Cultivation of Superfood – Spirulina (Blue-green Algae): An Agribusiness outlook

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ABSTRACT
Spirulina is multi-cellular and filamentous cyano-bacteria that have gained substantial predominance in the health sector, food industry and aquacultures in contemporary times. It has a very high content of macro and micronutrients, essential amino acids, proteins, lipids, vitamins, minerals and anti-oxidants. In recent years, spirulina has garnered enormous attention from research fraternity as well as industries as a flourishing source of nutraceutical and pharmaceuticals. It is considered a complete food supplement to combat against malnutrition deficiencies. In developing countries like India where malnutrition is a renowned social challenge that can be defeated by the supplement of spirulina products in the diet. The commercial cultivation of spirulina and converting into consumable forms (tablets/granules) can be an economic enterprise in India also. Such agribusiness has been commenced by an agripreneur under Agri-Clinics and Agri-Business Centers (ACABC) scheme. The agripreneur was interviewed and informed that this agribusiness had a good turnover with low capital investment, and also providing employment opportunities to others.
Keywords: ACABC scheme, Super food, Spirulina, Agribusiness.

The progressive lifestyles, dynamic restructuring of micro and macro niches, and unavailability of nutrition sources contribute to the expansion of incidence of malnourishment and additional health risks. In such a circumstance, it is imperative to examine other alternatives for supplementing the diet that will boost the health status of individuals (Ravi *et al*., 2010). Therefore, it is indispensable to create a means to provide cost-effective nutrition and dietary supplements. One supplement source, with ease of production, processing, distribution along with a wide range of macro and micronutrients of human health benefits is the cultivation of spirulina and its consumption.

Spirulina – a kind of blue-green algae contains several nutrients, including B-vitamins, β-carotene, and vitamin-E and also comprises antioxidants, minerals, chlorophyll, and phyco-cyanobilin. It was first discovered by Spanish scientist Hernando Cortez and Conquistadors in 1519. Now, modern lifestyle personalities endorse Spirulina as a secret, potent 'super-food or a miracle from the sea' (Fathima and Salma, 2001; Dillon, 2014). The United Nations world at food conference declared that Spirulina as the best food for the future, and it is gaining popularity nowadays among the wide population (Pulz & Gross, 2004). The nutritional profile of Spirulina powder (composition by 100 g) is shown in Table 1.

The spirulina has also multiple applications for clinical practices - allergy, rhinitis, and immuno-modulation; antiviral applications; cholesterol-lowering effects and effects on diabetes, anticancer effects; chronic arsenic poisoning; and antioxidant effects (Karkos *et al*., 2011). Therefore, the demand for this supplementary diet is picking up in many countries to suffice the nutritional requirements of its population. As a result, many healthcare industries produce Spirulina products, viz., Earthrise Nutritionals (USA California, earthrise.com); DIC Lifetec Spirulina (Japan, dlt-spl.co.jp/business/en/spirulina/); Cyanotech Spirulina (USA Hawaii, cyanotech.com); Boonsom Spirulina Farm (Thailand, boonsomfarm.com); FEBICO (Taiwan, febico.com); etc. Hence this kind of agribusiness has a lot of business opportunities for future food, especially in poor countries like India to reduce the malnutrition.

Agri-Clinics and Agri-Business Centre (ACABC) - a central sector scheme started by the Government of India in 2002 to attract educated youth in agriculture sector for creation of self-employment opportunities along with providing extension services to the farmers (Afroz *et al*., 2020). This scheme promotes agribusiness in the country since its inception. Under this scheme, Shri M. Vamshi Krishna had undergone a two-month residential training at ICAR-Indian Institute of Millets Research, Hyderabad. After training, he started an agribusiness of commercial spirulina production in Peddatupra village of Ranga Reddy district of Telangana, India (Figure 1). He has registered his spirulina products under the Food Safety and Standards Act of India (FSSAI), Government of India. In this article, the different steps followed for its cultivation by the agripreneur is elaborated so that this agribusiness can be taken up by other inspired youth for agriculture and allied sector business.

Table No. 1: Nutritional profile of Spirulina Powder (composition by 100 g)

Macronutrients	
Calories	373Kcal
Total fat	4.3g
Total carbohydrate	17.8g
Essential amino acids	21.9g
Non-essential amino acids	35.4g
Minerals	
Calcium	468 mg
Iron	87.4 mg
Phosphorus	961 mg
Iodine	142 mcg
Magnesium	319 mg
Zinc	1.45 mg
Selenium	25.5 mcg
Copper	0.47 mg
Manganese	3.26 mg
Chromium	<400 mcg
Potassium	1660 mg
Sodium	641 mg

Vitamins	
Vitamin A (as β-carotene)	352.0 IU
Vitamin K	1090 mcg
Thiamine HCL (Vitamin B1)	0.5 mg
Rivoflavin (Vitamin B2)	4.53 mg
Niacin (Vitamin B3)	14.9 mg
Pyridox HCL(Vitamin B6)	0.96 mg
Vitamin B12	162 mcg
Phyto-nutrients	
Phycocyanin (mean)	17.2%
Chlorophyll (mean)	1.2%
Superoxide dismutase (SOD)	531,000 IU
Gamma linolenic acid (GLA)	1080 mg
Total carotenoids (mean)	504 mg
β-carotene (mean)	211 mg
Zeaxanthin	101 mg

(Source: Salmeán *et al*., 2015; mcg= microgram, mg= milligram, IU=international unit)

Fig 1: Shri M Vamshi Krishna An agripreneur of spirulina production

Cultivation of Spirulina

Spirulina is one among various algal species discovered growing in natural freshwaters. These are observed in natural habitats such as soil marshes, seawater, and brackish waters where alkaline waters subsist. It can withstand low temperatures 15°C during nights and 40°C for a few hours in the daytime also. In natural habitats, their growth cycles depend on the limited supply of nutrients. In Japan, large scale cultivation of microalgae of chlorella (early 1960s) followed by Spirulina commenced in the early 1970s. Today, there are more than 22 countries that cultivate Spirulina commercially on a large-scale (Ravi *et al*., 2010). The distinct stages for commercial cultivation of spirulina as practiced by the agripreneur are shown in Figure 2.

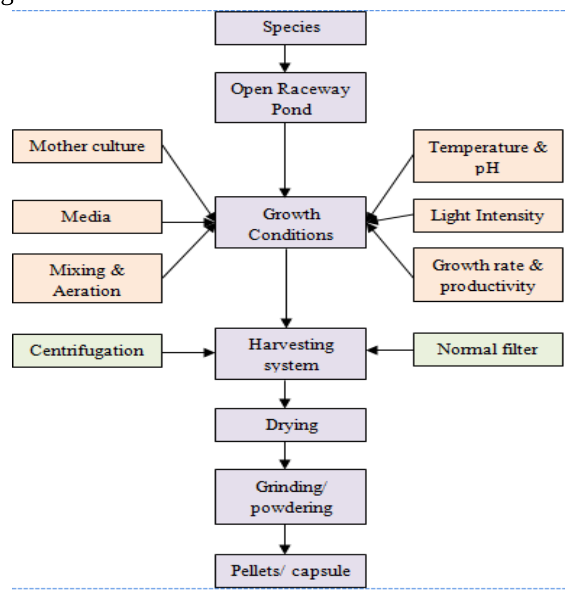

Fig 2: Phases of Spirulina Cultivation

Species selection

It is a very crucial stage in spirulina cultivation. The two species which are most commonly utilized are Spirulina platensis and Spirulina maxima (De Smet, 1997) due to its valuable components, positive effects, and being a supplement which is nontoxic for human well-being. The agripreneur, Shri M. Vamshi Krishna, is growing Spirulina platensis species for producing commercial products.

Open Raceway Pond

A raceway pond is a shallow artificial pond utilized for the cultivation of algae. The cultivation of Spirulina can be done in open systems like ponds, lakes or lagoons or a closed system (Singh and Sharma, 2012). The open ponds are utilized commercially to produce high value spirulina products, which may be shallow big ponds, circular ponds, tanks and raceway ponds. The cultivation is usually carried out in two ways: a) concrete ponds and, b) pits lined with PVC or other plastic sheets. The agripreneur had constructed concrete ponds for its cultivation (Figure 3). The installation of single or multiple ponds can be arranged with each pond size of 50 m long, 2-3 m wide, and with 20 to 30 cm depth are ideal pond conditions but the length of the ponds can be of any length depending on the land availability (Karthikeyan et al., 2016). With such infrastructures, Spirulina biomass yield of 35 tonnes/ hectare/yr has been reported in a commercial open mass cultivation pond at Siam Algae, Bangkok (Habib *et al.*, 2008).

Fig 3. Open Race-way Pond

Growth conditions

Spirulina growth conditions are similar to terrestrial plants but they utilize resources very efficiently to increase biomass productivity with comparatively less water use (Sudhakar *et al*., 2014; Lucie *et al*., 2016). Spirulina cultivation for commercial and large-scale production has to be executed in given regions with suitable climatic conditions. The tropical and sub-tropical regions are well-suited places for its cultivation. It requires sunshine throughout the year. The growth rate and production of Spirulina depend on numerous factors such as wind, rain, temperature fluctuation, and solar radiations.

Mother culture: The fully developed concentrated Spirulina culture required for inoculums preparation and culture maintenance. The preferred Spirulina strain must have a high proportion of coiled filaments (<25% straight filaments, or none), and at least 1 per cent of gamma-linolenic acid (GLA) based on the dry weight. The colour of the culture should be explicitly green. The growth rate is about 30% per day when the temperature and other climatic conditions are satisfactory (Pal *et al*., 2011). The growth is proportional to the area of the culture exposed to light; therefore, the agripreneur had maximized this area at all times.

Media: Spirulina flourishes in alkaline brackish water. The culture medium should provide all essentials to nurture Spirulina in a suitable environment. It should compose of sodium carbonate and other suitable medium as source of nitrogen, phosphorus, iron and trace metals (Raoof *et al.*, 2006). The makeup media should also consist of urea. It can grow on either nitrate or urea alone but using both at the same time is more advantageous. The water used should be clean or filtered to avoid the growth of other algae during cultivation. The media preparations should be arranged in such a way that it meets the local growing conditions for spirulina. The most commonly used is Zarrouks media (Zarrouk, 1966; Pragya *et al.*, 2013). The cost of nutrients accounts for about 15-25% of the total production cost (Selvendran, 2015). The agri-preneur had prepared the media to meet the local growing conditions but following the standard procedure.

Mixing and Aeration: The agitation of the mother culture in the media is an inevitable step to homogenize and assure a good distribution of light among all the filaments of Spirulina during its growth. The mixing of the mother culture plays an important function in increasing the productivity of the cultures (Chisti, 2016). Similarly, the aeration is also very crucial for obtaining good quality and better yield of Spirulina species. It can be achieved by rotators, which maintain the cells in suspension by gentle agitation of growing cells. The agri-preneur had installed motorized-rotators in its pond for constant mixing as well as stir. It also assists to circulate carbon dioxide concentration uniformly and eliminates inhibitory substances such as oxygen (Richmond & Vonshak, 1978). When aeration is not adequate, the efficiency of energy utilization and biomass production will be low.

Temperature and pH: Spirulina can develop at 20ºC-37ºC but the ideal temperature for Spirulina for high growth with high protein content is between 29ºC-35ºC (Kumar *et al*., 2011). The variation in atmospheric temperature is the main factor affecting the biomass production rates in Spirulina cultivation. The bleaching of cultures may take place when temperatures are above 35°C while it cannot withstand in temperatures less than 20°C (Kumar *et al*., 2011). The agripreneur has installed exhaust fans to regulate the temperature within the production unit.

The pH maintenance of the media over 9.0 is obligatory in Spirulina cultures in order to avoid contamination by other algae. The pH adjustment is made by increasing the carbon dioxide level by the addition of carbonate salts into the culture (Selvendran, 2015). When pH is between 9 and 11, it indicates a healthy culture. The effect of pH on the algal growth, pigment production and protein content of Spirulina species has the direct effect on the antioxidant system (Vonshak & Guy, 1987; Ogbonda *et al*., 2007). The agripreneur is regularly testing the pH (Figure 4) while it is growing. It is controlled by taking necessary measures, accordingly.

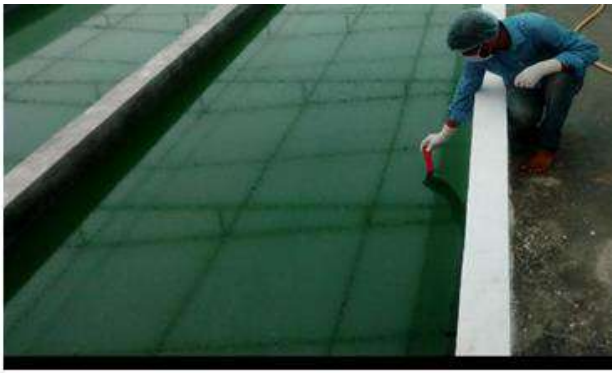

Fig 4. pH testing of spirulina culture

Light intensity: All photoautotrophic organisms including photosynthetic bacteria, cyano-bacteria, and higher plants, transform light energy into chemical energy through photosynthesis. In open-air cultivation system, natural light or solar radiation is the sole source of light for the autotrophs. The light has a direct effect on spirulina production for its protein content, growth rate, and pigment synthesis (Saeid & Chojnacka, 2015). The optical density of the culture is directly proportional to the light intensity. Higher the optical density higher is the requirement of light and lower is the optical density, lower is the requirement of light (Samuel, *et al*., 2010). The agripreneur has covered the production unit by net-shades which assist to regulate the light intensity for the cultivation.

Growth Rate & Productivity: In commercial Spirulina farming, it is needed to recreate the culture medium where water is the main source medium for Spirulina to grow naturally. It should have all the essential and required resources of nutrition for the healthy growth of Spirulina (Bharathiraja *et al*., 2015). The water level in tanks should be controlled which is important for the photosynthesis process to take place in Spirulina. A minimum shallow level of 20 cm is ideal water level height. The deeper the water level, sunlight penetration will be reduced, which will affect algae growth.

Harvesting system

The concentration of algae in the production unit (pond) will be the determining factor for harvesting. In general, the spirulina will be ready for harvest after five days once the seeding process is done. The most suitable time for harvesting is early morning because the percentage of proteins in the Spirulina is highest during the morning. Besides, the cool temperature makes the work easier and more sunshine hours (during day-time) will be available to dry the product. The harvested spirulina is left for drying by the agripreneur in Figure 5. The harvesting of spirulina is carried out in two steps:

Fig 5. Harvested Spirulina

Centrifugation: It is a method to separate Spirulina algae from the media. It is generally carried out by a centrifuge is equipment, driven by a motor that puts an object in rotation around a fixed axis, applying a force perpendicular to the axis. This method is reasonably efficient but sensitive algal cells may be damaged by pelleting against the rotor wall.

Filtration: During commercial production processes filtration devices are used for harvesting. These are of two types, i.e., inclined and vibrating screens. The inclined screens are 380-500 mesh with a filtration area of 2-4 m^2 per unit and are capable of harvesting nearly about 10-18 m^3 of Spirulina culture per hour (Ogbonna *et* *al*., 1999). It is considered as most suitable method for harvesting Spirulina. The vibrating screens filter the same volume per unit time as the inclined screens but require one-third of the area. The next step is the washing of excess salts from the biomass. The washed cake is frequently homogenized before being dried.

Drying

Spirulina can be consumed fresh but it has to be used after slight drying (Ankita *et al.*, 2013). Spirulina is relatively quickly digestible in its fresh form (Richmond & Vonshak, 1978). Spirulina should be consumed within 6 hrs of its harvest although it can be stored for later consumption for a period of up to one or more year by sun-drying or in a solar drier. After drying, it will last for several months and also the nutritional content can be preserved. There are different drying methods include sun drying, freeze-drying, spray-drying, drum-drying, and cooking. Spirulina has a thin and fragile cell wall, hence, sun-drying is sufficient to sterilize the algae and make it consumable. Sun-drying is the most popular drying method but requires a few precautions. Direct sun-drying must be very quick, otherwise, the chlorophyll will be destroyed, and the dry product will appear blue. The agripreneur was drying the spirulina after its harvest through either sun-drying or by drying machine.

Grinding/powdering

Spirulina is consumed as a whole food/dietary supplement which is prepared in tablet, flake and powder form (Figure 6). The dry chips or rods of spirulina are usually converted to powder by grinding to enhance their apparent density. Grinding is continued for about 6-10 hrs, till the average powder size reaches 200-800 nm. The two most common forms of commercially available Spirulina are powder and tablets. It is also a component in some protein and energy-boosting powder mixes.

Fig 6. Powered Spirulina

Pellets/capsules

Spirulina powder is pressed together into a tablet or granule shape (Ogbonda et al., 2007) for improved acceptance and performance. It is formulated as a completely balanced diet which provides optimum growth and health (Slade & Bauen, 2013). It contains proteinated trace minerals for higher stability, biological availability and overall human health. The advantages of Spirulina pellets are as follows:

- Excellent water stability
- Easily consumable
- Contains extra levels of preservative and antioxidants
- Longer shelf life

Spirulina Cultivation Training

This is not a big science to learn. The training period wouldn't take many days; it's a brief learning process that can last just a few days. It is always recommended to have hands-on experience along with training because small and simple mistakes will destroy the whole farming. The proper training will support to produce quality yield with maximum returns and without losing any money that will be invested right from the start. These are the following few training centers:

- GMs Spirulina, C/S No. 121/1, Opposite to Central Admin. Building, Indira Colony, Urun lslampur, Maharashtra – 415 409
- Nallayan Research Centre for Sustainable Development, Navallor village, Kanchipuram district, Tamil Nadu
- Spirulina Production, Research and Training Centre, Kondayampatti village, Madurai Centre for Conservation and Utilization of Blue Green Algae
- Division of Microbiology, ICAR-IARI, New Delhi – 110012

Costs and Profit in Spirulina Farming

This economics of Spirulina farming is adopted from DST, 2019, which means to provide a general overview of investment and revenues and the figures mentioned are not actual but for a agribusiness understanding. The pond should be constructed of size 10'×20' and required about 20 such ponds. Each pond will generate on an average about 2 kg wet culture per day. It should be noted that one-kg wet culture will give 100 grams of dry powder only. Based on this, on an average, a 20 tank Spirulina farming business will generate 4-5 kg of dry Spirulina powder on a daily basis. The production of Spirulina in a month will be around 100 to 130 kg per month. Dry Spirulina powder in the market will fetch about Rs. 600 per kg. A farmer can earn about Rs.40000-45000 per month. A farmer can make more profits by increasing tanks made with low-cost, durable materials apart from concrete ponds by utilizing maximum space available in the land, which will reduce labor and investment with more profit returns.

Table No. 2: Production Economics of Spirulina farming

Capital Investment			Economics of Farming	
#	Particulars	Cost (Rs.)	Total Capital Investment	12,50,000.00
1.	Pond Construction (20 @ 50,000/-)	10,00,000.00	Operational cost (monthly basis)	25,000.00
2.	Plant Machinery	15,000.00	**Total Cost (Rs.)**	12,75,000.00
3.	Laboratory Equipment	5,000.00	**Gross Income**	
4.	Water Treatment Plant	1,50,000.00	Sale of Spirulina Powder (@ Rs. 600 per kg)	72,000.00
5.	Piping Work	25,000.00		
6.	Electrical Works	15,000.00		
7.	Drying Screens	10,000.00	**Income per month (Rs.)** (Sale – operational cost)	47,000.00
8.	Harvesting Screens	5,000.00		
9.	Packing Materials	2,500.00		
10.	Chemicals (per month)	2,000.00		
11.	Labor (monthly basis)	18,000.00		
12.	Miscellaneous	2,500.00		
	Total Capital Investment	12,50,000.00		

(Note: Adopted from Spirulina Farming, DST, Govt. of India, Mar 2019)

Conclusions

Spirulina has the potential for being a 'wonder food supplement' and various leading organizations have recommended its salubrious effects on human well-being. In developing countries like India can be very suitably utilized as a diet supplement to overcome the challenge of social malnutrition. Unlike a company set up for spirulina production in other countries, the commercial cultivation of spirulina can be an agribusiness in India to supply spirulina products to a large population of the country. Similar, agribusiness has been initiated under ACABC scheme which has great success. It has good turnover with low capital investment, and also providing employment opportunities to others. The agripreneur has been using a suitable design and method for spirulina production in his conditions. It was suggested by the agripreneur that proper designing of cultivation system, growth efficient techniques and use of organic fertilizer may be adopted to maximize the commercial spirulina productions.

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