ARTHROSPIRA PLATENSIS

Monograph

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1.0 Importance

Arthrospira platensis is a microorganism which thrives in freshwater lakes and ponds, with moderate temperatures and high amounts of sunlight. It has been dated back to the Aztecs and many ancient communities which have been thought to use it as a source of food due to its lack of toxicity and high nutritional value. During this century, *Arthrospira platensis* had been commonly referred to as "*spirulina*", however, it has recently been renamed to fit a better taxonomical structure.

This cyanobacterium has become more relevant in the 21st century, where nutrition and health have become the focus of many families which have decided to incorporate the supplement into their diets. When referring to the market it is more appropriate to talk about "*spirulina*" as a whole because although *A. platensis* is widely used, other *Arthrospira* branches can also be found, with all being labeled as "*spirulina*". The incorporation of this supplement in the daily lives of millions of people has lead the "*spirulina*" market into an unbelievable growth which is estimated to develop into a $779million USD market in 2026. This rise in trade around this product has boosted the economies of many countries which are now seeking to foment and develop their "*spirulina*" products.

Arthrospira Platensis has been studied thoroughly in the past decades, which have brought to light many innovative uses that can be given to this cyanobacteria. Ranging from medical products to ingestible products *A. platensis* has the potential to expand into all aspects of daily lives. This varied utility originates from the high C-phycocyanin content it has, which has antioxidant, anti-inflammatory and neuroprotective effects.

Through this monograph, the topics regarding *Arthrospira platensis* will be distributed into 5 sections, with this being the first. The second chapter of this document intends to cover the subjects of ecology, expanding on the distributional context, environmental factors in distribution, water and pH, and *A. platensis*' interaction with other plants. The third chapter will deal with the cyanobacteria's biology, expanding con chromosome complement, life cycle, phenology, reproduction, and ecophysiology. Chapter four, propagation and management, deals with the cultivation of *Arthrospira platensis* and the factors affecting it, along with the management of small and large scale production of this product. Lastly, Chapter five expands on the nutritional value, some of the uses that can be given to *A. platensis*, and the international market of *A. platensis*.

2.0 Ecology

2.1 Distributional Context

2.1.1 Affinities

More commonly known as *Spirulina,* the species *Arthrospira platensis* (*Figure 1*, below) is a prokaryotic bacteria from the phylum of cyanobacteria, meaning it utilizes photosynthesis but does not have chloroplasts (Fedor, n.d.)

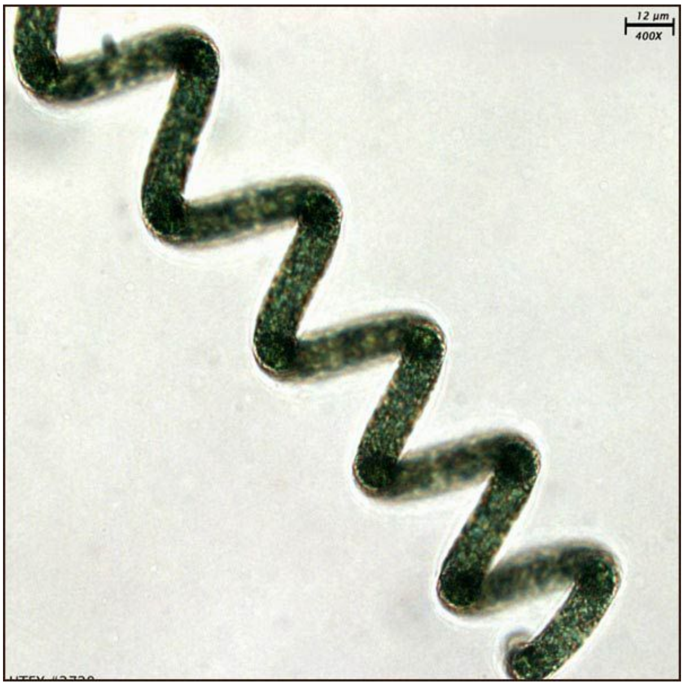


Figure 1: Arthrospira platensis through a 400x microscope (approx 12 µm). Obtained from Circulating Oils Library.

Arthrospira platensis, once known as *S. platensis,* is a long cylinder with a coiled shape, with granulated cross walls as seen in *Figure 1*, above. It grows trichomes, which are chains of vegetative cells surrounded by a slimy sheet ("trichome | Encyclopedia.com," n.d.), that enables it to go through binary fission, its method of reproduction. This cyanobacterium is a pubescent trichome cell, meaning it grows hairs with nearly cylindrical or disc-like shapes which branch out and make the cells look like trees (Fedor, n.d.). This planktonic bacteria thrives in tropical and subtropical water bodies which have high levels of carbonate and bicarbonate, along with a high pH (Vonshak, 1997). The genus *Arthrospira* can be divided into three main sub-species of the genus, *A. platensis, A. fusiformis, and A. maxima*. Each sub-species differs from each other by their helix diameter, with *A. platensis* having a larger diameter, and generally longer trichomes than the other genus variations (Ciferri, 1983), making it have several health benefits, along with making it able to survive in different climates.

Taxonomy of Arthrospira Platensis (Fedor, n.d.):

- Kingdom: Monera
- Phylum: Cyanobacteria
- Class: Cyanophyceae
- Order: Nostocales
- Family: Oscillatoriaceae
- Genus: *Arthrospira*
- Species: *platensis*

This genus has a very specific helical shape, which has a variation within each species, and within each strain of the species. Additionally, there have been reported instances of having a nearly straight structure occur either naturally, from chemicals, radiation or other factors, which makes the cell become unable to return to its helical shape (Ali, 2012).

2.1.1.1 Physical structure

Arthrospira platensis has a prokaryotic organization, with several thread-like structures (fibrils) of DNA, along with a photosynthetic system, a cell wall, ribosomes among others (Ali, 2012). Its cell wall has four layers, in which the first one is not digestible by humans because it contains b-1 and 2-glucan. However, the second layer contains proteins and lipopolysaccharides, making it easy on the stomach (Ali, 2012).

2.1.1.2 Photosynthetic structure

All blue-green algae such as *Arthrospira platensis* have a light-harvesting chlorophyll protein complex (LHC), which act as peripheral antennae systems, enabling a more efficient light absorbency (Kanehisa Laboratories, 2010). These systems convert solar energy into chemical energy in the forms of NADPH and ADP, which the cell can utilize to carry on with its functions ("Light-Dependent Reactions | Biology for Majors I," n.d.). The photosynthesis begins in photosystem II when a photon strikes the antenna pigments. This initiates a chain process where chlorophyll a moves to the electron transport chain, which brings along hydrogen ions to the thylakoid interior. The high content of ions then flows through the ATP synthesis through the process of chemiosmosis. This process creates the ATP molecules, which are then utilized to create sugar molecules in the second step of photosynthesis. Once this occurs a second photon hits photosystem I, which forms NADPH ("Light-Dependent Reactions | Biology for Majors I," n.d.). After this, the cycle continues to the light-independent reactions where carbon is fixated and oxygen is released.

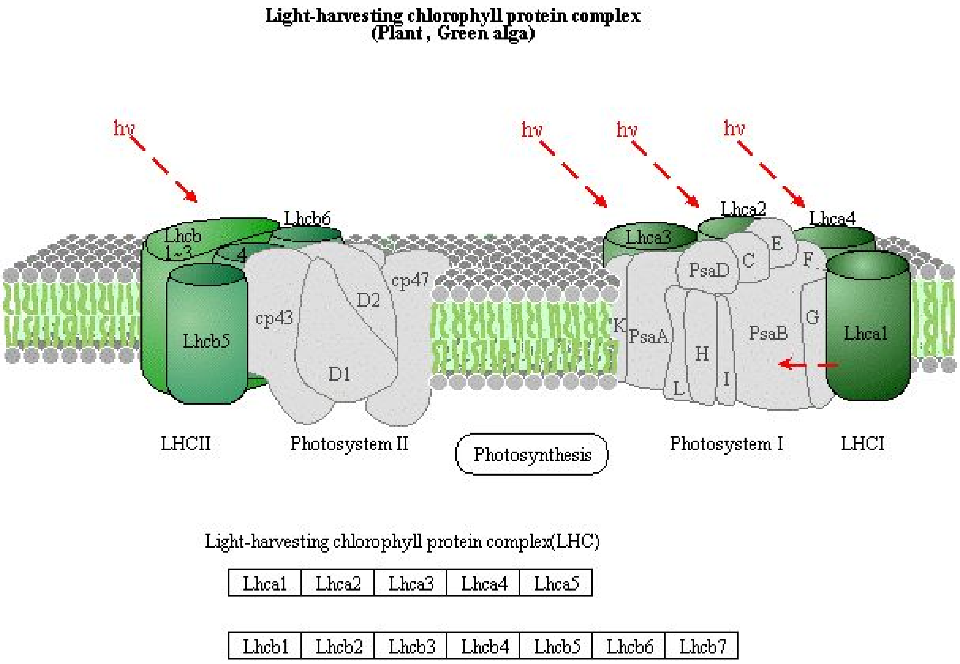


Figure 2: Photosynthesis antennae for blue-green algae (Kanehisa Laboratories, 2010)

2.1.2 Fossil Record

There has been recorded evidence of a similarly shaped specimen, which was discovered in 3.5-Ga-old Apex chert in northwestern Western Australia. Belonging to the Oscillatoriaceae family, *Arthrospira* has an extensive lineage which has evolved through time to become the bacteria seen today (Schopf, n.d.). This species is ubiquitous, and descendants or subspecies from it have been found throughout the whole world in different climates, each developing differing characteristics which allow it to survive. The previously mentioned qualities have made this bacteria able to exist in places where other organisms are not able to do so, stopping it from mixing with many organisms.

2.1.3 Origin

There is no way of tracing the origins of *A. platensis* due to its extreme capability to adapt to different environments, which made it able to exist and thrive throughout the whole globe. However, the Aztecs were the first humans which used this microorganism as a source of food by creating small cakes out of this alga (Ali, 2012).

2.1.4 Present Distribution

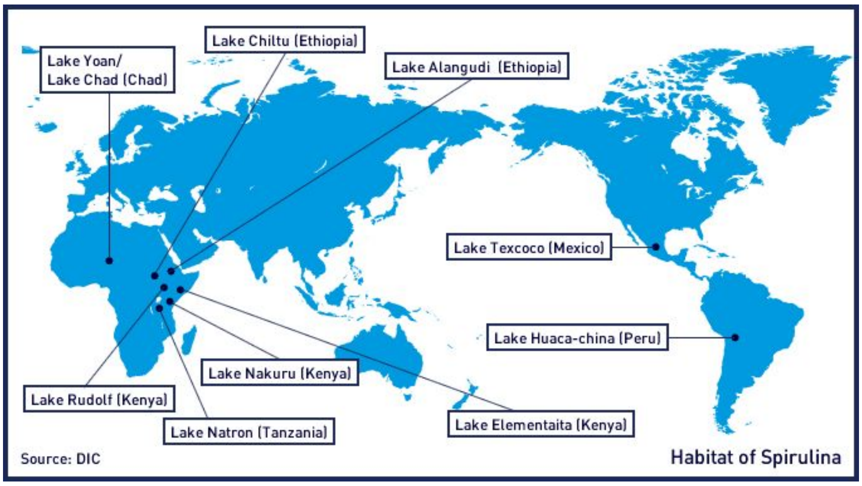
"Spirulina" is currently being consumed and distributed worldwide by several producers. Many countries, including Mexico, United States, India, Thailand, Myanmar, China, Cuba, and Japan, are large producers of this cyanobacteria, along with several farms in Australia, Chile, Israel, Bangladesh, Philippines, Peru, Brazil, and other countries around the world (Henrikson, 2011). With *Arthrospira platensis* offering remarkable health benefits for undernourished people, there have been numerous projects in order to cultivate spirulina in developing world villages throughout South America, Africa, and Asia (Henrikson, 2011).

2.2 Environmental Factors in Distribution

2.2.1 Elevation

Elevation does not directly affect the growth of spirulina, however, it can be naturally found in locations such as Lake Chad in Africa, at an elevation of around 286 meters (*Topographic map Lake Chad*, n.d.). Other locations include Lake Texcoco, with a surface elevation of 2,240 meters (Science.gov, n.d.). *Map 1* shows the natural locations where Arthrospira platensis has been found throughout the world.

Map 1: Natural Habitat of Arthrospira Platensis [*(IIMSAM, n.d.)*]



2.2.2 Climate

A. platensis has an optimum growth rate in subtropical climates in lakes with a temperature between 25º- 35º C (Jourdan, 2001). Any temperature below 20º C will not allow it to thrive, however, it will survive, whereas temperatures above 38ºC will endanger the cyanobacteria. Additionally, high amounts of light are optimal in order to allow *A. platensis* to grow and photosynthesize, however, around 30% of the received light should come from the sun (Jourdan, 2001). This means that the culture can receive more light whether it is Light Emitting Diodes (LED) or another type of lamp, however, it should never exceed 120,000 lux, because this will harm the cyanobacteria (Jadot, 2012).

Intense exposure to the sun results in a yellowish culture, which is undergoing photo-stress. This means that the cells are not capable of photosynthesizing all the light it's receiving, and the cells are lysing (Jadot, 2012).

2.3 Water and pH

2.3.1 Water

Arthrospira platensis is a freshwater alga, which thrives best in ponds and lakes ranging in a pH of around 7.5 to 11, with each pH different enzymes will develop better (Ismaiel, El-Ayouty, & Piercey-Normore, 2016). However, this species has proven to easily adapt in saltwater supplemented with nitrate, phosphate, bicarbonate, and Fe-EDTA, showing no significant differences in the chemical composition of the cyanobacteria (Materassi, Tredici, & Balloni, 1984).

The optimum pH for algal growth according to the Brazilian Journal of Microbiology is at pH 9.0, which maintained alkaline conditions, rocketing the biomass yield of *A. platensis* (Ismaiel et al., 2016). Additionally, any pH above 10 resulted in extremely low yields.

2.3.1.1 Zarrouk's Medium

Zarrouk's medium has been tested by scientists to be a really effective medium in which *A. platensis* (along with many other cyanobacteria), can grow effectively. However, many scientists have modified the original medium in order to boost *A. platensis'* potential to grow to a maximum of around 5.8µg to 6.1µg is the average specific growth rate as measured by scientists. (Rajasekaran Chandrasekaran, 2015).

Table 1: Components of Zarrouk's medium (Rajasekaran Chandrasekaran, 2015):

Ingredient	Standard media (gm/l)	Modified media (gm/l)
NaCl	1.0	1.0
CaCl2 . $2H_20$	.04	.04
KNO_3	-	2.5
$NaNO_3$	2.5	-
$FeSO_4 . 7H_2O$	.01	.01
Na	.08	.08
K_2SO_4	1	1
$MgSO_4 \cdot 7H_2O$	.2	.2
$NaHCO_3$	16.8	16.8
K_2HPO_4	.5	.5
A5 micronutrient	1ml	-

2.4 Interaction with Other Plants and Organisms

2.4.1 Interaction with Other Plants

Arthrospira platensis is a cyanobacterium which has adapted to be able to thrive in extreme conditions of high pH, which makes it really hard for other organisms and plants to be able to live alongside it. However, *A. platensis* can sometimes be found coexisting along other types of algae such as the siatom Navicula, Green alga Chlorella, and Yellow-Green alga (Centre de formation Professionnelle et de Promotion Agricole Hyères, 2005) These algae, which are part of the Oscillatoria, are able to survive alongside *A. platensis* because they have also evolved to tolerate an extremely wide range of pH and salinity.

2.4.2 Interaction with Other Beings

Arthrospira platensis is very prone to coexist with other bacteria which can survive in high pH, this includes rotifers, protozoa, and amoeba. Each of these interacts differently with spirulina, with some being parasites, and others simply coexisting with *A. platensis*.

2.4.2.1 Parasites

Amoeba is defined as a genus of the protozoans (n.d.) which is a little bacteria that will devour *A. platensis*. This includes several groups of amoeba such as:

- *Labyrinthula*
- *Rhizophydium algavorum*
- *Vampyrella sp.*
- *Leptophyrs vorax* (Carney & Lane, 2014)

Additionally, many mosquitoes deposit their eggs in *A. platensis* lakes or cultures, which gives their larvae a source of food. Having mosquito contamination might decrease the *A. platensis* yield around 10%, making it extremely dangerous for *A. platensis* (Saranraj, 2012).

Pictured below is a magnified image of Chytridiomycota fungi, a type of parasite that attacks A. platensis. Tom Volk of the University of Wisconsin La- Crosse. (Tom Volk, n.d.)

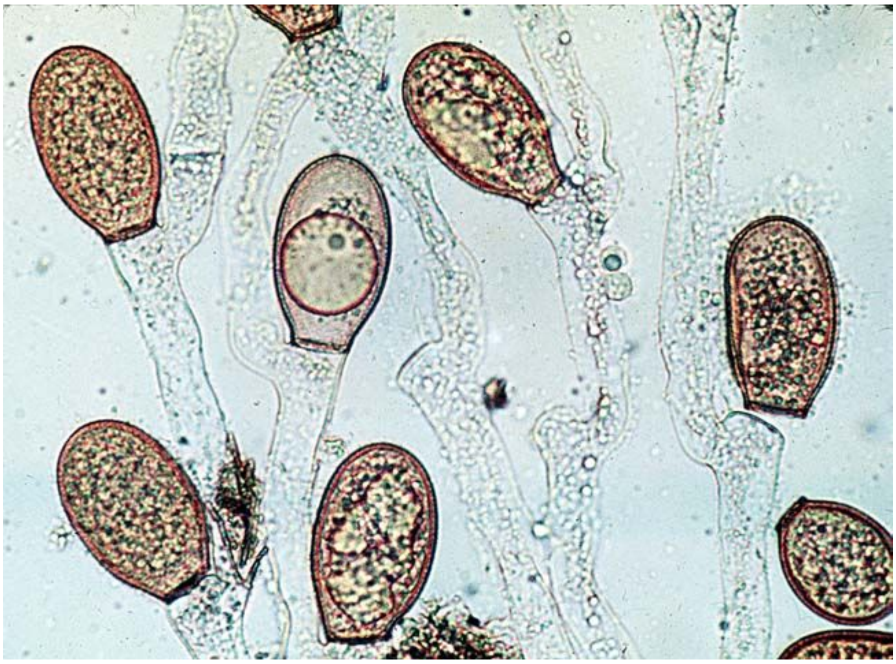


Figure 3: Chytridiomycota fungi, a common parasite among A. platensis. [*(Tom Volk, n.d.)*]

Many algae are victims of fungal parasites, with Chytridiomycota being an extremely common parasite for freshwater algae such as *A. platensis* (Carney & Lane, 2014). While it is extremely common in natural sources, it is widely unknown how this specific parasite affects commercial ponds. Other types of fungi that affect *A. platensis* and other cyanobacteria include:

- *Chytrids:*
    - *Phlyctidium scenedesmi*
    - *Rhizophydium sp.*
    - *Paraphysoderma sedebokerensis*
    - *Zygorhizidium sp.*
    - *Chytriomyces sp.*
- *Aphelids*
    - *Amoeboaphelidium protococcarum*
- *Labyrinthulids*
    - *Labyrinthula Cienk.*

(Carney & Lane, 2014).

These fungi differ on their nature, with *Chytrids* being zoosporic fungi, *Aphelids* being fungi, and Labyrinthulids being fungi-like organisms (Carney & Lane, 2014)

3.0 Biology

3.1 Chromosome complement

Arthrospira platensis has a single circular chromosome, of around 6630 protein-coding genes. Around 78% of these genes are similar to those found in other organisms, with the remaining 22% being unknown (Fujisawa et al., 2010). *Figure 4* below shows the chromosome of *A. platensis*.

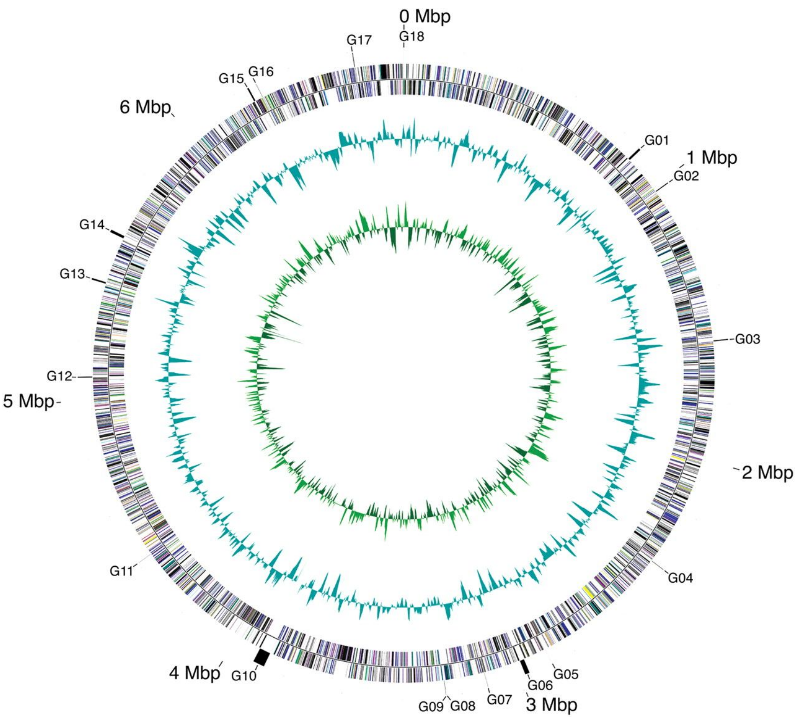


Figure 4: Schematic representation of the circular chromosome of A. platensis. "A scale indicates the coordinates in megabase pairs. From outside to inside: circle 1, the gaps in the genome; circles 2 and 3, predicted protein-coding genes on the forward and reverse strands; circle 4, G+C content; circle 5, GC skew. Eighteen contig gaps (G01-G18) are numbered in the clockwise direction starting from the end of the longest contig. Functional categories were color-coded according to the standard colors used by COGs. The genome sequence and annotation of A. platensis NIES-39 are available at GenBank/EMBL/DDBJ under accession no. AP011615." (Fujisawa et al., 2010)

3.2 Life Cycles and Phenology

Arthrospira platensis' life cycle is shown in *Figure 5* below. Essentially the life cycle is simply a cellular life cycle, starting with a single spiral, which is then divided into hormogonia cells that develop through time into a single spiral again (Sánchez, Bernal-Castillo, Rozo, & Rodríguez, 2003).

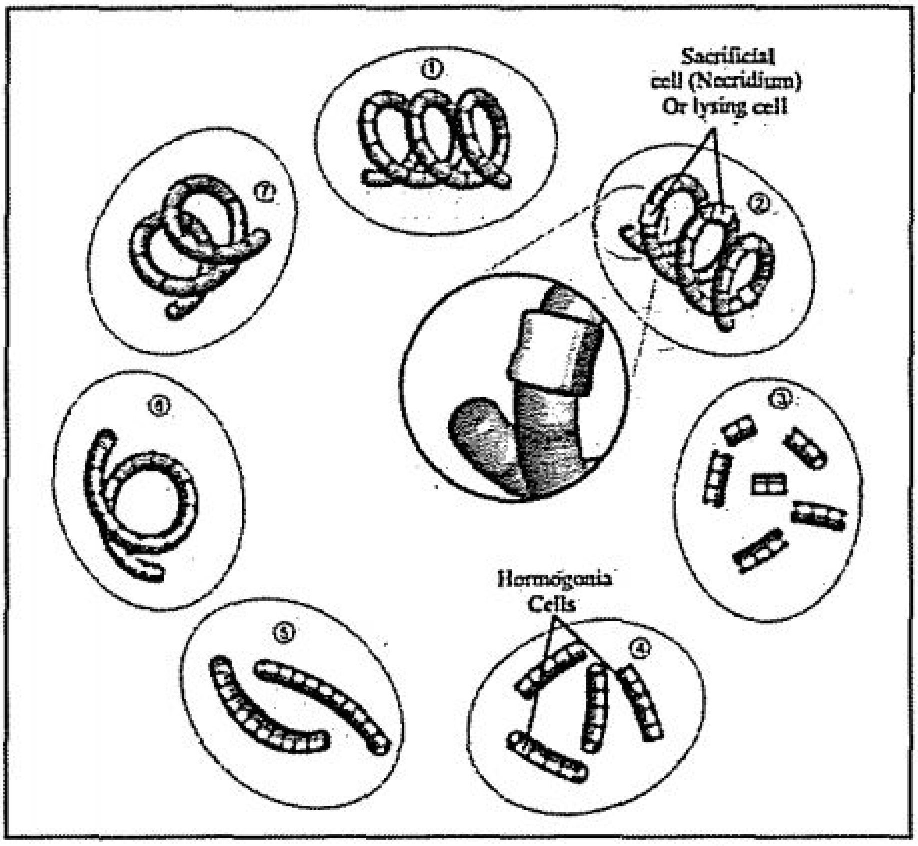


Figure 5: Life cycle of A. platensis (Sánchez et al., 2003)

The life cycle of *A. platensis* is characterized by three main stages called trichrome fragmentation, hormogonia cells enlargement a maturation process, and trichrome elongation (Sánchez et al., 2003). The mature trichrome is broken down into two to four chains of cells by specialized cells called necridia. These specialized cells undergo lysis, which leads to several disks gliding creating several hormogonia cells (Ciferri, 1983). The formation of trichomes including the necridic cells can be seen in *Figure 6* below. These cells then move away from the parent cell, in order to develop into a new trichrome. In order for the cell to become a new trichrome, they lose the attached portions of the necridal cells, making them round in the ends with little to no thickness in the walls (Ciferri, 1983).

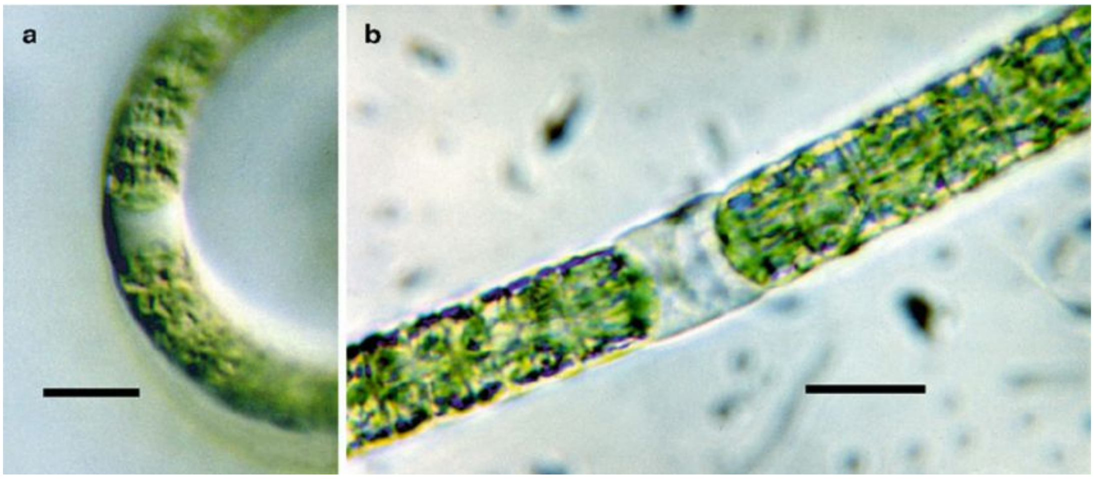


Figure 6: Formation of necridic cells, with the figure a being a coiled trichrome and figure b being a straight trichrome (Torzillo, 2013).

3.3 Reproduction

As mentioned in the previous section, *Arthrospira platensis* is a microorganism which does not require any sexual differentiation steps, but rather undergoes a simple cell division which results in its reproduction. Said cell division is divided into three fundamental stages in which the cell fragments, grows, and then is divided. For more information see Section 3.2 Life Cycle and Phenology.

3.4 Ecophysiology

3.4.1 Light

Arthrospira platensis' cellular growth is optimal when exposed to a light intensity of around 5k-lux, leading to the maximum cellular concentration, along with the highest chlorophyll obtained (E.D.G. Danesi, 2003). Considering *Arthrospira platensis* grows photo-autotrophically, the exposure to light is vital to productive cultivation, however, it does not affect the differentiation or development process of the cell (Vonshak, 1997). At a range of 150-200 μmol m^-2s^-1 Klux, which is about 10-15% of the total solar radiance at a 400-700 nm range, *A. platensis* becomes saturated which will eventually lead to photoinhibition in the cells (Vonshak, 1997).

3.4.1.1 Photoinhibition

Once the cell is exposed to the previously mentioned photon flux levels, the cell loses the photosynthetic capacities because of a high photon-flux density, which saturates the cell. Different strands of this same algae differ from their light sensitivity, with the content of protein D1 being a deciding factor (Vonshak, 1997). This is because D1 protein is a crucial component of the photosynthetic electron transport chain, which extracts sunlight energy via redox reactions (Oncel, Kose, & Faraloni, 2015). Additionally, cultures which were grown at a high light intensity tend to have a higher resistance to light stress.

3.4.2 Temperature

Temperature affects many aspects of *A. platensis* growth and development, including its capacity to photosynthesize, and its respiration rate. The optimal temperature for photosynthesis in this cyanobacterium was at around 30º- 35ºC, as can be seen in *Figure 7*, below, with respiration benefiting from a 35ºC temperature the most (Vonshak, 1997). As can be seen, temperatures above this range lead to a reduced relative growth rate. It must be noted, that this is a strand which has a wide range of growth, with others being more sensitive to temperature.

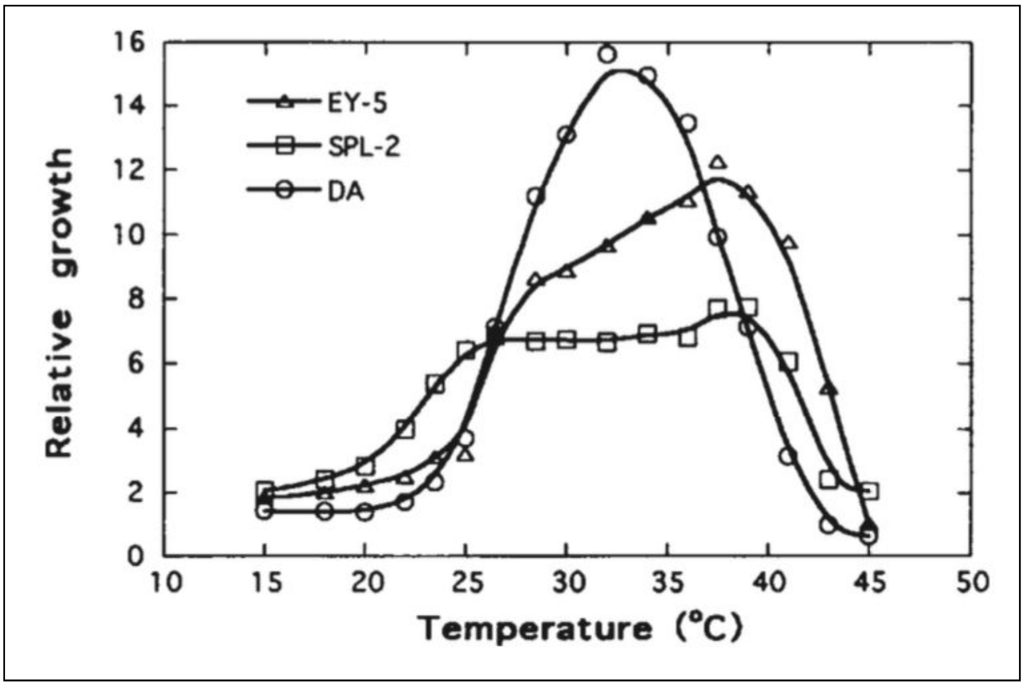


Figure 7: The effect of temperature on different strands of Arthrospira. A. platensis is labeled as SPL-2 (Vonshak, 1997).

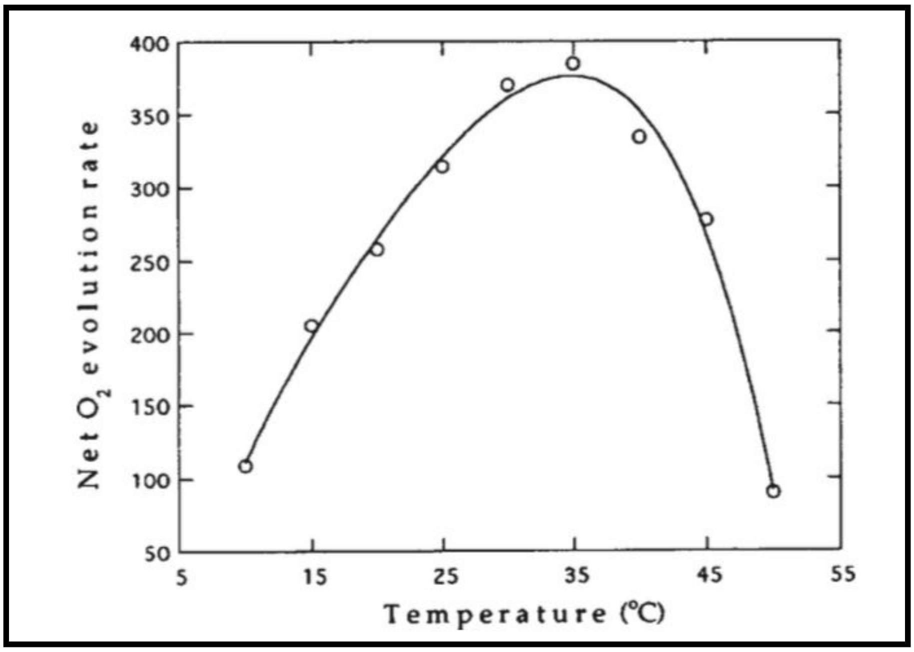


Figure 8: The effect of temperature (Cº) in photosynthesis on A.platensis cells (Vonshak, 1997)

3.4.3 Salinity

Arthrospira platensis cells which undergo high contents of salinity, get stressed and become less efficient in handling light energy (Vonshak, 1997). According to an experiment conducted by Vonshak in 1997, after 24 hours of high salinity, *A. platensis* shows a decrease in biomass, followed by a new, slower growth which can be attributed to high salinity in the water. In addition, having the ideal salinity controls whether or not there is a blooming, leading to eutrophication in the body of water in which it resides (Almahrouqi, Naqqiuddin, Achankunju, Omar, & Ismail, 2015). When it comes to cultures, *A. platensis* requires time to accommodate to higher salinity levels. Without said acclimatization period the culture might either completely collapse or result in lower productivity (Almahrouqi et al., 2015)

When it comes to the natural occurrence of *A. platensis* on Natron Lakes, it has been hypothesized that salinity does not affect its productivity due to the low contents of bicarbonate on the water (Torzillo, 2013).

4.0 Propagation and Management

4.1. Cultivation of cyanobacteria

When it comes to the cultivation of any cyanobacterium it is ideal to try and mimic the environmental conditions it is accustomed to growing in naturally. The basic requirements include a large container of water or pond, in which the cyanobacterium can develop and grow at its own rate, which is positioned in a location where it receives large amounts of light. As previously mentioned in section 2.3.1.1, for *A. platensis* the ideal medium is Zarrouk's Medium, but this can differ with different kinds of cyanobacteria, making the medium a crucial step for the optimal growth of cyanobacteria. Lastly, it is crucial that the algae have a sufficient supply of carbon, in order to be able to photosynthesize. These requirements can be seen in *Figure 9*, where the reactants are shown in order to produce biomass and oxygen.

$$CO_2 + H_2O + \text{nutrients} + \text{light energy} \rightarrow \text{biomass} + O_2$$

Figure 9: Chemical formula of photosynthesis in microalgae

4.1.2 Cultivation of *A. platensis*

Arthrospira platensis is a cyanobacterium which can adapt and thrive in most environments and waters, making it exceptionally easy to grow. However, different approaches must be taken in order to produce *A. platensis* indoors or outdoors. Many producers have opted for indoor and tank cultivations, due to the fact that outdoor cultivation requires extensive amounts of land, which are usually unavailable to the producer (Markou, 2014).

4.1.3 Indoor cultivation

For cultivation to be effective indoors, a clear container through which the *A. platensis* can absorb as much light possible is necessary. Recalling the information in 3.4.1, biomass production is directly related to light exposure, making it vital for the culture to be exposed to high amounts of sunlight.

4.1.3.1 Artificial light

The utilization of artificial lighting in cultures of *A. platensis* benefits the producer because of the low requirement of land, the better control over biomass density, and the steadier concentration which comes with a steady diurnal and nocturnal schedule (Markou, 2014). It is important to note, that although it has positive benefits in terms of the control it gives over the culture, it will have higher installation costs, along with high energy consumption throughout the whole cultivation process (Markou, 2014). In terms of the type of light source, it is preferred to utilize LED lights over fluorescent lights because these will have little to no impact over the temperature of the culture (Naqqiuddin, Sukumaran, Almahrouqi, Omar, & Ismail, 2015).

4.1.3.1.1 Color of light

The color of light affects the growth and development of the cyanobacterium which is exposed to it. In a study conducted by the Agricultural University of Athens, it was seen that the color of light affected biomass production, lipid content, chlorophyll content, and protein content (Markou, 2014). Studies have shown that microalgae seem to prefer blue or red light, benefitting vastly if the light correlates with the pigmentation of their light-harvesting complexes (Schulze, Barreira, Pereira, Perales, & Varela, n.d.). This would suggest that *Arthrospira platensis* will develop better when exposed to blue or green light, as can be seen in *Table 2*, where blue light has higher percentages in more than half of the categories.

In *Table 2* it can be seen how higher biomass was obtained with warmer LEDs (with this being red and pink), but higher chlorophyll, lipid content, and carbohydrates were obtained with blue LEDs. Additionally, carotenoids do not seem to be affected by the light emission, showing a minimal difference between each LED color. The biggest protein content, as it can be seen in *Table 2* is achieved through white light (50.1%), having similar results with a green light (49.8%). This preference for blue light has to do with *A. platensis*' photosynthetic system and chlorophyll b content, which makes the cyanobacteria thrive under the blue light.

Table 2: Chart of the effect of light on A. platensis based on an experiment conducted by the Agricultural University of Athens (Markou, 2014).

	Blue	**Green**	**Yellow**	**White**	**Red**	**Pink**
Biomass productivity (mg l^-1 d^-1)	4.68	9.73	15.43	15.75	30.69	**30.89**
Phycocyanin%	**17.6%**	11.7%	9.8%	9.9%	9.3%	8.2%
Chlorophyll %	**1.42%**	1.21%	1.19%	1.16%	1.04%	1.06%
Carotenoids %	2.79%	2.75%	**2.84%**	2.75%	2.73%	2.78%
Protein %	42.1%	49.8%	47.3%	**50.1%**	47.1%	45.2%
Lipids%	**6.0%**	4.8%	4.3%	4.6%	4.4%	3.8%
Carbohydrates %	**11.3%**	10.5%	9.8%	8.8%	10.8%	8.8%

4.1.3.1.2 R: FR Ratio

Cyanobacteria such as *Arthrospira platensis* require red light to exist, however, they are able to utilize blue light more efficiently. In addition, their lack of phycobilins makes it hard for them to utilize yellow light efficiently (Schulze et al., n.d.). For this reason it can be seen in Table 2 how high percentages could be achieved with red and pink light, however, the cyanobacteria develop better under blue light.

R: FR ratio refers to the red versus far-red light which many organisms are extremely receptive to. These types of light can affect the production within the cyanobacteria itself (Erik Runkle, 2011). Red light stands at around 620λnm whereas far-red light stands at around 700λnm as can be seen in *Figure 10*. This makes red algae grow better under it than blue-green algae such as *Arthrospira platensis*. While red light can be beneficial for *A. platensis*, free-floating chlorophytes are unable to detect far-red light, because of their lack of phytochromes (Schulze et al., n.d.).

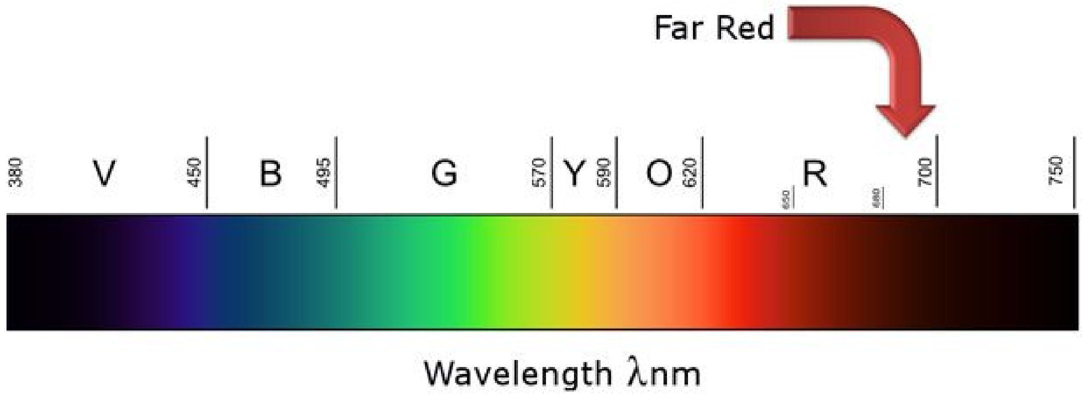


Figure 10: Wavelength of different colored lights (LED by passion, n.d.).

4.1.3.1.3 Fluorescence Spectrum

The fluorescence spectroscopy is an electromagnetic spectroscopy which excites a sample's electrons in order to analyze its fluorescence (Perkin Elmer, 1981) *Arthrospira platensis* shows a peak performance at 760 nm at 77k mainly because it has an extremely low-energy chlorophyll a, which leads to it not having any phycoerythrin in its phycobilisome (Akimoto et al., 2012). These fluorescence bands are due to the excitation energy produced in the transfer process between phycocyanin and allophycocyanin, which is inferred to take place between the photosystem I and II (Akimoto et al., 2012).

4.1.3.2 Water Medium

In order for *A.platensis* to successfully grow indoors, it requires a proper balance in nutrients that will allow it to propagate. For this specific strand, it is recommended to implement the use of a prepared medium known as Zarrouk's medium, which foments the growth of *A. platensis* cells. As previously mentioned in section 2.3, Zarrouk's medium is a nutrient-rich environment which can be provided for cyanobacteria to grow in. Consisting of various chemicals, said medium provides the perfect conditions for *A. platensis* to thrive. As seen in section 2.3.1.1, modified Zarrouk's medium includes potassium in various forms, which has proven to be a key component in maintaining a high growth rate of *A.platensis* (Rajasekaran Chandrasekaran, 2016). In addition, A5 micronutrients enhanced the growth, chlorophyll content and biomass content in *A. platensis*, making it a key component for the modified medium (Rajasekaran Chandrasekaran, 2016). It is important to note that filtered water should be utilized for the culture and when preparing the medium, in order to prevent foreign algae from entering the culture (Jourdan, 2001). Lastly, maintaining a pH of 10 or more will remove the chances of having excessive exopolysaccharides, which will not harm the culture, but will give it an unpleasant look.

4.1.3.3 Tank Specifications

For indoor cultivations, it is recommended to have a 20L clear tank, which can be either plastic or glass, in order for it to allow adequate light illumination on the culture (Naqqiuddin et al., 2015). Because this is an indoor cultivation, it is necessary to include an aeration pump, air stone, and plastic air tubing in order to provide proper aeration throughout the tank (Naqqiuddin et al., 2015). This allows for adequate gaseous exchange, meaning n adequate inflow and outflow of buildup gases. In order to have a good culture, the tank should be prepared before placing the cyanobacteria in the water, in order to prevent disturbance of the culture when building. In order to prevent contamination, it is recommended to include a lid to the tank, due to the possibility of absorption of toxins and heavy metals (Palaniswamy & Veluchamy, 2017).

4.1.3.4 Initiation of culture

In order to start a culture of *Arthrospira platensis*, it is necessary to obtain a live sample from a supplier. This "starter kit" contains the mother algae strand in a predetermined medium, which can be then introduced to the prepared tank. When selecting *Arthrospira platensis* strands for the culture, it would be best to select a strain with a high proportion of coiled filaments, which will facilitate the harvesting (Jourdan, 2001). Once introduced to the tank, this culture will then require frequent movement, in order to allow all the filaments to obtain light and CO_2 evenly. Additionally, this process prevents clumping and sedimentation through the tank ("Growing Spirulina at Home Information," 2017). It is advisable to maintain a high concentration of *A.platensis* after each dilution with the medium (0.3g/ L), making sure to maintain the culture's color in a clear green state (Jourdan, 2001).

4.1.3.4.1 Exopolysaccharide

Exopolysaccharides are sugar residues secreted by microorganisms into their surrounding environment as a protective diffusion barrier (Nwodo, Green, & Okoh, 2012). In other circumstances, this excretion is due to an excess of sugars, which the cell excretes in order to maintain a carbohydrate reserve (Nwodo et al., 2012). Considering the implications of an indoor culture, this secretion has no use for the monitored culture, however the uses for the exopolysaccharide range from medical to industrial uses. Spirulan, the exopolysaccharide produced by *Arthrospira platensis*, had been documented to serve as an inhibitor for pulmonary metastasis in humans, along with preventing tumor cells' proliferation and adhesion (Nwodo et al., 2012).

4.1.4 Management of indoor produce

Once the culture has been established and is in good condition, harvesting of the product will be simple. However, once the product gets old, it becomes sticky and harder to obtain. When harvesting it is better to work during morning hours where there are cooler temperatures and higher protein content (Jourdan, 2001). In addition, the sunshine hours that will be available will aid in the drying process of the *A. platensis*.

When harvesting, there are two basic steps in order to obtain the *A. platensis*: filtration and removal of residual medium. Filtration is achieved by passing the culture through a fine cloth such as cheesecloth by utilizing gravity as the driving force. Additionally, the culture should be stirred prior to harvesting, due to the fact that coiled *A. platensis* cells tend to float and form a top layer. If said layer was to be harvested the percentage of straight *A.platensi*s cells would increase, making harvesting more strenuous (Jourdan, 2001). Once filtration is complete, it is necessary to remove the residual medium in order to be consumed or dried for diverse uses. Filtration is accelerated by moving the filter, which after a while will allow the biomass to agglomerate, preventing the cells from sticking to the cloth. After this, applying pressure to the cloth bad will expel the remaining residual medium. Once the medium coming out of the bag becomes greenish the process must be stopped, due to the fact that this means product is being lost (Jourdan, 2001). It is not recommended to wash the produce with fresh water, which might cause rupture because of osmotic shock, and will make biomass more prone to fermentation (Jourdan, 2001).

Arthrospira platensis can also be harvested in small scale production through a process called sedimentation. In said process liquids and solids are separated from each other utilizing the force of gravity, which allows the denser *A. platensis* cells to sediment. This process is quite time consuming and requires more energy, making it not recommendable (Al hattab, 2015)

4.1.5 Outdoor Culture

Outdoor production works for larger scale or mass production of *Arthrospira platensis*, logically taking up more space, and different specifications than those of indoor cultivation.

4.1.4.1 Pond specifications

Ponds utilized for outdoor cultivation are usually shallow (12-15cm deep), and either lined with concrete, PVC or another durable plastic material (Habib, 2008). In addition, the pond should include a paddle wheel which will mix the culture which can vary in shape as seen in *Figure 11*. This is necessary to allow a proper amount of sunlight to all the cells, which will not obtain proper sunlight if it remains still. Through experimentation, it can be seen how outdoor, non-shaded cultures have higher growth and productivity compared to indoor and outdoor shaded cultures (Sukumaran et al., 2018).

Figure 11: Outdoor cultures in China and Japan, which show different pond shapes and paddle shapes [(Henrikson, 2011)](#).

4.1.4.1.1 Paddle

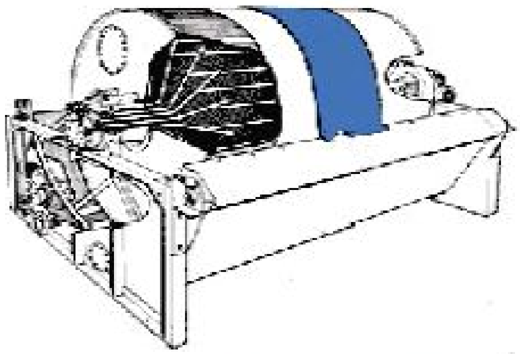
The paddle utilized to move around the culture is the most vital portion of the pond. Varying in shapes and sizes in order to adapt to the pond it is located in, it allows the proper aeration of the culture by moving the cells around. In addition, agitation of the culture allows the cells to assimilate nutrients better and prevents photoinhibition of the cells (Sukumaran et al., 2018). As seen in *Figure 11*, circular ponds work with a pivoted agitation system, whereas raceway ponds such as the one in Hainan, China, will work best with paddle wheels.

4.1.6 Management of Large Scale Produce

Large scale produce can be managed in several ways, which include more industrial ways such as vacuum or pressure filtration, or a simple mesh straining. The type of method implemented largely depends on the budget for the culture, along with the time required to obtain the produce. Filtration has been one of the most common options of microalgae harvesting, due to its variety and simplicity. This method requires the use of a permeable medium which can retain the cells while allowing liquid to pass through (Al hattab, 2015). The pressure difference required to allow the liquid to pass through can be obtained through gravity, pressure, or a vacuum, depending on the energy consumption required and the budget of the supplier.

4.1.6.1 Vacuum Filtration

Vacuum filtration achieves solid separation by capturing the microalgae cells onto a filter by suctioning the liquid through the filter (Al hattab, 2015). The type of vacuum filter differs depending on the filter membrane utilized. These membranes include drum filter, suction filter, filter thickener, belt filter, and starch pre-coated filter, with it being found that drum filters resulted in clogging and filter thickeners resulted in a low solid content compared to the high energy requirements (Al hattab, 2015). Effectiveness of this process depends on the membrane size and the size of the cells that are going to be harvested.



(a) Vacuum drum filtration [50]

Figure 12: Vacuum drum filtration system (Al hattab, 2015)

4.1.6.2 Pressure filtration

Pressure filtration separates particles from their liquid suspension by pressurizing the mixture. By raising the pressure above atmospheric pressure, a flow of fluids is created which facilitates the formation of cakes in the filter (Al hattab, 2015). There are two options for pressure filtration: plate and frame filter, or a pressure vessel, which can be seen in *Figure 13*. The first method forces the liquid vertically through the filter by utilizing high pressure, whereas pressure vessels pumped the fluid through fitted cloths which trapped the microalgae within them, creating cakes (Al hattab, 2015). This is an energy efficient method, however, its efficiency is dependent on the microalgae type, with it being proficient for *Arthrospira platensis*.

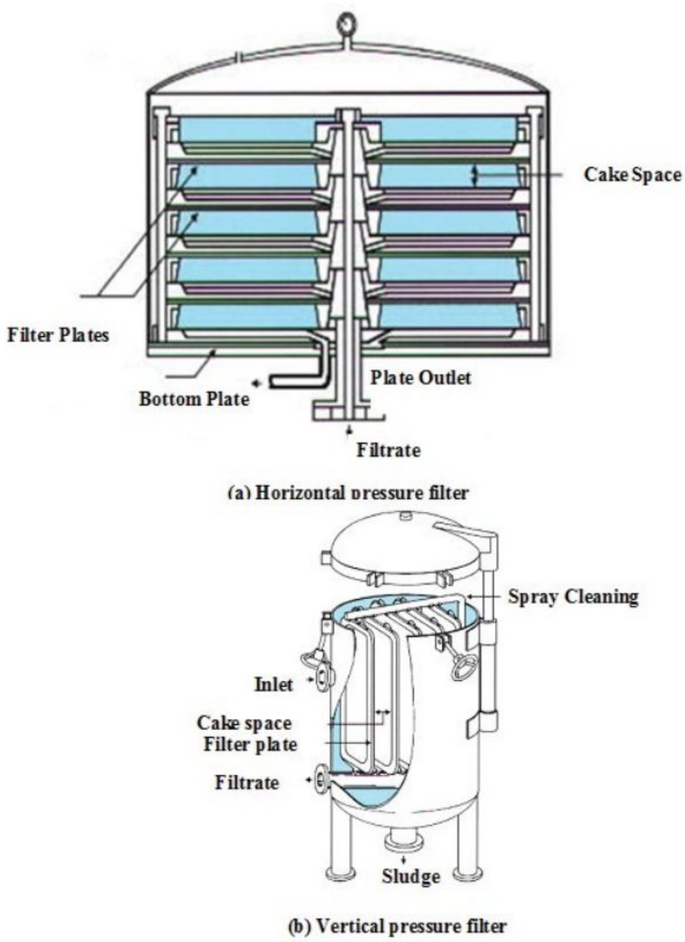


Figure 13: Different forms of pressure filtration, with a being a horizontal pressure filtration and b being a vertical pressure filtration (Al hattab, 2015).

4.1.6.3 Crossflow filtration

Crossflow filtration is one of the most effective methods for large scale harvesting. In this process, the culture flows tangentially across a membrane, which retains larger particles and allows the smaller particles to permeate. This separation can be seen in *Figure 14*, where the retenant (retained particles) flow, and the smaller particles permeate. This is a highly effective method because it allows the complete separation of debris and microalgae cells in a cheap way (Al hattab, 2015).

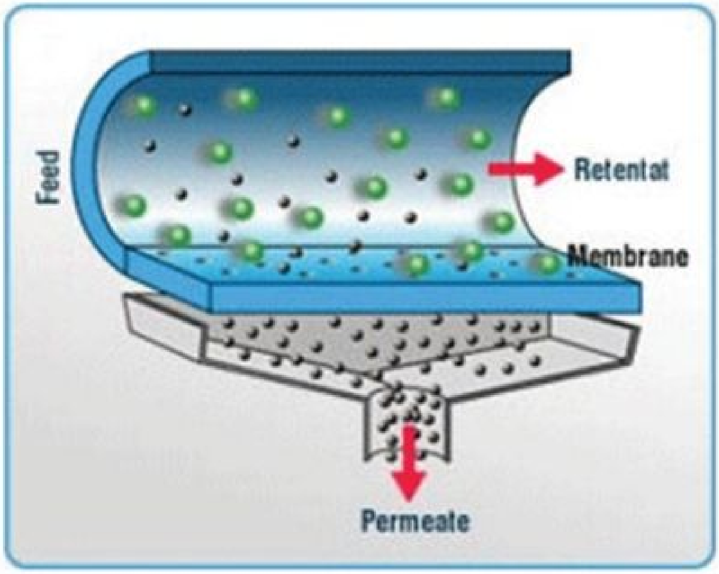


Figure 14: Crossflow filtration system process (Al hattab, 2015).

5.0 Uses and Values

Arthrospira platensis has been labeled as a “super-food” in this past century because of its high nutritional value for humans, along with the various uses that have been found for this cyanobacteria. In addition, it has been found to be a great addition for different animal feed, thanks to its high nutritional value in contrast to its simple cultivation.

5.1 Nutritional value

Arthrospira platensis’ nutritional value can vary depending on the cultivation method utilized, which can alter the cell’s composition. As can be seen in *Figure 15*, *A. platensis* has a vast amount of vitamins and minerals that are vital for humans. Some of these include:

- Vitamin B12: essential for the normal formation of red blood cells (William C. Shiel Jr., 2018).
- Beta-carotene: turns into vitamin A when consumed, which is good for normal vision, the immune system, and the proper functioning of vital organs (NIH, 2013).
- Iron: boosts energy levels, gastrointestinal processes, immune system, and helps regulate body temperature (Megan Ware, 2018).
- Calcium: required to maintain a strong bone structure, allow blood clotting, muscle contractions, and the work of several enzymes (Nancy Choi, 2017).
- Phosphorus: second most abundant mineral in the body, essential for the formation of bones and teeth, along with kidney and muscle functions, and aid with nerve signaling (Emily Wax, 2017).

The high content of these nutrients in a low dosage of *Arthrospira platensis* makes it a great food supplement with a high nutritional value. Additionally, this is a great food to include in a diet which lacks animal products, because it can supply most of the nutrients that are generally found in animal products. It is also a food with high protein content, with 65-70% of its dry weight being protein, which is higher than other foods considered a high protein source at around 35% (Chamorro-Cevallos, 2015). *A. platensis* has been deemed as being superior to other vegetable protein sources, not only because of its high content of protein but also because of the better absorption of the protein into the body.

Nutritional profile of Spirulina *Powder (composition by 100 g)*

Macronutrients		***Vitamins***	
Calories	373	Vitamin A (as β-carotene)[b]	352.000 IU
Total fat (g)	4.3	Vitamin K	1090 mcg
Saturated fat	1.95	Thiamine HCL (Vitamin B1)	0.5 mg
Polyunsaturated fat	1.93	Rivoflavin (Vitamin B2)	4.53 mg
Monounsaturated fat	0.26	Niacin (Vitamine B3)	14.9 mg
Cholesterol	< 0.1	Vitamin B6 (Pyridox. HCL)	0.96 mg
Total carbohydrate (g)	17.8	Vitamin B12	162 mcg
Dietary fiber	7.7		
Sugars	1.3	***Minerals***	
Lactose	< 0.1	Calcium	468 mg
Protein B	63	Iron	87.4 mg
Essential amino acids (mg)		Phosphorus	961 mg
Histidine	1000	Iodine	142 mcg
Isoleucine	3500	Magnesium	319 mg
Leucine	5380	Zinc	1.45 mg
Lysine	2960	Selenium	25.5 mcg
Methionine	1170	Cooper	0.47 mg
Phenylalanine	2750	Manganese	3.26 mg
Threonine	2860	Chromium	<400 mcg
Tryptophan	1090	Potassium	1,660 mg
Valine	3940	Sodium	641 mg
Non-essential amino acids (mg)			
Alanine	4590	***Phytonutrients***	
Arginine	4310	Phycocyanin (mean)[b]	17.2%
Aspartic acid	5990	Chlorophyll (mean)[b]	1.2%
Cystine	590	Superoxide dismutase (SOD)	531,000 IU
Glutamic acid	9130	Gamma linolenic acid (GLA)	1080 mg
Glycine	3130	Total carotenoids (mean)[b]	504 mg
Proline	2380	β-carotene (mean)[b]	211 mg
Serine	2760	Zeaxanthin	101 mg
Tyrosine	2500		

Figure 15: Nutritional profile of Arthrospira platensis powder by 100 grams (Chamorro-Cevallos, 2015).

5.2 Toxicology

There have been several toxicology studies of *Arthrospira platensis*, with no study finding significant toxicological results, deeming it almost completely safe for human consumption. In *Figure 16* it can be seen how *Arthrospira Platensis* presents no alterations for organs, body weight, hematology, urine, reproductive processes, or genetic mutations.

Toxicity of Spirulina	
Toxicity Test	*General Results*
Acute	The oral and single treatment with as much 800 mg/kg of *Spirulina* to rats produced no mortality, nor alterations in body weights, tissues and organs. Also, there was no allergic skin reaction with an application of up to 2000 mg/kg.
Subchronic	The feeding of *Spirulina* in different experiments to rats or mice at a dietary level until 30% for 13 weeks, produced no toxic effects on body and organ weights, hematology, serum, urine and histopathology values. Only one study, in mice, with a diet containing 60% of the algae induced an increase in the kidney, heart and lung weights and a nephrocalcinosis syndrome.
Chronic	*Spirulina* given in as much as 48% in the experimental diet for 86 weeks, produced no adverse effects on hematology, urine, serum biochemistry, nor in macroscopic or histopathological findings.
Reproductive	Fertility, teratogenic, peri- and postnatal development and multigenerational studies in different species of rodents, showed no deleterious effects by *Spirulina* treatment at 10, 20 and 30% levels in the diet.
Genotoxic	Short and long-term studies with *Spirulina* at 10, 20 and 30% levels included in the diet, failed to reveal germinal mutations of the dominant-lethal type in rats and mice. Negative results were also reported using the *Salmonella typhymurium* test.

Figure 16: Toxicological studies results of Arthrospira Platensis (Chamorro-Cevallos, 2015).

5.3 Uses

Arthrospira platensis has various uses because of its extremely nutritional composition, which include medicinal, nutritional, and for animal feed.

5.3.1 Medicinal uses

The C-phycocyanin found in *A. platensis* is a phycobiliprotein (water soluble protein), which has various uses including being an antioxidant, anti-inflammatory, neuroprotective and hepatoprotective (Romay, González, Ledón, Remirez, & Rimbau, 2003). This compound can be credited for most of the medicinal benefits of *Arthrospira platensis*, thanks to the massive amounts of benefits it provides the consumer. C-phycocyanin is a natural pigment extracted from marine algae, which has been found to be non-toxic and non-carcinogenic, making it apt for human consumption and medical use (Romay et al., 2003).

5.3.1.1 Malnourishment treatment

Arthrospira platensis has been widely used to combat malnourishment in various countries, due to the simplicity of its harvesting along with the high nutritional value in a low amount of product. In various studies conducted it was shown how the administration of around 10g per day to malnourished children rapidly improved their nutritional status (Matondo, Takaisi, Nkuadiolandu, Kazadi Lukusa, & Aloni, 2016). In addition to this, it has been found that 1 to 3 grams a day for 4-6 weeks are enough to rehabilitate a malnourished child making it a highly effective treatment (Birot, Jouvencel, Raginel, & Rouillé, 2012).

5.3.1.2 Anemia treatment

Anemia is defined as a medical condition in which a person has a lower than the average number of red blood cells, or low hemoglobin. This condition diminishes the capacity of the blood to carry oxygen, leading the person to feel fatigued, be pale, and be short of breath (William C. Shiel Jr., n.d.) *Arthrospira platensis* has a positive impact in anemic people, thanks to its ability to provide essential amino acids, vitamin B12, folic acid, and high amounts of iron to the individual (Seyidoglu, Inan, & Aydin, 2017). Various studies have been conducted, which have arrived to the conclusion that this cyanobacterium have positive impact in the lives of anemic people, helping with their conditions and aiding their symptoms.

5.3.1.3 Obesity

Arthrospira platensis has shown to have hypocholesterolemic effects, which means that thanks to its C-phycocyanin content it is able to inhibit the reabsorption of bile acid in the ileum and the absorption of cholesterol in the jejunum (Seyidoglu et al., 2017). The reabsorption of bile in the ileum is not a constant process, due to the changes in diets, drugs, and disease which impact the rate at which the body can reabsorb the bile acid (Martínez-Augustin & de Medina, 2008). For this reason, an obese individual is more likely to have a less effective BA absorption, which leads to a saturation of the ileum, ultimately causing gastrointestinal diseases.

In another study conducted it was found that the ingestion of around 2.8g a day of *A. platensis* by a group of obese people showed lower body weight along with lower cholesterol levels (Seyidoglu et al., 2017).

5.3.1.4 Hepatoprotective effects

Based on experiments conducted on rats, it was shown that the C- phycocyanin found in *Arthrospira platensis* can be utilized to reduce liver toxicity, while simultaneously protecting the liver enzymes (Romay et al., 2003). This reduction of liver toxicity suggests that C-phycocyanin can be utilized to reduce hepatic brain injuries through the reduction of thioacetamide which can be obtained by an increased antioxidant activity provided by *A. platensis* (Romay et al., 2003).

5.3.1.5 Tumor treatment

The C-phycocyanin has demonstrated active anti-tumor effects from peptide components which show various inhibitory effects on tumor cells (Liu, Huang, Zhang, Cai, & Cai, 2016). The application of C-PC in tumor cells can combat cell growth by blocking DNA synthesis by inhibiting the cycle at either S or M phase, stopping the tumor cells from entering G1 (Liu et al., 2016). Cancerous cells are able to thrive because of damage in the gene regulation which inhibits the apoptosis of the cells, making C-PC induced apoptosis ideal for cancerous treatments in the body. Said induced apoptosis was found to be regulated by Bcl-2, making it efficient to control tumor progression and the metastasis in the body, without becoming a threat to healthy cells (Liu et al., 2016).

Arthrospira platensis also includes Poly-ADP-ribose polymerase (PARP), which is a DNA repair enzyme, which has been studied to promote the release of C-phycocyanin from the mitochondria into the cell, facilitating the phycobiliprotein from conducting apoptosis in the cells (Liu et al., 2016).

5.3.1.6 Anti-inflammatory effects

The efficiency of the anti-inflammatory effects provided by *Arthrospira platensis* is directly dependent on the dosage level, which will provide the body with sufficient C-phycocyanin to control cyclooxygenase-2 and nitric oxide in the body (Wollina et al., 2018). Both of the previously mentioned molecules are highly inflammatory, making the suppression of their production vital for the de-inflammation process.

5.3.1.7 Antiviral effects

An aqueous extract from *Arthrospira platensis* inhibits plaque formation in a broad range of viral strains due to the antiretroviral activity found in the extracts which allow halting the reproduction of virus (Chen et al., 2016). In a conducted study influenza strains were incubated with an *A.platensis* extract for 72 hours, which resulted in the *A.platensis* being able to inhibit around 70-94% of the virus yields it was tested with (Chen et al., 2016). The use of this cyanobacteria can be developed into a solution to viral treatments thanks to the safety and toleration organisms have when the algae is administered at a high dosage. Additionally, the lack of toxicity in *A. platensis* makes it a safe alternative for many patients. It is important to note that the disruption of plaque formation caused by *Arthrospira platensis* is the most effective during early stages of the infection, having a reduction of around 50% effectivity when administered in more advanced stages of a viral infection (Chen et al., 2016).

Aqueous extracts from *Arthrospira platensis* have also been found to inhibit HIV-1 replication in humans at a rate of success of around 50%, making this cyanobacterium a possible treatment for HIV patients in a near future (Ayehunie, Belay, Baba, & Ruprecht, 1998)

5.3.2 "Superfood"

Arthrospira platensis has been marked as a "superfood" thanks to its incredibly high nutritional value which was mentioned above. This has created a boom in its market, with health and fitness enthusiasts including the cyanobacteria into their diets. Millions of recipes have been created, in order to make *A. platensis* (known in the market as Spirulina) part of their diet. Recipes are accessible on the internet, along with *Arthrospira platensis* supplements and powders which can be included in daily routines.

Many sources recommend adding A. platensis to foods such as smoothies, toast, or salads as a dressing. Although possible, it is not advised to include this is sweet recipes because of its salty and seaweed-like flavor.

5.3.3 Animal feed

The high nutritional value of *Arthrospira platensis* combined with the simplicity and speed of harvesting it has makes it an ideal source of food for various animals. Containing essential amino acids, vitamins and minerals combined with high protein content, *A. platensis* fulfills the nutritional necessities most livestock require, showing no potential harm or toxicity for the animal.

5.3.3.1 Chicken

The use of *Arthrospira platensis* as a supplement for chicken feed has shown to have various results, with some being positive, neutral or negative. When *A. platensis* replaced soybean meals in rations (10-20% replacement), chicken showed a decline in growth rate. However when the algae replaced groundnut cake or fishmeal the diet change showed no variation in growth (Holman & Malau-Aduli, 2012). It has also been shown that *A. platensis* levels of around 50-100g /kg were able to maintain a typical growth rate in the group, with more than 200g/kg would bring a decline in growth rates to the group (Holman & Malau-Aduli, 2012).

However, the dietary supplement brought by the introduction of *Arthrospira platensis* to chicken production can be highly seen by the producer. The producer can evade the use of premixes when including *A. platensis* due to the high nutritional value this cyanobacterium provides to the chickens, therefore lowering the feeding costs for the producer. In terms of health, chickens receiving the mentioned algae showed to have better health conditions (even when receiving a low dosage) than those who did not receive the supplement or received other types of supplement (Holman & Malau-Aduli, 2012).

In terms of egg production, the inclusion of Arthrospira spirulina into a chicken's diet has shown the ability to reduce the cholesterol content of the eggs. This is due to the high antioxidant and omega-3 polyunsaturated fatty acids provided by *A. platensi*s, which is replaced in the egg for the cholesterol (Holman & Malau-Aduli, 2012). Other effects on chickens include a richer yolk color, along with a meat pigmentation and texture which has been found to be preferred by customers (Holman & Malau-Aduli, 2012).

5.3.3.2 Pigs

The use of *Arthrospira platensis* as a supplement for pig feed has been found to have inconclusive results. This is due to various factors including the breed of the pig, its age, and it's living conditions. While some breeds of pigs such as the crossbred weanling showed higher growth rates, other breeds showed no change (Holman & Malau-Aduli, 2012). It is important to note that sperm quality has been shown to improve with this algae.

5.3.3.3 Ruminants

These mammals' ability to digest unprocessed algae makes them ideal for a diet with *Arthrospira platensis* supplements. These animals are able to acquire the nutrients from the algae by a fermentation process in their stomach prior to digestion, making the acquisition of nutrients increase. In levels of around 20%of total feed intake, *A. platensis* showed an increase in microbial crude protein production for the individual, simplifying the absorption within them (Holman & Malau-Aduli, 2012).

5.3.3.4 Cattle

Cattle had a highly positive impact when it came to milk production, showing an increase of around 21% when *A. platensis* was included in their diets. Additionally, the quality of the produced milk increases drastically, showing a higher fat, protein, and lactose content along with a decrease of saturated fatty acids (Holman & Malau-Aduli, 2012). The condition of the cow's body is also improved drastically (8-11%), thanks to the high intake of nutrients provided by *Arthrospira Platensis* (Holman & Malau-Aduli, 2012). Additionally, just like with pigs the bull's sperm quality is improved when bulls received a bio-extract from *A. platensis*.

5.4 Market

As of 2018, the *A.platensis* market was at around $346 million USD, ranging in different dietary supplements, animal feed, medical use, and even cosmetic products (Kunsel & Onkar Sumant, 2019). Said market is expected to grow around $433 million USD in around 8 years thanks to the high interest in the product because of its health benefits (Kunsel & Onkar Sumant, 2019). As can be seen in *Figure 17*, *A. platensis* is highly dominant in the market thanks to its variety of uses, which are not as varied in *A. maxima*. The commercial uses of A. platensis range from nutraceuticals, cosmetics, food and beverages, animal feed, and others, with nutraceuticals having the dominant position in the market along with the highest expectancy of growth (Kunsel & Onkar Sumant, 2019). *Figure 17* shows the expected market growth from $346 million USD to $779 million USD.

Figure 17: Expected Arthrospira market growth (Kunsel & Onkar Sumant, 2019)

5.5 Imports of *Arthrospira Platensis*

Arthrospira platensis can be most commonly found in the market labeled as a food supplement, which makes importing countries have rules and regulations for the imports. Currently, most of the import of *A. platensis* into all countries come from India, making the supplements a key factor to their economy ("Export Data and Price of spirulina powder | Zauba," 2016).

5.6 Exports of *Arthrospira Platensis*

Arthrospira platensis markets have been mainly dominated by India, North America, and other Southeast Asian countries, however, there are many production and exporting sites around Europe as well. Some countries in the *A. platensis* market include (Kadri, n.d.):

- United States
- Canada
- Mexico
- Germany
- United Kingdom
- Italy
- Japan
- India
- China
- Colombia
- South Africa
- Egypt
- Australia
- Nigeria

5.6.1 India

Most of the "spirulina powder" destined to other countries is being exported from India, boosting its economy which is now one of the fastest growing economies in the world. In 2016 alone, more than 600 export shipments of *A.platensis* going out of the country to different destinations ranging from United States, Germany, New Zealand, etc, ("Export Data and Price of spirulina powder | Zauba," 2016).

5.6.2 United States

The US has one of the highest import rates of *A. platensis* and is overall dominant when it comes to the market (and is expected to remain this way) because of its population's increasing demand for naturally derived food coloring (Kunsel & Onkar Sumant, 2019). Additionally, the United States has some powerful manufacturers in the global market including Cyanotech Corporation and Cellana Inc., both based in Hawaii (Research, 2018).

5.6.3 Kenya

The Kenyan government has been working to boost *A. platensis* production in the country, however, the producers have failed to supply the regional market. These efforts have risen because of the nutritional benefits this supplement will bring to the country, making the government eager to invest in the production of this product. When it comes to international markets, Kenya has limited their reach because of the regulations of food imports which would impose higher production costs for the manufacturer (Antonio Piccolo, 2011).

5.6.4 Colombia

The production of *Arthrospira platensis* in Colombia has been a recent initiative which has been highly invested in by the government because of its high nutritional value which can benefit the country's health along with the economy. There are now various manufacturers in the country in the regions of Meta, Atlántico, and la Guajira (Tiempo, 2014). Around 600 million pesos have been invested by the Corporación Autónoma Regional del Atlántico with the hopes of fomenting the production and commerce of *A. platensis* in the country (Tiempo, 2016). Currently this is not a market strong enough to be expanded into an international one, however, the goal is for it to become such in the near future.

The cultivation of *Arthrospira platensis* has been considered for the department of la Guajira, which is the department with the highest malnutrition, morbidity and child mortality rates of the country (GÓMEZ & TIRADO, 2017). This interest in the cultivation emerged from the possibility of treating the previously mentioned issues with the ingestion of *A. platensis* in low doses, making it ideal for la Guajira. In addition, the semiarid climate of this region benefits the cultures of *A. platensis* which will not have to stop its production (unlike cultures in seasonal locations), making it able to produce high amounts of product which will provide for the communities.

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