; Photographed by Yong-Huang Wen



additional thermo-proof layer made of synthetic fiber cotton and covering the greenhouse of “seed” ponds. The “seed” culture is also electrically heated in several plants in this stage, which maintains culture temperature at over 25°C all day. By using these combined methods of temperature control, *S. platensis* or *S. maxima*, which are thermophilic algae (Vonshak 1997), can be used in this area as the “seeds” of large-scale cultivation.

By utilizing all the advantages and technical strategies above, the total annual production has increased sharply, the quality has been improved, and the production cost of *Spirulina* has decreased in recent years in Inner Mongolia.



Fig. 3 Simplified inner structure of the culture pond and the greenhouse for *Spirulina* cultivation at Wulan Town, Ordos City. Photographed by Yong-Huang Wen

After offsetting the extra cost of transportation, investment in the construction of greenhouses and others, the cost of *Spirulina* production here is 25–30% lower than elsewhere (ca 3–4 US\$ kg⁻¹) in China. Now, the quality of *Spirulina* produced in Ordos Plateau is comparable with that produced in other places in China, meeting the requirement of food safety not only in China, but also in the EU.

Consequently, a novel model for commercial production of thermophilic *Spirulina* with large-scale was formed in temperate attitude, which would be of great significance both for China and for other places in the world.

Problems, prospects, and suggestions

There are noticeable differences in *Spirulina* production among different companies (Table 1). According to our

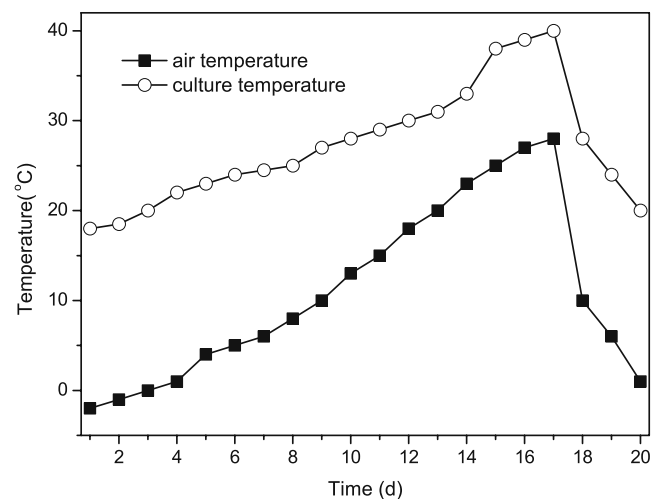


Fig. 4 Effect of plastic greenhouse on temperature controlling of the *Spirulina* culture. Outdoor air temperature and maximum culture temperature is recorded on 13:00 pm in consecutive 20 days in April, 2009 in a *Spirulina* plant at Wulan Town, Ordos City

investigation, many technical factors, including strain or species, “seed” management, control of culture conditions, harvest of biomass and cyclically reusing the culture medium, contribute to this. There are many differences in these aspects among different companies, for instance, different companies use different sources of “seed” (strains) of *Spirulina*, and different models of “seed” management are applied in different seasons by different producers. Some companies do not pay enough attention to control temperature overnight when “seed” expansion begins in April and others maintain the “seed” under suitable scale and optimum temperature even in winter. There are also many differences in other technical aspects of *Spirulina* production.

All these differences indicate that there is no common technical standard in *Spirulina* production among companies in this region currently. Therefore, we suggest that a general technical standard be set up as the guide for the producers in this region, forming protocols on four technical aspects in *Spirulina* production: (1) strain or species and “seed” management; (2) control of temperature, cell density, dissolved oxygen, pH, and speed of paddle wheel; (3) strategy for addition of CO₂ and nutrients; (4) strategy for biomass harvest and reuse of old medium. Among these, “seed” management and temperature control are particularly important for *Spirulina* production in temperate Inner Mongolia. Meanwhile, standard for quality controlling in *Spirulina* production and processing, for instance, GMP, ISO9001 or HACCP, should be established in order to promote sustainable development of *Spirulina* industry.

In Inner Mongolia, Ordos City alone has a total land area of 20,064 km² with a large proportion of sandy land. The local government and *Spirulina* producers have an ambitious plan to enlarge the scale of the *Spirulina* industry to a great extent. A special industry zone for *Spirulina* production was established earlier at Wulan Town in Ordos City, where a *Spirulina* project has been initiated and aims to reach an annual output of 3,000 t (dw) in a few years. A 1,000,000-t plan for *Spirulina* production has also been sketched out. Considering the nutritional and therapeutic function, the widespread application of *Spirulina* as human food, animal feeds, and other high valuable products (Belay 2002; Gershwin and Belay 2008), and the advantage of realizing low-cost production of *Spirulina* by using above-mentioned strategies in this region, we believe that this would not be an unreachable dream for the local government and industries.

For the purpose of better development of the *Spirulina* industry in Inner Mongolia in the future, suggestions on technical innovation and improvement of the *Spirulina* industry are presented as follows.

Coal and other natural energy resources could be used better in *Spirulina* production, for instance, wind energy is very rich in this region, it would be economical to run paddle-wheels by using wind. In the process of energy

generation or *Spirulina* drying, CO₂ and residual heat could be used as a carbon resource or applied to temperature/pH control in *Spirulina* cultivation. Selection and application of low-temperature-adapted strains would also be very important for *Spirulina* production. Besides raceway ponds with greenhouse cover, design of novel closed photobioreactors with effective temperature maintenance, high productivity, and reasonable cost would be an alternative approach to prolong the growth period of *Spirulina*. Development of high value products as well as cheap products with a large market could be encouraged. It could be expected that though the improvement and innovation of technology in the near future, Inner Mongolia will become the largest base for *Spirulina* production not only in China, but also in the world.

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