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Mass production of *Spirulina*, an edible microalga

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Abstract

Spirulina (*Arthrospira*) is a filamentous cyanobacterium that is grown commercially for food and feed and as a food coloring and additive. Currently there are many companies producing *Spirulina* in different countries to the tune of 3000 tons a year. This paper attempts to describe the problems of mass culture of *Spirulina*, deriving information from two commercial facilities: Siam Algae Company (Thailand) and Earthrise Farms (U.S.A.).

Introduction

Spirulina (*Arthrospira*) grows naturally in alkaline lakes, and has a long history of being used as a human food. The rediscovery of *Spirulina* by J. Leonard and Compere in the 1960s (Leonard & Compere, 1967) led to the beginning of mass production of *Spirulina* for commercial purposes in the late 1970s. The first attempt of mass production was carried out by Sosa Texcoco Co. in Mexico, supported by the technology of Institute Francais du Petrole (IFP) (Duran-Chastel, 1980; Ciferi, 1983; Ciferi & Tiboni, 1985). Since then, many producers have become successful in the outdoor open pond production of *Spirulina.* The production in the world may now exceed 3000 tons on a dry weight basis. Table 1 shows some of the past and present producers. Most of the market for *Spirulina* is as a food supplement, namely health food; although it is also marketed as feed, especially for the aquaculture industry, and as a blue color extract for food.

Table 1. Representative producers of *Spirulina* in the past and present.

Companies	Country/territory
Spirulina Mexicana (Sosa Texcoco) SA	Mexico
Siam Algae Co., Ltd.	Thailand
Nippon Spirulina Co., Ltd.	Japan
Koor Foods Co., Ltd	Israel
Earthrise Farms	U.S.A.
Cyanotech Corporation	U.S.A.
Nan Pao Resins Chemical Co., Ltd.	Taiwan
Blue Continent Co., Ltd.	Taiwan
Far East Microalgae Co., Ltd.	Taiwan
Tung Hai Chlorella Co., Ltd.	Taiwan
Parry Agro Industries Ltd.	India
Yunnan Spirin Co., Ltd.	Mainland China
Hainan DIC Microalgae Co., Ltd.	Mainland China

In the past, many producers were confronted with various problems on how to achieve the high productivity and cost performance that they enjoy today. As long as *Spirulina* is used for food purpose, its safety and quality must be assured. Mass production of quality *Spirulina* requires special techniques and control practices to solve the problems which are associated with outdoor open pond culture under recycling condition of culture water. Problems related to harvesting, drying and packaging must also be addressed.

This paper will touch upon some of the problems encountered in mass production of *Spirulina* at two *Spirulina* farms, Siam Algae Co. (SAC) in Bangkok, Thailand and Earthrise Farms (EF) in California, U.S.A. Based on the author's experience in DIC (Dainippon Ink & Chemicals Inc., Japan), which is the parent company of these two *Spirulina* farms

Table 2. A typical composition of basal medium for mass production of *Spirulina*

Ingredients	Amount (g l^{-1})
$NaHCO_3$	16.8
K_2HPO_4	0.5
$NaNO_3$	2.5
K_2SO_4	1.0
NaCl	1.0
$MgSO_4 \cdot 7H_2O$	0.2
$CaCl_2 \cdot 2H_2O$	0.04
$FeSO_4 \cdot 7H_2O$	0.01
EDTA	0.08

mentioned above, some solutions to these problems from an industrial perspective will be discussed.

Description of sites studied

Most of the studies were done at two *Spirulina* farms owned by DIC, namely SAC and EF. The facility of SAC was constructed in 1977 in the suburbs of Bangkok, Thailand and started mass production in 1978. Mean ambient temperature at the site ranges from 25 to 29 °C, which enables outdoor production of *Spirulina* throughout the year. Mean annual rainfall in this area is around 1400 mm. Most of the rainfall happens during the rainy season from May to October. EF is located in Imperial Valley, California, USA and has been in operation since 1983. Mean ambient temperature in this place is from zero to 40 °C, sometimes reaching up to 50 °C and down to the freezing point, restricting the production season within April to October. During the production season, there is almost no rain. The mean annual rainfall in this production site is a mere 10 mm.

Mass production system of *Spirulina*

A schematic diagram of the typical production system of *Spirulina* is presented in Fig. 1. Only a brief description of the production process will be given here as detailed information can be found in the reviews by Belay et al. (1994) and Belay (1997).

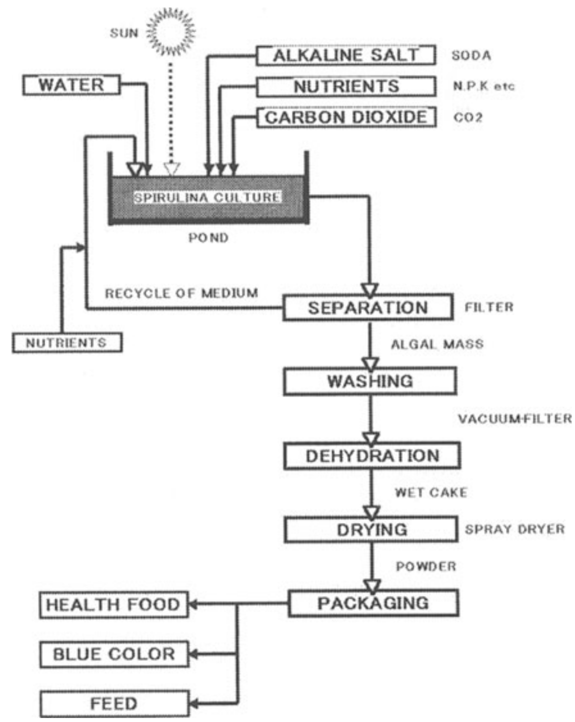

Figure 1. A schematic diagram of production system of *Spirulina.*

The culture pond

The basic shape and design of the culture pond developed by the author (Shimamatsu, 1987) are shown in Fig. 2. The pond is a rectangular open channel with a paddle wheel generating a circulation flow. Special provision is made at every corner of the pond as shown in Fig. 3. This system gives an uniform flow speed and uniform mixing effect at every point in the pond, free from any stagnation spot. SAC has 13 concrete-made ponds in total, each having an area of 2000 m^2 and EF has 30 PVC-lined ponds of 5000 m^2 each for mass production of food grade *Spirulina*.

The harvest system

Algal mass is recovered from the culture through a series of filtration steps utilizing filtration equipment such as inclined gravity screen and vibrating screen and is further concentrated into a wet algal cake by a horizontal vacuum filter. The final cake will have about 15% solids.

Drying and packaging

The wet algal cake is dried into fine powder by the spray dryer, and packed in an oxygen barrier bag

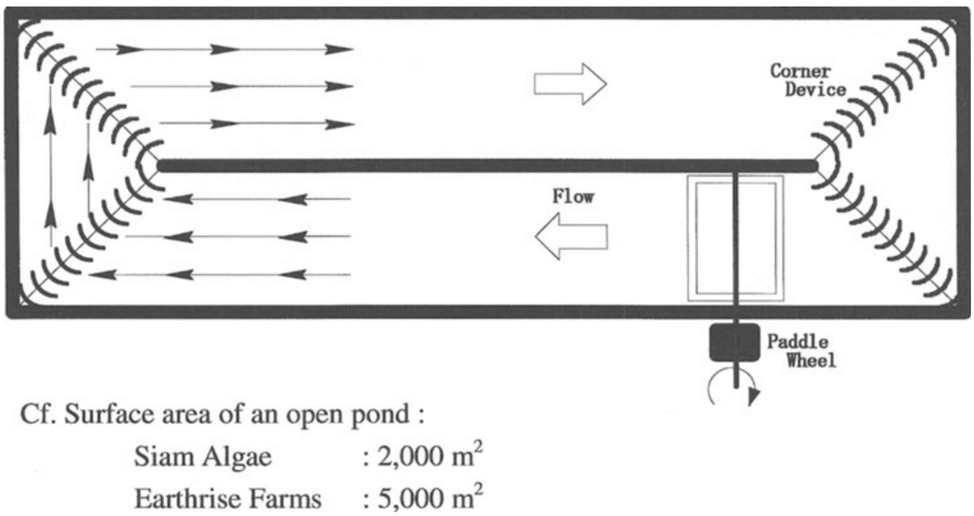

Figure 2. A pond design for mass culture of *Spirulina*.

in order to keep the quality of the product for prolonged period. This process is particularly important in order to maintain the content of less stable components, such as beta-carotene. Both facilities in Thailand and U.S.A. have accumulated enough experience in this area and have developed their own drying and packaging proprietary technology.

Problem of outdoor commercial biomass production

In the past, SAC and EF were confronted with various problems in the mass production of *Spirulina* under the conditions of recycling of culture water and continuous cultivation. How to keep an unialgal culture throughout the production season without contamination and to maintain consistent quality of the product were the major problems that had to be solved. The problems encountered are discussed below in relation to other important factors.

Strain selection

The strain for mass production is selected carefully among the extensive collections of *Spirulina* from around the world which are periodically subcultured in the laboratory in order to maintain actively growing cells. Major criteria in the selection of strains are growth rate, biochemical composition and resistance to environmental stress at each production site. It must be emphasized, however, that a strain which shows a good performance in a laboratory does not always display the same behavior in outdoor open pond operation.

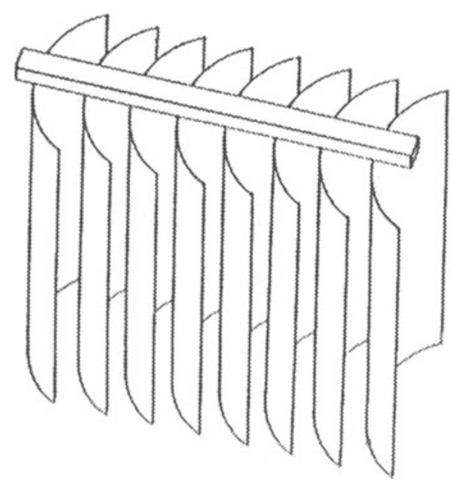

Figure 3. Corner device of the pond (shown in Fig. 2).

The culture medium

The typical medium used in growing *Spirulina* is shown in Table 2 as a simplified Zarrouk medium. Trace elements are adjusted depending on the quality of the culture water. The pH of the medium is kept between 9.5 to 10.5 using carbon dioxide. The desired growth rate and the cost of the nutrients may dictate the choice of the nutrients used. For example, while nitrate is usually used as a nitrogen source, ammonium hydroxide (ammonia water) can also be used.

Table 3. A typical analysis of *Spirulina* product. Based on sample of dried *Spirulina* powder of Siam Algae Company (SAC) analyzed by Japan Food Research Laboratories.

Composition	Quantity (per 100 g dry wt)
General composition	
Moisture	3.00 g
Protein	61.40 g
Fat (Lipids)	8.50 g
Fibre	3.00 g
Ash	7.70 g
N-free extract	16.40 g
Colorants	
Phycocyanin	16.20 g
Carotenoids	477.00 mg
Chlorophyll-*a*	1.20 g
Vitamins	
Provitamin A	214.00 mg
Thiamin (V.B_1)	1.98 mg
Riboflavin (V.B_2)	3.63 mg
Vitamin B_6	0.59 mg
Vitamin B_{12}	0.11 mg
Vitamin E	11.80 mg
Niacin	13.20 mg
Folic acid	42.00 μg
Panthothenic acid	0.88 mg
Inositol	74.00 mg
Minerals	
Phosphorus	914.00 mg
Iron	57.40 mg
Calcium	171.00 mg
Potassium	1.77 g
Sodium	1.05 g
Magnesium	257.00 mg

Table 4. Quality standard of *Spirulina* in Japan based on the criteria of the Japan Health Food Association (JHFA) announced on August, 1986.

1.	**Appearance and Characteristics**	
	Dark green in color,	
	Slight seaweed smell,	
	No nasty smell and bad taste.	
2.	**Essential Components**	
	Crude Protein	>50 %
	Total Carotenoids	>100 mg %
	Chlorophyll-*a*	>500 mg %
	c-Phycocyanin	>2000 mg %
3.	**Pheophorbide**[a]	
	Existing Pheophorbide	<50 mg %
	Total Pheophorbide	<100 mg %
4.	**Arsenic**	< 2 ppm as As
5.	**Heavy metals**	< 20 ppm as Pb
6.	**Standard plate count**	$<5 \times 10^4$ (per g)
7.	**Coli form**	Negative
8.	**Moisture**	<7 %

[a]Revised in July 1990.

Table 5. Food and Drug Administration (FDA)'s requirement for *Spirulina* in USA.

1.	*Spirulina*	No foreign algae
		No contaminants
2.	Insect fragment:	<30 pcs per 10 g
3.	Rodent hair:	< 1.5 pcs per 150 g

However, *Spirulina* cells are easily damaged by higher ammonia concentrations. More than 3 ppm of ammonia would be toxic to *Spirulina*. Urea might be toxic also because *Spirulina* has a high urease activity. The higher calcium content of the make-up water results in the precipitation of calcium salt which causes the loss of alkalinity and some minerals such as iron and phosphorus in the culture.

Operational practices in pond culture

It is said that higher flow speed of the culture in the ponds is recommendable for effective photosynthesis (Richmond, 1988; Richmond et al., 1990). However, in our experience, increase of flow speed above 30 cm s^{-1} sometimes results in fragmentation of the algal trichomes which leads to decreases in harvest efficiency. This increases the risk of contamination and foaming of the culture. Such accumulation of organic matter can actually inhibit photosynthesis and growth (Belay, 1997). Algal density in the culture is generally kept between 400 to 600 mg dry weight l^{-1}. This range of density is mainly dictated by harvest efficiency. At density lower than 100 mg dry weight l^{-1}, some photoinhibition or even photooxidation due to high light intensity may occur (Vonshak & Richmond, 1988; Vonshak et al., 1988). Thus, during the scaling-up stage of the culture from a seed pond to a production pond, special consideration must be paid on the density of algal biomass. The culture depth of the ponds is usually kept between 15–30 cm. Depths greater than 30 cm will result in severe reduction in photosynthesis due to light limitation.

Contamination problems

In mass production of *Spirulina* with open ponds, how to maintain the unialgal culture for a long time without any contamination by other organisms is a major challenge. In Thailand, SAC suffered from the problems caused by rainfall. Dilution of the culture medium by heavy rainfall facilitates the growth of unfavorable organisms including bacteria, green algae, protozoa and insects. The challenge under such circumstance is how quickly could the medium be restored to its original concentration, preferably within one day. Occasionally, phage-like phenomena were experienced that destroyed all the culture at once. It is not known why such phenomenon occurs but we believe it is probably associated with some sort of viral infection. We have not observed permanent bleaching of the algae although there was some pigment loss. Contamination by green algae and bacteria are the common and major problems in mass production of *Spirulina* with outdoor open ponds, particularly under the condition of continuous recycling of the culture medium. This recycling operation can easily result in the accumulation of organic matter because of decomposition and death of algae. This encourages the growth of various contaminants. Accordingly, special practices are required so as not to induce much stress or damage to the algae mechanically and operationally. How to minimize the accumulation of organic matters in the culture is the key issue to avoid or control contamination. On the other hand, ecological technique can also be useful occasionally to control the single cell green algae such as *Chlorella* or *Oocystis*. Some examples of this type of ecological control can be observed from the unialgal culture of *Spirulina* in natural lakes (e.g. Lake Ankorongo, Madagascar; Lake Texcoco, Mexico) where some predators weed out all of the green algae but not *Spirulina*. The problem of contamination by aquatic insects and ground insects is unavoidable. Removal of these insects is done commonly by netting. Knowledge of the ecological interaction of these aquatic insects is also useful for their control.

Harvesting and drying

Problems encountered in harvesting are usually related to the efficiency of harvesting techniques. The latter are affected by factors such as amount of algal biomass, contamination, suspended matter and the nature of the harvesting machinery used. Both farms in Thailand and U.S.A. have developed their own proprietary harvesting and drying methods to maximize harvest efficiency and minimize loss in quality.

Production cost

This is an area where little information is available because companies are not willing to disclose their cost of production. Success in reducing production cost is dependent upon (1) growth rate of the algae, (2) control of contamination and hence reduction in culture renewal time, (3) increased harvest efficiency and (4) the overall operational efficiency of the farm.

Safety and quality assurance

There are established national and international quality standards for *Spirulina* products. Tables 3–5 show the typical analysis of the contents of *Spirulina* product, the quality standard in Japan and United States Food and Drug Administration's (FDA) requirement for *Spirulina* product respectively. Recently, cyanobacterial toxins have become a major issue in public health due to the increased occurrence of toxic cyanobacterial blooms. These toxic blooms contain algae that produce hepatotoxins called microcystins (Carmichael, 1994). *Spirulina* companies like Earthrise Farms have already developed methods for the determination of these toxins and actually certify each lot of their product to be toxin free. *Spirulina* does not normally contain microcystins but contamination of outdoor culture by other cyanobacteria is a possibility.

Conclusion

In the past 20 years, mass production of *Spirulina* has developed rapidly. However, most producers have been confronted with several problems before they achieved economical success in the *Spirulina* market. These problems relate mainly to outdoor production and harvest efficiency. Another major problem is the maintenance of stable and high quality in an outdoor-grown *Spirulina*. Several companies have overcome these problems and are now the major players in the domestic and international *Spirulina* market.

The future calls for a concerted effort to maximize output from such outdoor pond production facilities. There are lots of challenging opportunities for research in academia and private enterprises. Indeed, cooperation between researchers in the academia and those with rich experience in actual outdoor mass culture can bring significant improvement in this area and bring down the cost of production so that many more people can benefit from the health food qualities of *Spirulina*.

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