الجمهورية الجزائرية الديمقراطية الشعبية
People's Democratic Republic of Algeria
وزارة التعليم العالي و البحث العلمي
Ministry of Higher Education and Scientific Research
المدرسة الوطنية العليا لعلوم البحر و تهيئة الساحل
National Higher School of Marine Sciences and Coastal Management

Final dissertation for state engineering diploma in marine sciences

Option: Marine Biotechnology

Theme:

Exploring spirulina’s potential for bioplastic production

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Academic year: 2023-2024

Acknowledgements

All glory is due to the Almighty Allah, upon whom we rely for endurance and strength in life.

We want to offer our special thanks and appreciation to our supervisor Mr A. Boughrira and our professor Mr M. Kada for their valuable guidance and support, and their perceptive directives. We are grateful to them for their constant support.

Our Sincere acknowledgements to the members of the jury for their efforts to read and evaluate this work.

Lastly, special thanks to our friends and family who helped us throughout our research. We appreciate their feedback and support.

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Abbreviations list

LDPE: Low-Density Polyethylene

PTT: Polytrimethylene Terephthalate

PHA: Polyhydroxyalkanoates

PHB: Polyhydroxybutyrate

$MgSO_4$: Magnesium Sulfate

$FeSO_4$: Ferrous Sulfate

$(NH_4)_3PO_4$: Ammonium Phosphate

K_2SO_4: Potassium Sulfate

$CaCl_2$: Calcium Chloride

$NaHCO_3$: Sodium Bicarbonate

K_2HPO_4: Dipotassium Hydrogen Phosphate

$NaNO_3$: Sodium Nitrate

$MgSO_4 \cdot 7H_2O$: Magnesium Sulfate Heptahydrate

$FeSO_4 \cdot 7H_2O$: Ferrous Sulfate Heptahydrate

EDTA: Ethylenediaminetetraacetic Acid

H_3BO_3: Boric Acid

$MnCl_2 \cdot 4H_2O$: Manganese (II) Chloride Tetrahydrate

$ZnSO_4 \cdot 7H_2O$: Zinc Sulfate Heptahydrate

$CuSO_4 \cdot 7H_2O$: Copper (II) Sulfate Heptahydrate

MO_3: Molybdenum Trioxide

$Co(NO_3)_2 \cdot 6H_2O$: Cobalt(II) Nitrate Hexahydrate

$K_2Cr_2(SO_4)_2 \cdot 24H_2O$: Potassium Chromium Sulfate Dodecahydrate

$NiSO_4 \cdot 7H_2O$: Nickel (II) Sulfate Heptahydrate

$Ti(SO_4)_3$: Titanium(III) Sulfate

NH_4VO_3: Ammonium Metavanadate

Na_2WO_4: Sodium Tungstate

NaCl: Sodium Chloride

KNO_3: Potassium Nitrate

$NH_4H_2PO_4$: Monoammonium Phosphate

$CO(NH_2)_2$: Urea

NaOH: Sodium Hydroxide

HCl: Hydrochloric Acid

pH: Potential of Hydrogen

mm: Millimeter

DNA: Deoxyribonucleic Acid

um: Micrometer

°C: Degree Celsius

°F: Degree Fahrenheit

% : Percentage

CO_2 : Carbon Dioxide

OH^- : Hydroxide Ion

g/L: Grams per Liter

L: Liter

cm: Centimeter

g: Gram

ml: Milliliter

2N HCl: 2 Normal Hydrochloric Acid

rpm: Revolutions Per Minute

min: Minute

h: Hour

Introduction

The global reliance on petroleum-derived plastics has led to a growing environmental crisis, with widespread pollution and the depletion of non-renewable resources. In response, there is an urgent need to reduce plastic usage and develop sustainable alternatives that can address the shortcomings of conventional plastics. Bioplastics, derived from renewable biological sources, have emerged as a notable contributor to this effort.

This study explores the potential of the cyanobacterium *Spirulina platensis* as a feedstock for the production of bioplastic materials. Spirulina is a nutrient-rich microalgae that has garnered significant attention for its diverse applications in the fields of food and biofuels. Its ability to accumulate polyhydroxybutyrate (PHB), a type of polyhydroxyalkanoate (PHA), makes it an attractive candidate for bioplastic development.

The primary objectives of this study are cultivating *Spirulina platensis* under controlled conditions and optimize its growth, extraction of the PHB within the its biomass, and using Spirulina as a biological source for the fabrication of bioplastic films. By leveraging the inherent properties of Spirulina, this research aims to demonstrate the feasibility and potential of this microalgae as a sustainable alternative to conventional petroleum-based plastics.

The findings contribute to expanding the knowledge base concerning the application of microalgae in the advancement of environmentally friendly bioplastic materials. The successful production and characterization of Spirulina-based bioplastics could pave the way for the adoption of this renewable resource in various industries, ultimately reducing the environmental impact of plastic waste and promoting a more sustainable future.

CHAPTER I: LITTERATURE REVIEW

1 Plastics

1.1 Definition

A plastic is a versatile material made primarily of polymers, either synthetic or semi-synthetic. It possesses the quality of being easily shaped through molding, extrusion, or pressing into diverse forms. Known for its lightweight, durability, flexibility, and cost-effectiveness, plastics have become widely used in various applications **(Manutchehr-Danai, 2009).** Initially sourced from fossil fuel-based compounds like natural gas and petroleum **(Andrady and Neal, 2009).**

1.2 History

The history of plastic dates back to ancient Mesoamerican civilizations around 1600 BC, where natural rubber was utilized in crafting various items **(Hosler et al., 1999).** The development of modern thermoplastics began in the nineteenth century, marked by significant milestones such as Goodyear's invention of vulcanized rubber in 1839 and the discovery of polystyrene by Eduard Simon. Throughout the twentieth century, plastics saw rapid advancement with the synthesis of numerous new polymer classes **(PlasticsEurope, 2008).**

Key plastic polymers such as polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), polystyrene (PS), and polyethylene terephthalate (PET) emerged as prominent materials with diverse applications. Polypropylene, discovered in 1954, had found widespread use in packaging, construction, and household goods. Polyethylene, synthesized in 1933, had demonstrated versatility in various forms, including film production and electrical insulation **(Andrady and Neal, 2009).**

Commercial production of PVC commenced in the late 1920s, primarily used in non-combustible building materials and packaging. PS, developed in the 1930s, had found applications in insulation and packaging, including expanded PS cups and trays. PET, introduced in the 1940s, and had gained popularity in bottle production due to its transparency and resistance properties **(PlasticsEurope, 2008).**

1.3 Types

1.3.1 Thermoplastics

A group of plastics characterized by their ability to melt when heated and solidify when cooled. These reversible properties give the material its name, and allow it to be melted, reshaped and solidified repeatedly. This family of plastics includes **(PlasticsEurope, 2020):**

Polyethylene (PE)

Polypropylene (PP)

Polyvinyl-chloride (PVC)

Polyethylene Terephthalate (PET)

Polystyrene (PS)

Expanded polystyrene (EPS)

Polyamides (PA)

Polycarbonate (PC)

Poly methyl methacrylate (PMMA)

Thermoplastic elastomers (TPE)

Polyarylsulfone (PSU)

Fluoropolymers, etc.

1.3.2 Thermosets

Thermosets are a group of plastics that experience a chemical transformation upon heating, forming a three-dimensional network structure. Once heated and molded, these plastics cannot be remelted and reformed. Examples of such plastics include **(PlasticsEurope, 2020):**

Polyurethane (PUR)

Unsaturated polyesters

Epoxy resins

Melamine resins

Vinyl esters

Silicone

Phenol - formaldehyde resins

Urea - formaldehyde resins

Phenolic resins

Acrylic resins, etc.

1.4 Benefits

Plastic and rubber are omnipresent and essential in modern society. They are impacting nearly every aspect of daily life, from packaging materials like containers and plastic bags to durable building products such as plastic pipes and vinyl cladding. With over a third of plastic consumption dedicated to packaging applications, and a comparable portion utilized in construction materials, the enduring nature and resistance to decay and corrosion make plastic a preferred choice for various purposes. **(Andrady and Neal, 2009)**.

1.5 Disadvantages

Despite the numerous benefits of plastic use, its environmental impact has become a pressing issue **(Millican and Agarwal, 2021).** Since the onset of mass plastic production in the 1950s, plastic debris has accumulated across terrestrial environments, open oceans, remote islands' shorelines, and even the deep sea **(Barnes et al., 2009).** This accumulation has evolved into a substantial environmental challenge, with millions of tons of plastic waste generated annually. Plastic pollution poses threats to wildlife, contaminates water, air, and soil, and contributes to climate change **(Kirchhof, 2005).** In addition, most plastics are not biodegradable, they can take hundreds or even thousands of years to decompose in the environment **(Andrady, 1994).** Moreover, the production and disposal of plastics can release harmful chemicals into the environment, posing health risks to humans by leaching into food and water sources. Also, recycling plastic is costly, presenting a significant challenge for waste management efforts **(Andrady and Neal, 2009).**

1.6 Recycling

Approximately 4% of the world's oil and gas production, a finite resource, serves as raw material for plastics, with an additional 3-4% utilized for energy during manufacturing. A significant portion of annual plastic production is dedicated to crafting disposable items like packaging, which are discarded within a year. These facts alone underscore the unsustainable nature of our current plastic usage. Moreover, due to the enduring nature of the polymers involved, large volumes of discarded plastics accumulate as debris in landfills and natural environments globally. Recycling emerges as a crucial solution to mitigate these impacts, representing a dynamic frontier in the plastics industry. By recycling, we can diminish oil consumption, lower carbon dioxide emissions, help reduce the overall volume of waste to be processed **(Hopewell et al., 2009).**

However, recycling alone is not the optimal solution for addressing plastic pollution. In fact, there has been a pursuit for alternative approaches, notably the development of biodegradable plastics capable of decomposing more rapidly than conventional synthetic counterparts. This quest aims to mitigate the environmental impact of plastics by introducing materials that break down more efficiently, potentially reducing pollution and waste accumulation **(Rajpoot et al., 2022).**

2 Bioplastics

2.1 Definition

Bioplastics refer to materials derived from biomass sources such as vegetable fats and oils, corn starch, straw, woodchips, sawdust, and recycled food waste. These materials can be categorized as biodegradable, bio-based, or a combination of both. Biodegradable bioplastics undergo decomposition in aqueous environments due to bacterial activity. This degradation process ultimately results in the formation of CO_2 and H_2O under aerobic conditions, and CO_2 and CH_4 under anaerobic conditions **(Censi et al., 2022).** Bioplastics are made entirely or partially from biomass-based sources. **(Naser et al., 2021).**

2.2 Types

Some examples of bioplastics are: poly(hydroxyalkanoates) (PHAs), poly (ε-caprolactone) (PCL), poly (butylene succinate) (PBS), poly (lactic acid) (PLA), and poly (ethylene succinate) (PES), poly(glycolic acid) (PGA), the copolymer of glycolic acid and lactic acid (PLGA), (poly(propylene carbonate)) PPC, (poly(furfuryl alcohol)) PFA, chitosan, and protein-based bioplastics **(Censi et al., 2022).**

PHAs (polyhydroxyalkanoates) are a class of biopolymers, where the most common representatives are the homopolyesters poly(3-hydroxybutyrate) (P3HB), poly(4-hydroxybutyrate) (P4HB), and, to a lesser extent, poly(3-hydroxyvalerate) (PHV), along with their copolymers poly(3-hydroxybutyrate-co-3-hydroxyvalerate) (PHBV) and poly(3-hydroxybutyrate-co-3-hydroxyhexanoate) (PHBHx), medium-chain-length PHAs like PHO (poly(3-hydroxyoctanoate)) homopolyesters, and their copolymers and blends **(Lackner et al., 2023).**

Poly-hydroxy-alkenoates (PHAs) and poly(lactic acid) (PLA) are among the most commonly utilized biopolymers, alongside polypropylene, showing the highest relative growth rate in industrial production **(Naser et al., 2021).**

One type of PHA, the poly(3-hydroxybutyrate) (P3HB), stands out as the most extensively studied within the PHA family. It serves as the carbon reservoir for various bacterial colonies, synthesized through bacterial fermentation from methane. This process involves the oxidation of methane to methanol via the enzyme methane monooxygenase, followed by the conversion of methanol to formaldehyde by methanol dehydrogenase **(Atiwesh et al., 2021).** The PHB shows a linear structure composed of CH_3 and CH_2 sequences, coupled with an ester -COOR group, imparting specific physical and chemical properties such as thermoplasticity and hydrophobicity, as well as mechanical traits including crystallinity grade and fragility. Commercial PHB closely resembles polypropylene derived from fossil fuels, featuring notable stiffness, fragility, a crystallinity grade ranging between 60 and 80%, a fusion temperature near 180°C, and both amorphous and crystalline phases **(Suzuki et al., 2021).** PHB can be a virgin polymer or with copolymers and additives in blends with better thermoplastic properties, such as the poly (3-hydroxybutyrate-co-3-hydroxyvalerate) [P (3HB-co-HV)] **(McAdam et al., 2020).**

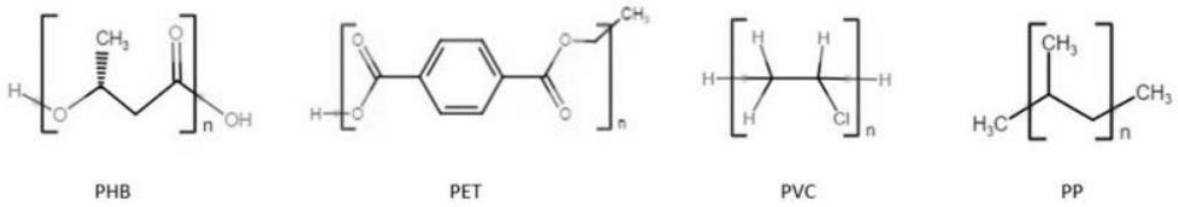


Figure 1: *Chemical structures of PHB in comparison to commonly used petroleum-based polymers (polyethylene terephthalate (PET), polyvinylchloride (PVC), PP (McAdam et al., 2020).*

2.3 Benefits and drawbacks

As plastic waste continues to accumulate in the environment, posing threats like microplastic pollution and other detrimental effects, the adoption of bioplastics offers a potential solution **(Lackner et al., 2023).**

However, the production of biomass for bioplastics demands significant land resources, water consumption, and intensive farming practices to boost yields. This process may involve the use of pesticides and chemicals, which could be minimized through eco-friendly synthesis methods **(Bezirhan and Bilgen, 2015).**

On the other hand, bioplastics are biodegradable without any filler addition, which is often used for increasing their mechanical properties **(Van Roijen and Miller, 2022).** Despite the growing demand for bioplastics, some impediments to their larger exploitation come from their expensive production and recycling **(Chen, 2013).** A plausible cost-reduction option would be

to extract PHA from cells through halogenated solvents such as $CHCl_3$ and CH_2Cl_2. However, these are toxic chemicals primarily used to prevent polymeric solutions from becoming too viscous. **(Censi et al., 2022).**

A wide variety of bioplastics have been introduced to address the environmental challenges associated with conventional petroleum-derived plastics. However, bioplastics are not without shortcomings. Studies show that even bio-based plastics cannot be easily recycled. In fact, bioplastics also end up in landfills, wherein gradually undergo degradation, leading to CO_2 and methane formation. Nevertheless, it is important to assess the environmental impact of bioplastics compared to the damage caused by conventional plastics **(Censi et al., 2022).**

2.4 Usage

Currently, bioplastics find widespread application primarily in packaging, And industrial containers and materials, such as bottles, film, clamshell cartons, and loose-fill materials, as well as waste collection and carrier bags. Plastic packaging, constituting 37% of plastic usage in Europe, holds significant prominence, with food packaging emerging as the largest plastic-consuming sector within the packaging domain **(Chen, 2013).**

Table 1: *Overview of bioplastics (source: Lackner et al., 2023).*

Bioplastic Material	**Short**	**Family (Class)**	**Biobased**	**Biodegradable**	**Applications**	**Fossil Counter parts**
Poly(lactic acid)	PLA	Polyester	Yes	Partly	Packaging, 3D printing, consumer goods, medical fields, agriculture	PS
Polyhydroxyalkanoates	PHA	Polyester	Yes	Yes	Packaging, 3D printing, biomedical use, bioremediati	PP and others

					on, commodity materials	
Poly(butylene succinate)	PBS	Polyester	Partly	Partly	Packaging, disposable tableware, medical articles, agriculture (mulching films, release of pesticides, and fertilizers), fishery	-
Poly(butylene adipate-*co*-terephthalate)	PBAT	Polyester	Partly	Partly	Packaging, antimicrobial foils, single-use catering items, agriculture, textile industry	LDPE
Starch, thermoplastic starch	TPS	Polysaccharide	Yes	Yes	Injection-molded commodity materials, thermoformable flat films	-

Bio-poly(trimethene terephthalate)	Bio-PTT		Partly		Textile fibers (carpets, car floor mats)	PTT
Bio-poly(propene)	Bio-PP		Partly		Automotive parts, electrical devices, concrete additive, textile fibers plastic bank notes in tropical regions, packaging materials	PP
Poly(ε-caprolactone)	PCL	Polyester		Yes	Biomedical use (release of pharmaceuticals, wound glues, tissue engineering), packaging	-
Cellulose acetate	CA	Polysaccharide (esterified)	Yes	Partly	Cigarette filters, artificial silk, eyeglasses frames	

Poly(ethene furanoate)	PEF	Polyester	Yes	Partly	Bottles, foils, fibers	PET

2.5 Bioplastics from microalgae

The world hosts numerous species of microalgae, each with unique qualities and the potential to produce bioplastics. Microorganisms such as Chlorella, Spirulina, and others play a crucial role in developing sustainable and biodegradable materials that could revolutionize the plastics industry. Spirulina species, in particular, can produce bioplastics with superior tensile properties compared to petroleum-based plastics like polystyrene. Spirulina-based polymers demonstrate excellent tensile strength, elongation, and flexibility. Additionally, Spirulina species can synthesize biopolymers such as PHA and PHB under photoautotrophic conditions. In bioplastic composites, Spirulina can also be used as a filler or reinforcing fiber, enhancing the mechanical properties of the resulting bioplastics **(A and G, 2024).**

2.5.1 Bioplastics binders

Microalgae, renowned for their high protein content, hold considerable potential as biopolymer materials. Nonetheless, the production of functional bioplastics from microalgae without the use of binders presents substantial challenges. Binders like glycerol and gelatin are crucial as they significantly enhance the physical and mechanical properties of the bioplastic.

Glycerol’s moisture-retaining properties properties prevent the bioplastic from drying out, while its compatibility with other components ensures a uniform, stable mixture. Glycerol also contributes to biodegradability and improves processing characteristics, facilitating efficient production **(Dianursanti et al., 2018).** Gelatin enhances moldability, plasticizing properties, and overall mechanical strength. Its natural, biodegradable nature further boosts the final product's environmental friendliness. Gelatin’s compatibility with PHB ensures a cohesive bioplastic material, enhancing ease of shaping and molding **(Adetunji and Erasmus, 2024).**

3 Spirulina

3.1 Presentation of *Spirulina platensis*

Arthrospira (Spirulina) is a spiral blue-green microalgae **(Yousefi et al., 2019)**, represents a filamentous cyanobacterium characterized by its non-heterocystous nature and multicellular, cylindrical morphology, often exhibiting screw-like coiled trichomes. This organism thrives across diverse habitats, including those with elevated salinity levels **(Jacquet et al., 2013)**, it grows optimally in pH range of 9- 11 and there is least chance of contamination of other microbes **(P., 2014)**. Its global distribution has led to the isolation of several species and strains, which have become pivotal subjects in both theoretical and applied research domains. Notably, Arthrospira has garnered substantial commercial interest and has been developed for the food industry in local areas, but also for alternative biofuel feedstock, skin-care product resources, and more. Despite its significant economic value, nothing has been published yet on viruses associated with the dynamics of this genus. **(Jacquet et al., 2013).**

Spirulina is one of nature's first photosynthetic organisms, capable of converting light directly into energy for complex metabolic processes **(P., 2014)**, it is microscopic in size but can grow up to 0.5 mm long, making it visible. It has a prokaryotic organization, a pluristratified cell wall, a photosynthetic lamellar system, ribosomes and DNA region fibrils. It is an excellent source of proteins, vitamins, fatty acids, minerals, photosynthetic pigments and numerous secondary metabolites **(Sánchez-Muros et al., 2020).**

***Figure 2**: Spirulina Platensis powder (Limited, 2015)*

3.2 Composition of *Spirulina platensis*

Spirulina, a type of microalgae, has been identified to have a variety of biopolymers, such as polysaccharides, proteins, and polyesters, that can be utilized in the manufacturing of bioplastics. The polysaccharides found in Spirulina, such as carrageenan and agarose, have been found to exhibit gelling and thickening properties, making them useful in the food and cosmetic industries.

In addition, Spirulina proteins have demonstrated their potential in the development of biodegradable plastics that have good mechanical properties. Spirulina, a protein source that has been used in the food industry for decades, is well-known for its ability to adapt to extreme conditions. Also, Spirulina contains many pigments including chlorophyll-a, β-carotene, etc. and the phycobiliproteins, C-phycocyanin and allophycocyanin **(P., 2012).** *Spirulina platensis* contains a high concentration of protein. Its composition is shown in Table 1

Table 2: *Composition of spirulina platensis source:* ***("A Review Study on the Potential of Microalgae Biomass Producing Biopolymer," 2023.)***

Component	(wt%)
Protein	60
Lipid	6
Fattyacid	265 mg / 10 g
Aminoacid	2410 mg / 10 g
VitaminA	2300IU
VitaminB1-B3	2.3 mg / 10 g
Vitamin B6&B12	112 mcg
VitaminE	4IU
Phycocyanin	20%
Chlorophyll	1.5%
B-Carotenoids	0.15%
Pantothenicacid	4 mg·/ 100 g
Folicacid	100 mg·/ 100 g
Polysaccharide	0.4 g·/ 100 g

3.3 History

In the 16th century, a German researcher, Dr Darwin, discovered a spiral-shaped blue-green algae and named it spirulina. Later, Dr Christopher Hills, "The Father of Spirulina", rediscovered this alga in Lake Chad in Africa, and popularized it as a food supplement. According to him, spirulina contains billions of years of evolutionary wisdom encoded in its DNA. Spirulina is a 300-million-year-old cyanophyceae filamentous microalga (family Oscillatoriaceae). Its name comes from the Latin word for tiny spiral. It occurs naturally in alkaline, mineral-rich and unpolluted water **(Kebede and Ahlgren, 1996).**

3.4 Systematic

The word 'spirulina' is the commercial name of the *Arthrospira* genus, not to be confused with the non-edible Spirulina genus, also considered to be a genus of cyanobacteria (examples: *Spirulina subtilissima*, *Spirulina princeps*) **(Fox, 1999).**

Distinguishing between Arthrospira and non-edible Spirulina solely based on their appearance is challenging due to their similar morphology. Molecular analyses, however, provide a reliable method for identifying Arthrospira species like *A. platensis* and *A. maxima* **(Sili et al.,2012).**

Table 3: *Spirulina classification* ***(AlFadhly et al., 2022).***

Common Names	**Taxonomic Classes**
Bacteria	Domain
Eubacterla	Kingdom
Cyanobacteria	Phylum
Cyanophyceae	Class
Oscillatoriophycideae	Sub-class
Oscillaorlales	Order
Osellatorlaceae	Family
Arthrospira	Genus
A.platensis	Species

There are several species that differ only in their geographical location: *Spirulina platensisis* the main African species, *S.geitleries* the Mexican species **(Arrignon, 2002)** and also known as *Spirulina maxima* **(Vonshak,1997),** *S.lonarfrom* Lake Lonar in India, *S.orovilca* from Lake Orovilca, *S.paracas* from water basins near Paracas, and *S.ventanilla* from Peru. Additionally, there's Spirulina crater from Mexico and Spirulina tamanrasset from Algeria **(Fox, 1999).**

3.5 Morphological features

Spirulina species show great plasticity in morphology. This is attributed to environmental factors like temperature and other physical and chemical factors and possibly also due to genetic change. In nature and in culture, Arthrospira forms helical trichomes of varying size and degree of coiling from tightly coiled morphology **(Figure 3)** to an even straight uncoiled form **(Figure 4).** The trichomes in Arthrospira species show distinct transverse cross-walls under the light microscope. The filaments are solitary and reproduce by binary fission. The cells of the trichomes are broader than long and the width can vary from 3 to 12 um though it can reach 16 um occasionally. The cell organization is that of a typical prokaryote with a lack of membrane-bound organelles **(Gershwin and Belay, 2007).**

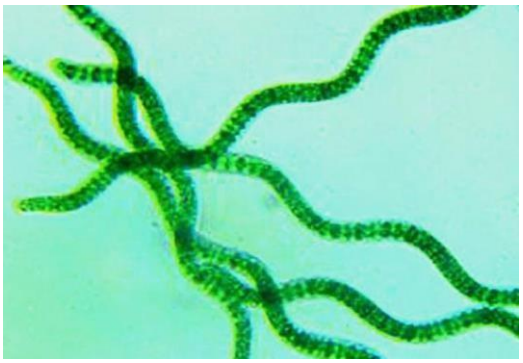


Figure 3*: Tightly coiled morphology of Spirulina ("What is Spirulina?," 2011.)*

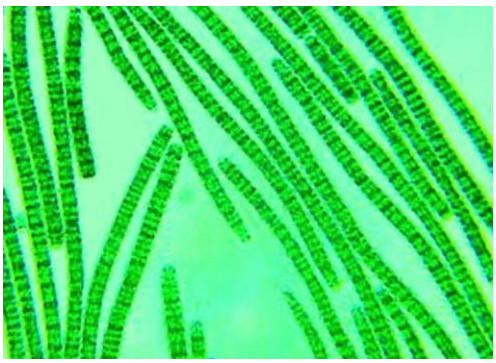


Figure 4: *Straight uncoiled form of Spirulina ("What is Spirulina?," 2011.)*

3.6 Habitat

Spirulina is commonly found in aquatic ecosystems such as lakes, ponds, and tanks **(P., 2014),** it is found in tropical and subtropical regions, particularly in warm bodies of water with high carbonate/bicarbonate content, elevated pH, and salinity. The large, gas-vacuolate filaments, which range from 3 to 12 micrometers in diameter, can be easily collected through filtration and other physical separation methods. Spirulina was first isolated from a freshwater sample in 1827 by Turpin. It has existed on Earth for over 3 billion years and continues to grow

abundantly in wild, very alkaline, mineral-rich, and largely pollution-free soda lakes around the world. These freshwater ponds and lakes, which favor Spirulina growth, have a notably higher pH range (9 to 11) than ordinary lakes and cannot sustain other forms of microorganisms **(Rosario and Josephine, 2015).**

The water in these environments is too salty, with pH levels reaching up to 11, to support fish, terrestrial crops, or be used for drinking. However, it is ideal for growing Spirulina, which thrives in very warm waters between 32°C and 45°C (approximately 85°F to 112°F) and can even survive temperatures as high as 60°C (140°F). In fact, the hotter the conditions and the more mineral salts concentrate as water evaporates, the more prolifically Spirulina grows. **(Rosario and Josephine, 2015)**

3.7 Applications of spirulina

Spirulina platensis, a type of blue-green algae, has a wide range of applications, including in the food industry, pharmaceutical, and poultry industries. It is considered a complete nutritional source and has been used as a dietary supplement for its high protein, vitamins, and minerals content. It is also used in medicine to treat various health conditions due to its bioactive compounds Additionally, Spirulina has been studied for its potential use in preventing oxidative stress and inflammation **(Fais et al., 2022).** In the poultry industry, the addition of Spirulina platensis has been shown to positively influence productive performances **(Bondar et al., 2023).** Also, it has been used as a complementary dietary ingredient of feed for fish and shrimp **(P., 2014)**. Furthermore, Spirulina platensis has been studied for its potential use in bioplastics, with research showing that it can be used to fabricate strong and stiff bioplastics **(Iyer et al., 2023)**. The growth and productivity of Spirulina depend on factors such as nutrient concentration, temperature, light spectrum, intensity, and pH, which influence its biochemical composition. Spirulina is listed by the US Food and Drug Administration (FDA) as "generally recognized as safe" (GRAS) and is relatively easy to cultivate but flourishes only in alkaline lakes with an extremely high pH and in large sunny climates**.** It is sold mainly as a dietary supplement in the form of health drinks or capsules **(Costa et al., 2019).**

3.8 Cultivation

The world production of spirulina increased since 1995 by more than 4000Tones/an **(Statistics CUBIA, 2000).** This species can be developed artificially in laboratory developed media and/or naturally under lake conditions. Moreover, Algeria developed Spirulina in the synthetic

medium in the south region of the country, precisely the area of Tamanrasset, but though the Spirulina produced locally does not meet the needs for the consumers **(Adiba et al., 2014).**

3.9 Growing Conditions

The cultivation of microalgae, such as Spirulina, relies on three main factors: temperature, light, and pH. Microalgae are particularly sensitive to sudden changes in these conditions. Additionally, other factors, such as the agitation of the medium, should be considered to ensure optimal growth.

3.9.1 Light

Light is an important factor, but direct exposure to sunlight is not recommended. Preferably, it is recommended to expose the crop to 30% sunlight except that a larger amount may be needed to quickly warm the crop in the morning. Spirulina grows only in light, but 24-hour lighting is not recommended either. During dark periods, Spirulina undergoes essential chemical processes, such as protein synthesis and respiration. High light intensity without proper agitation can cause photolysis, while high light intensity combined with strong agitation promotes optimal growth **(Fox, 1999).**

3.9.2 Temperature

Temperature is the parameter that controls the speed of reactions. This tends to rise sharply in the greenhouse or in full sunlight, creating problems of evaporation from the culture medium. The optimum temperature for spirulina growth is in the 35-38°C range, while the minimum is 15-20°C **(Fox, 1999).**

3.9.3 pH

The ideal pH range for Spirulina cultivation is between 8.5 and 10.5 **(Jourdan et al., 1999).** Spirulina naturally tends to alkalize its environment. Dissolved CO_2 in water, when utilized by Spirulina, releases carbonate ions ($CO3^{2-}$), which through hydrolysis, release OH^- ions (Danesi, E.D.G, Rangel-Yagui C.O, Carvalho J.C.M. And Sato S, 2004)**.**

3.10 Growing Technique

The Spirulina cultivation process involves several essential steps, as outlined below:

3.10.1 Seeding

In a location without Spirulina, or to start with a new strain, begin with one gram of concentrated Spirulina in one volume of culture. For larger volumes, multiply the initial seed volume accordingly. Successive cultures are recommended. If the culture concentration is low, provide shading and continuous agitation; otherwise, the Spirulina will clump together **(Jourdan et al., 1999).**

3.10.2 Agitation

Agitation is necessary to ensure good cultivation, performed at least 2 to 4 times a day. It helps homogenize the culture and ensures even light distribution among all Spirulina filaments. Agitation enhances productivity in high-density cultures, evenly distributes CO2, and removes inhibiting substances like oxygen **(Dubey, 2006).** It can be manual (using a broom) or electric (using a pump or impeller). Continuous nocturnal agitation is beneficial for environmental self-purification **(Jourdan et al., 1999).**

3.10.3 Shading

Shading is essential when the crop temperature is very low (<10°C) and light intensity is high, to prevent Spirulina from being damaged by photolysis. Shading also makes the crop easier to harvest and enhances the quality of the Spirulina **(Danesi et al., 2004).**

3.10.4 Harvesting

To maintain the concentration of Spirulina between 0.4 and 0.6 g/L, regular harvesting is recommended. Without harvesting, the concentration will continue to increase until it reaches a balance between photosynthesis and respiration. High concentrations for extended periods can lead to cell death **(Jourdan et al., 1999).**

Harvesting techniques for Spirulina platensis typically involve a combination of methods such as gravity sedimentation, filtration, and centrifugation. Due to the filamentous nature of Spirulina, mechanical methods like centrifugation are often preferred for efficient biomass recovery. Additionally, bioflocculation followed by gravity sedimentation has been suggested as a cost-effective approach for harvesting Spirulina biomass, although considerations regarding potential microbiological contaminations and the quality of the end product must be taken into account **(Barros et al., 2015).**

3.10.5 Extrusion and Drying

Drying can be done in the shade, in a stream of air at room temperature, under a mosquito net **(Fox, 1999).** The drying time depends on the thickness of the biomass, temperature, and humidity. It typically takes around 4 hours, but can be as quick as one hour **(Jourdan et al., 1999).**

3.10.6 Culture mediums

Table 4: *Culture mediums used for spirulina species*

Species	**Culture medium**	**Ingredients and proportions**		**Reference**
Arthrospira platensis	Hiri	Natron	16 g/l	**Hiri (2008)**
		Table Salt NaCl	1 g/l	
		MgSO4	0.1 g/l	
		FeSO4	0.01 g/l	
		$(NH_4)3PO_4$	0.1 g/l	
		K_2SO_4	0.5 g/l	
		$CaCl_2$	0.1 g/l	
		Urea	0.1 g/l	
		Fresh water	1 l	
Spirulina maxima *Spirulina platensis*	Zarrouk	**Solution A9**		**Zarrouk (1966)**
		$NaHCO_3$	16 g/l	
		K_2HPO_2	0.5 g/l	
		$NaNO_3$	2.5 g/l	
		K_2SO_4	1 g/l	
		$MgSO_4, 7H_2O$	0.2 g/l	
		$CaCl_2$	0.04 g/l	
		$FeSO_4, 7H_2O$	0.01 g/l	
		EDTA	0.08 g/l	

		Solution A5	
		H_3BO_3 2.86 g/l	
		$MnCl_2$, $4H_2O$ 1.8g/l	
		$Zn\ SO_4$, $7H_2O$ 0.22 g/l	
		$CuSO_4$, $7H_2O$ 0.08 g/l	
		MO_3 0.01 g/l	
		Solution A6	
		$CO(NO_3)$, $6H_2O$ 0.44 g/l	
		$K_2Cr(SO_4)$, $24H_2O$ 0.096 g/l	
		$NiSO_4$, $7H_2O$ 0.0477 g/l	
		$Ti(SO_4)_3$ 0.04 g/l	
		$NH4VO_3$ 0.029 g/l	
		$NaWO_4$ 0.0179 g/l	
Arthrospira platensis	LMK	Sodium chloride 13 g/l Sodium carbonate 2 g/l N.P.K fertilizer 2 g/l Urea 0,5 g/l Ammonium phosphate 0,1 g/l Magnesium sulfate 0,1 g/l Potassium sulfate 0,5 g/l Iron sulfate 0.01 g/l Calcium chloride 0.1 g/l Fresh water 1 l	**Aliane (2014)**
Arthrospira platensis	K marine	$NaHCO_3$ 8 g/l NaCl 5 g/l KNO_3 2 g/l	**K marine (2023)**

		$MgSO_4$ 0.16 g/l $NH_4H_2PO_4$ 0.08 g/l $CO(NH_2)_2$ 0.015 g/l $FeSO_4$ 0.005 g/l	

CHAPTER II: Materials and methods

This study aims to produce bioplastic from Spirulina platensis powder. The process involves cultivating the microalgae, extracting PHB crystals to demonstrate its bioplastic potential, and then harvesting and drying the microalgae to create bioplastic films.

1 Cultivation

1.1 Materials

- 2L of *spirulina platensis* living culture
- 4 jars (1L)
- 3 lab beakers (2L)
- Bucket (20 L)
- Aquarium (100 × 40 × 30 cm)
- Culture mediums (K marine, LMK)
- Nutrient medium (K marine)
- Oxygen pump and tubes
- White light lamp
- Thermal resistance
- PH meter
- Thermometer
- Analytical balance
- Manual + graduated pipettes
- Laboratory spatula
- Chemical reactives: NaOH, HCl

1.2 Methods

Spirulina platensis living culture was purchased from SARL K marine and brought to the aquaculture laboratory at ENSSMAL along with its culture and nutrient medium.

Figure 5: *the purchased spirulina platensis living culture*

Figure 6: *spirulina platensis and the nutrient medium.*

Figure 7: *spirulina platensis medium's powder*

The living culture was first seeded and transferred into 1L and 2L jars, which were then placed inside the aquarium. The seeding process involved adding 13 g of culture medium powder to 1L of water, mixing well in a 2L container, and then adding 250 ml of spirulina culture to the mixture.

Figure 8: *weighing of medium powder*

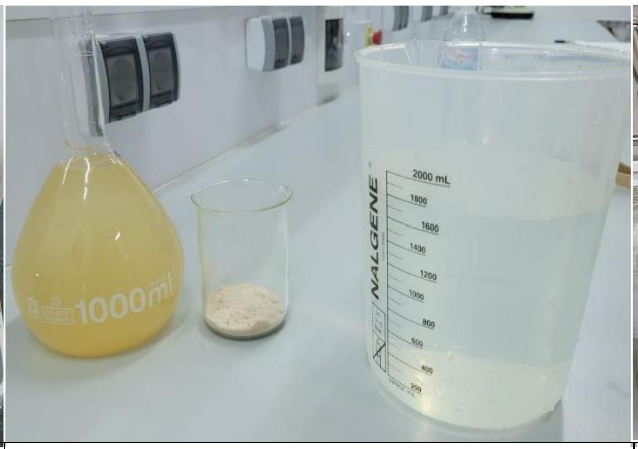


Figure 9: *mixing medium with water*

Figure 10: *adding spirulina to the medium*

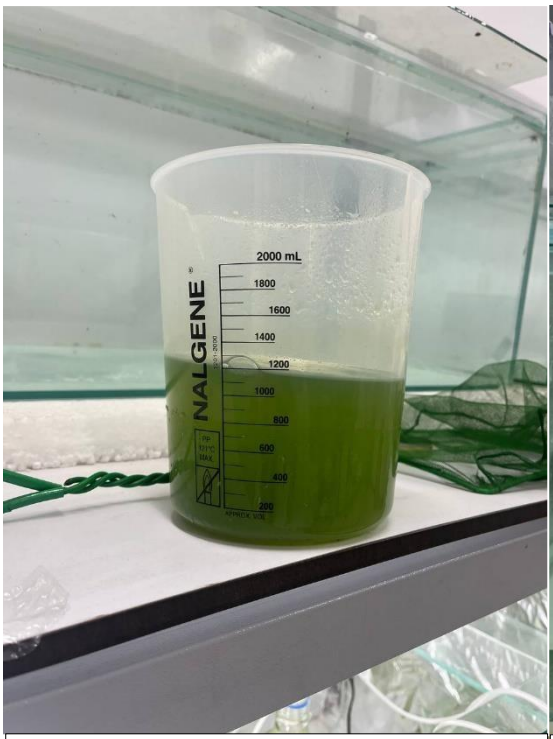


Figure 11: *the freshly seeded spirulina culture*

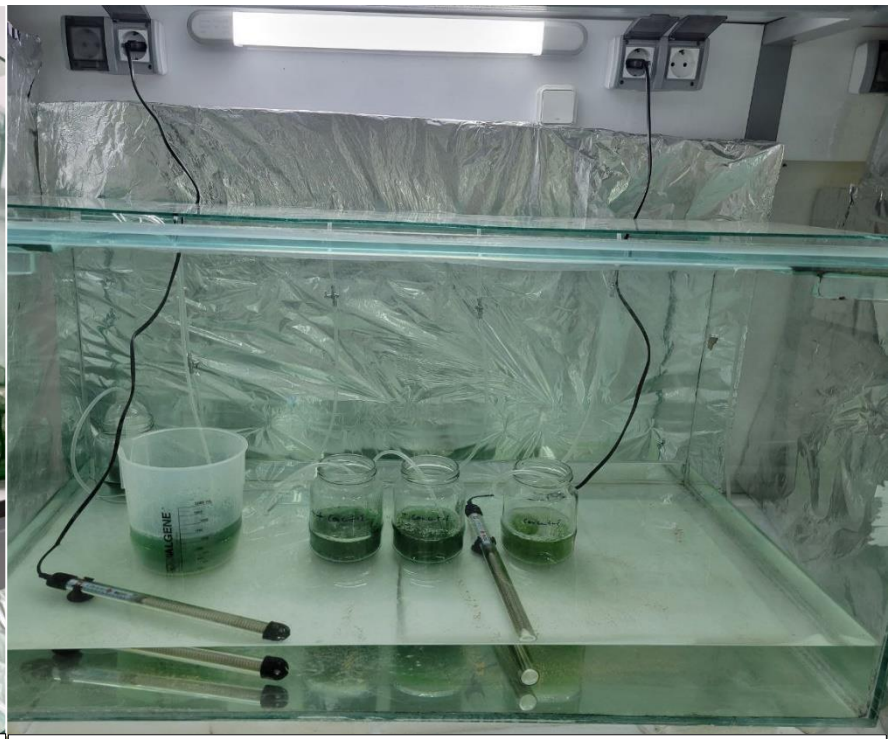


Figure 12: *spirulina platensis culture inside the aquarium*

The culture was kept under continuous and daily monitoring of pH levels and temperature.

The water temperature was kept at 30°C with a thermal resistance, and the pH level of the spirulina was maintained at 9-10 using NaOH or HCl.

Figure 13: *pH meter*

Figure 14: *Thermometer*

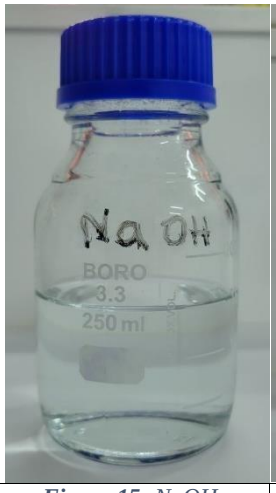


Figure 15: *NaOH*

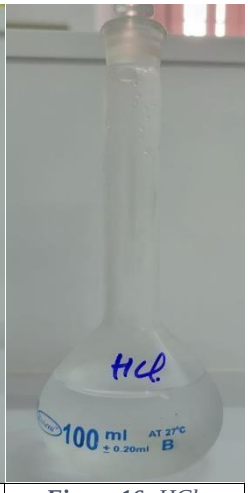


Figure 16: *HCl*

To ensure uniform distribution of nutrients and CO2, the culture was mixed using a spatula at least three times a day. Furthermore, to sustain the spirulina culture and support its continuous growth, a 2 ml of nutrient medium was added every 48 hours.

Figure 17: *Adding 2 ml of nutrient medium*

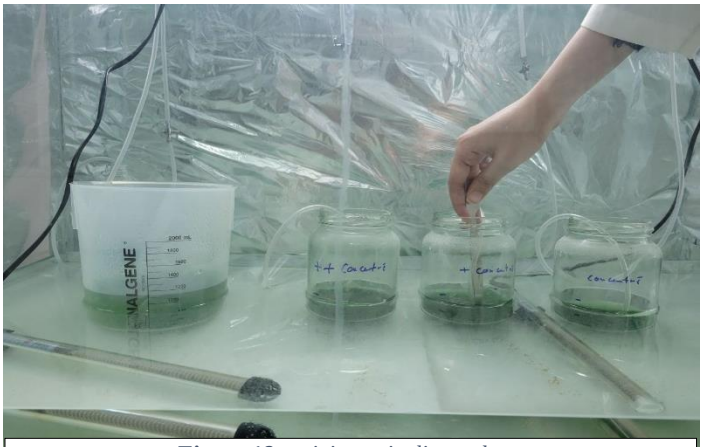


Figure 18: *mixing spirulina culture*

Spirulina was reseeded weekly in fresh K Marine culture medium to increase its volume. To maintain proper conditions/concentration, the culture medium volume was adjusted to a 4:1 ratio if the spirulina was too concentrated and a 3:1 ratio if it was less concentrated.

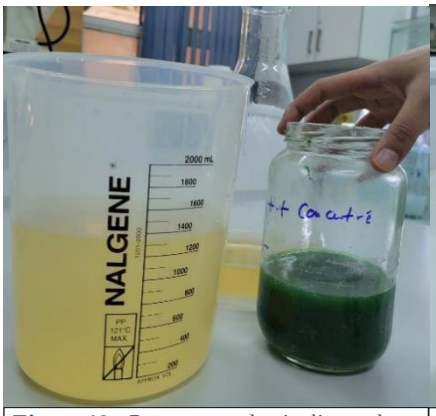


Figure 19: *Concentrated spirulina culture with a fresh culture medium*

Figure 20: *pouring the spirulina into a fresh medium*

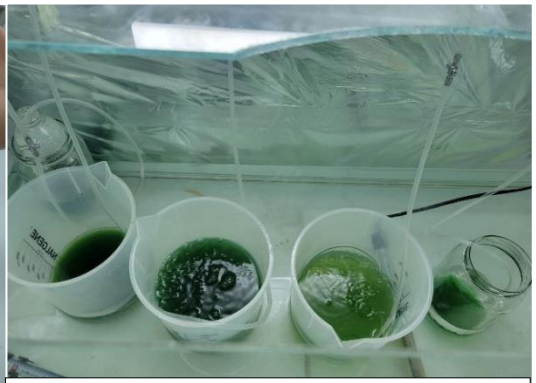


Figure 21: *Results after reseeding*

When the existing medium was nearly depleted, a new culture medium LMK was prepared in various quantities (1, 2, 5, 10 L). Initially, one was used for a new seeding of one beaker of spirulina (1.1 L), while the remaining batches were stored for future use.

Figure 22: *LMK culture medium ingredients*

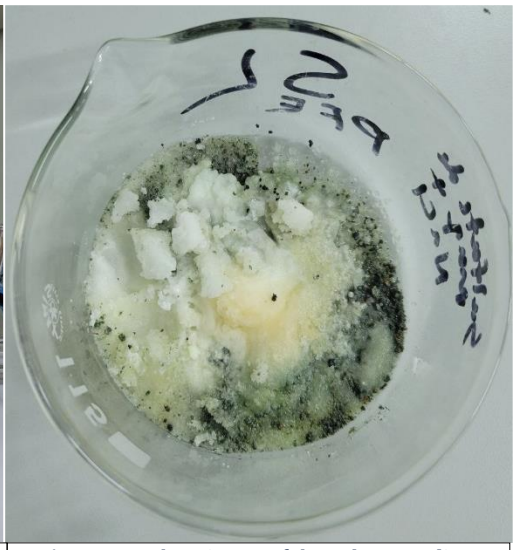


Figure 23: *The mixture of the culture medium ingredients*

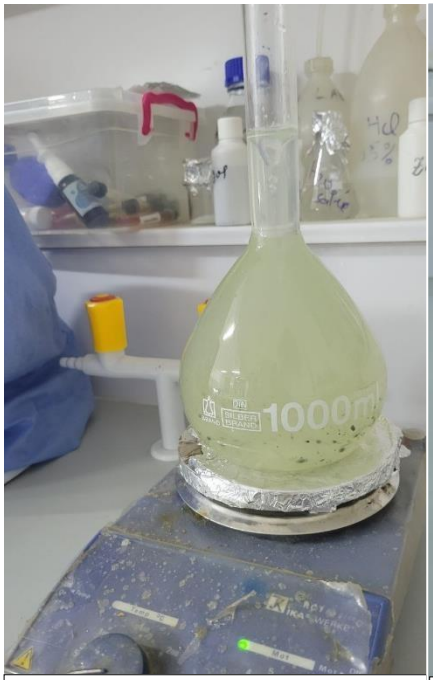


Figure 24: *mixing LMK medium ingredients with water*

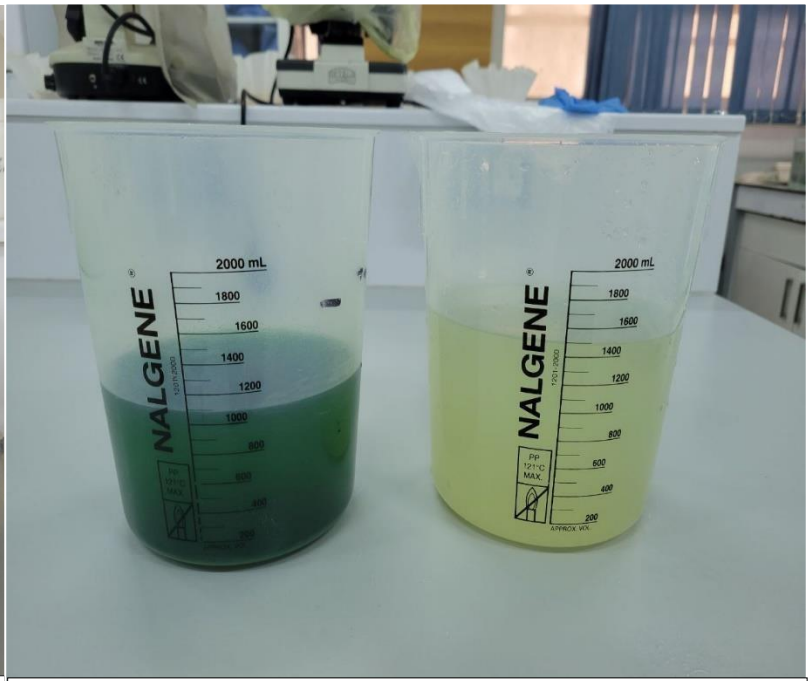


Figure 25: *adding the spirulina culture to the new medium (LMK)*

After seeding, the spirulina culture was observed for 10 days to check if the new medium was suitable. During this time, microscopic observations were made to monitor the spirulina's growth.

Figure 26: *Spirulina culture after seeding*

After observing the results, additional medium was prepared and used in several seedings. The spirulina culture expanded in volume, and its characteristic blue-green color became evident.

Figure 27: *10 L of LMK medium prepared*

Figure 28: *the seeded culture inside the aquarium*

2 Extraction of Polyhydroxybutyrate (PHB)

The extraction of PHB from Spirulina platensis was carried out using a chemical method.

2.1 Materials

- Spirulina platensis culture
- Chemical reactives: 2N HCL, Chloroform.
- Microcentrifuge
- Microcentrifuge tubes
- Oven

- Balance
- Vortex mixer
- Water bath
- Stirring water bath
- Laboratory tubes
- Microscope
- Microscope slides

2.2 Method

Initially, 10 ml of Spirulina platensis culture were collected and centrifuged at 4000 rpm for 30 minutes to separate the cells.

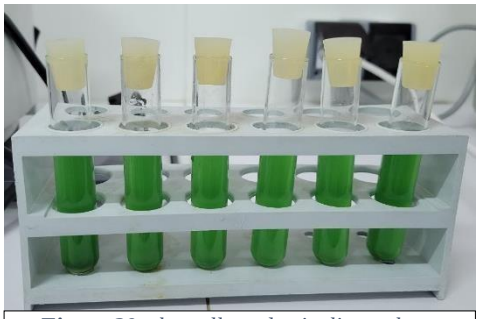


Figure 29: *the collected spirulina culture*

Figure 30: *centrifugation*

Then, the pellet was placed in the oven and dried at 100°C for 24 hours.

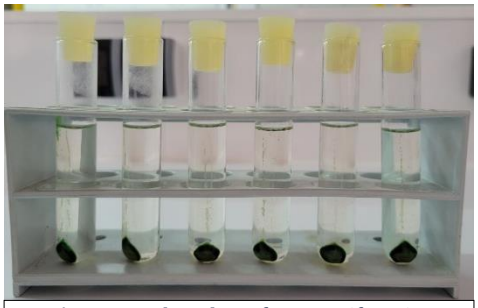


Figure 31: *the tubes after centrifugation*

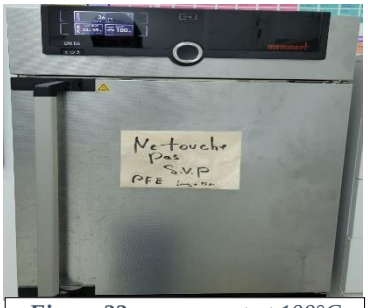


Figure 32: *an oven set at 100°C*

The dried cell pellet was suspended in sterile water, homogenized, and then passed through vortex mixing.

Figure 33: *vortex mixing of the dried pellet and water*

Figure 34: *the mixture after vortex*

To this mix, 2 ml of 2N hydrochloric acid (HCl) were added, and then was heated in a water bath for 2 hours at 80°C.

Figure 35: *the addition of HCl 2N to the suspension*

Figure 36: *water bath set at 80°C*

The mixture was once again centrifuged at 4000 rpm for 20 minutes, followed by 5 ml of chloroform added to the supernatant.

Figure 37: *chloroform*

Figure 38: *the result of adding chloroform to the supernatant*

The chloroform mixture was left overnight at 28°C on a stirring water bath to extract the PHB.

Figure 39: *stirring water bath*

The mixture was centrifuged one more time at 4000 rpm for 20 minutes, extracted with 0.1 ml of chloroform and dried at 40°C.

Figure 40: *addition of chloroform*

Figure 41: *an oven set at 40°C*

After drying, a sample was placed on a glass slide. A droplet of distilled water was added, and it was examined under a microscope to detect the presence of PHB crystals.

Figure 42: *results after drying*

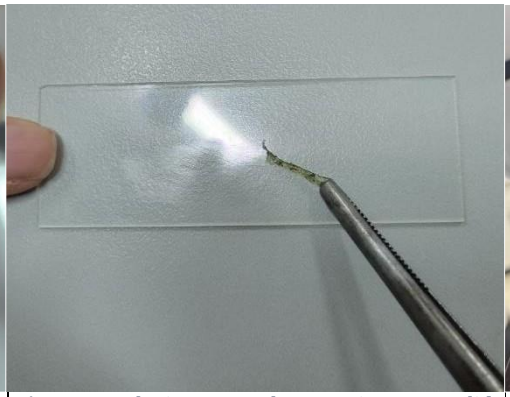


Figure 43: *placing a sample on a microscope slide*

Figure 44: *placing the sample under the microscope*

3 Harvesting and drying

After cultivating Spirulina platensis in LMK medium and obtaining a large volume of culture, the cells were harvested and dried for bioplastic production.

3.1 Materials

- Spirulina platensis culture
- Manual pipettes
- Microcentrifuge + tubes
- Stainless steel spatula
- Distilled water
- Crystallizer
- Laboratory oven

- Laboratory mortar

3.2 Method

The harvesting and drying process was conducted as follows:

When Spirulina platensis reached sufficient growth, the culture exhibited floating cells on the surface of the medium and/or a dark blue-green colour, indicating a high concentration due to continuous stirring.

Figure 45: *the concentrated spirulina culture*

Initially, the Spirulina platensis culture was gathered using manual pipetting and transferred into microcentrifuge tubes. Each tube was filled to a consistent level, leaving enough space to close the cap securely.

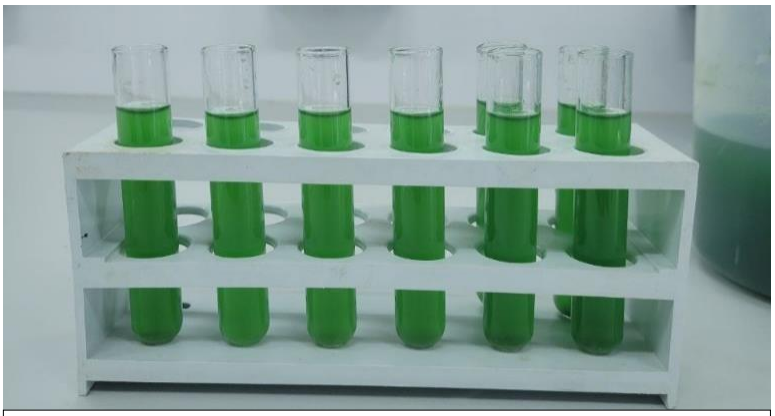


Figure 46: *microcentrifuge tubes filled with spirulina*

The microcentrifuge was balanced by placing tubes of equal weight on opposite sides. Then, the centrifuge was set to the correct speed and time. For Spirulina, usual settings are approximately 4,000 RPM for 5-10 minutes.

Figure 47: *the microcentrifuge*

After centrifugation, the Spirulina biomass formed a pellet at the bottom of the tubes. The supernatant (the liquid above the pellet) was carefully decanted without disturbing the pellet. Any remaining supernatant was removed using a pipette.

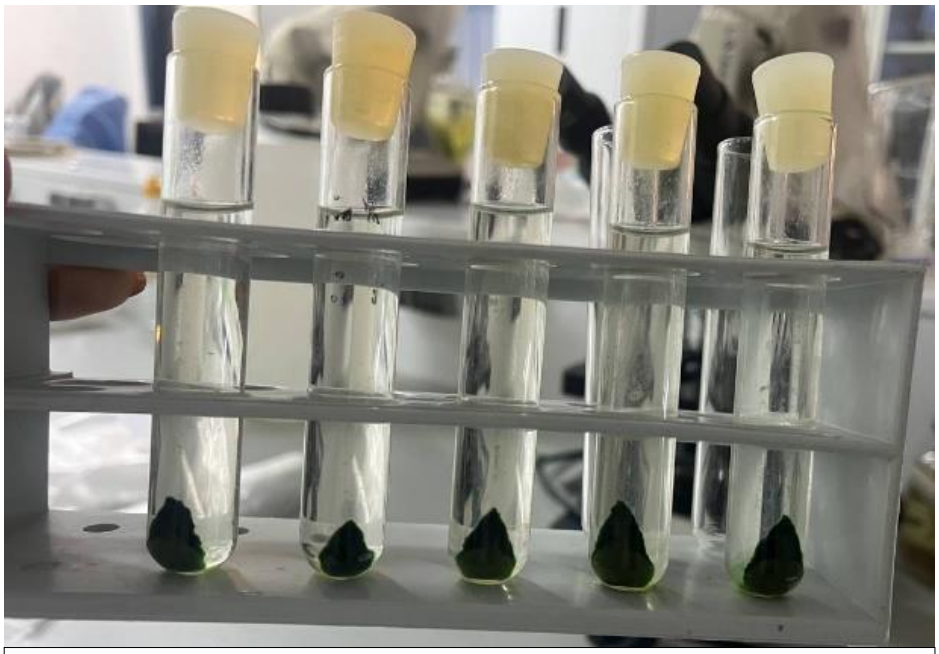


Figure 48: *the tubes after centrifugation*

When needed, the pellet was washed with a small amount of clean water or buffer to remove any remaining medium, and then centrifuged again to form a new pellet of biomass. The harvested Spirulina pellet was transferred to a crystallizer. The biomass was spread evenly to form a thin layer for uniform drying.

Figure 49: *spirulina biomass in a crystallizer*

The laboratory oven was preheated to a low temperature, usually around 40-50°C, as higher temperatures can reduce Spirulina quality. The tray was then placed in the oven. The biomass was left to dry for several hours while frequently checked. Drying times varied depending on the thickness of the biomass layer and the specific oven, typically taking 8-12 hours.

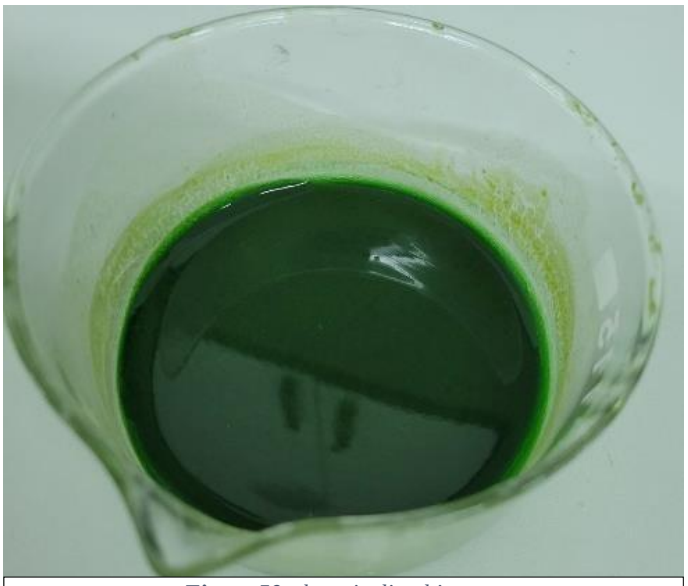


Figure 50: *the spirulina biomass*

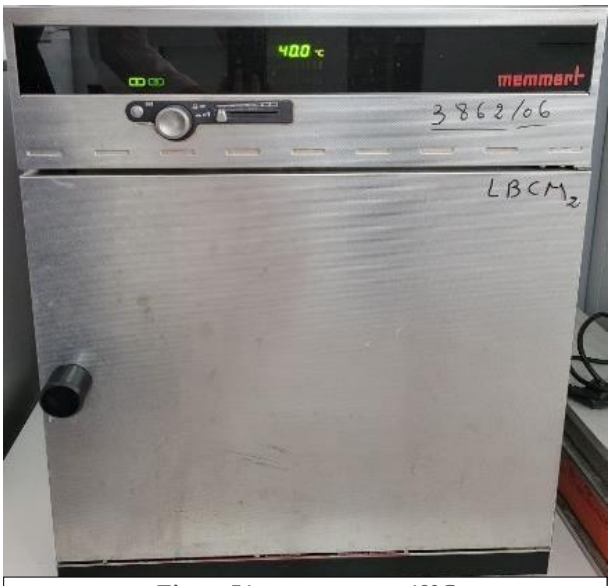


Figure 51: *an oven set to 40°C*

Once the Spirulina was completely dry, it was crispy and brittle. The tray was then removed from the oven.

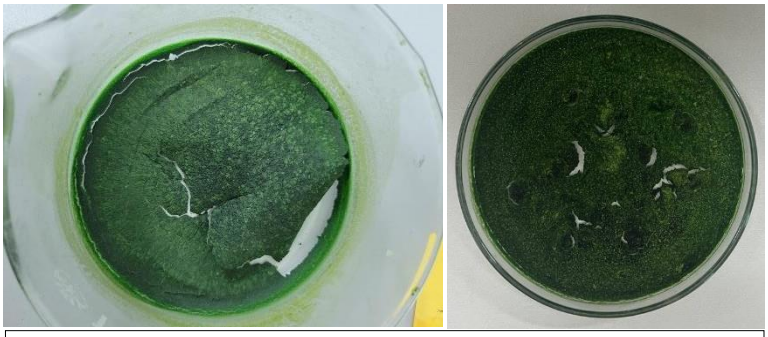


Figure 52: *dry spirulina biomass*

The dried Spirulina was allowed to cool to room temperature. It was then crushed with a mortar into a fine powder.

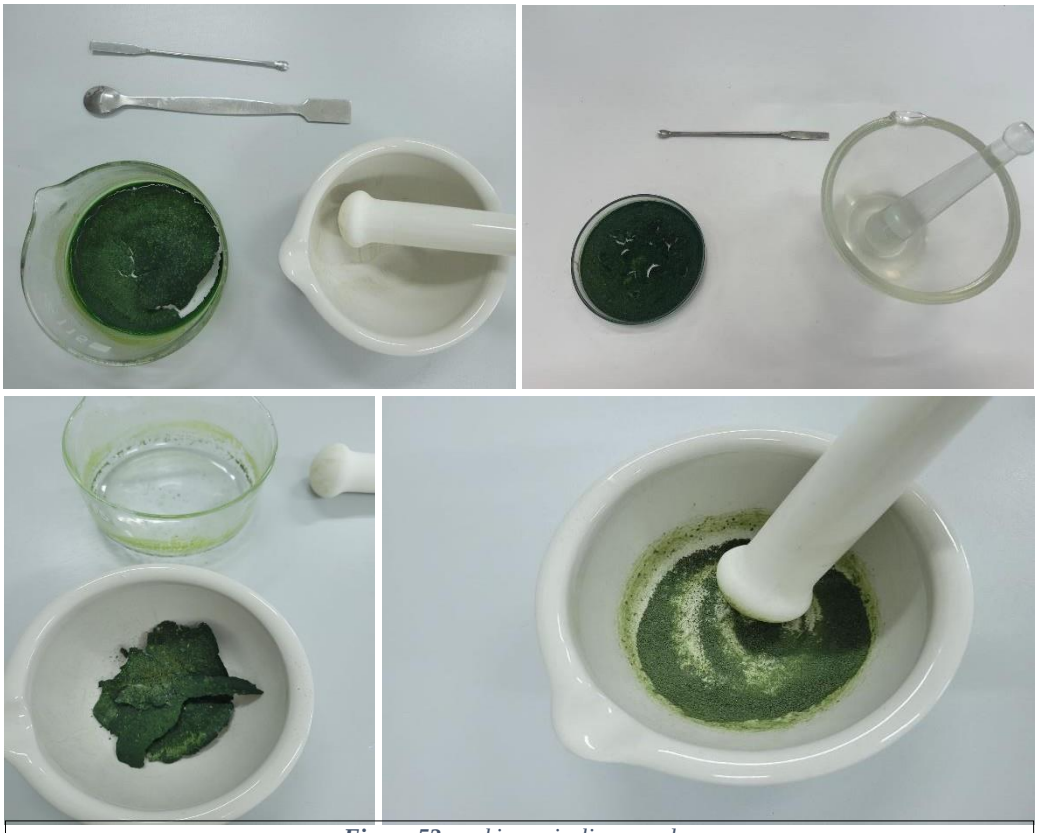


Figure 53: *making spirulina powder*

The dried Spirulina was stored in an airtight container in a cool, dark place to preserve its quality.

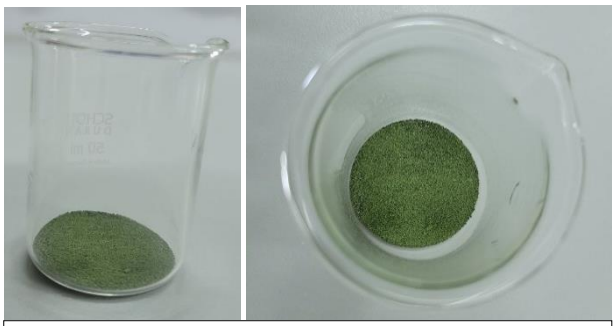


Figure 54: *spirulina powder*

4 Bioplastic production

4.1 Ingredients

- Glycerol
- Gelatin
- Spirulina powder
- Water

4.2 Materials

- Balance
- Beckers
- Graduated test tubes
- Spatula
- Magnetic stirrer
- Silicone mold

4.3 Method

After preparing the Spirulina powder, it was used as the biological source for making the bioplastic film.

To prepare a 1% glycerol solution, we added 2ml of glycerol to 200ml of distilled water. It was then placed on a magnetic stirrer and heated.

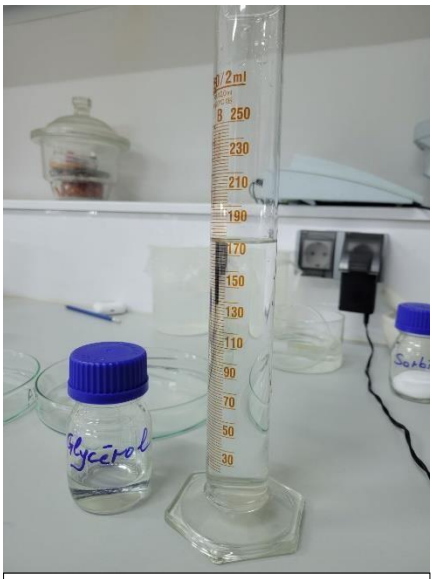


Figure 55: *the 1% glycerol solution preparation*

Afterwards, 2.25 grams of Spirulina powder were combined with 2.25 grams of gelatin and added to 160ml of 1% glycerol solution.

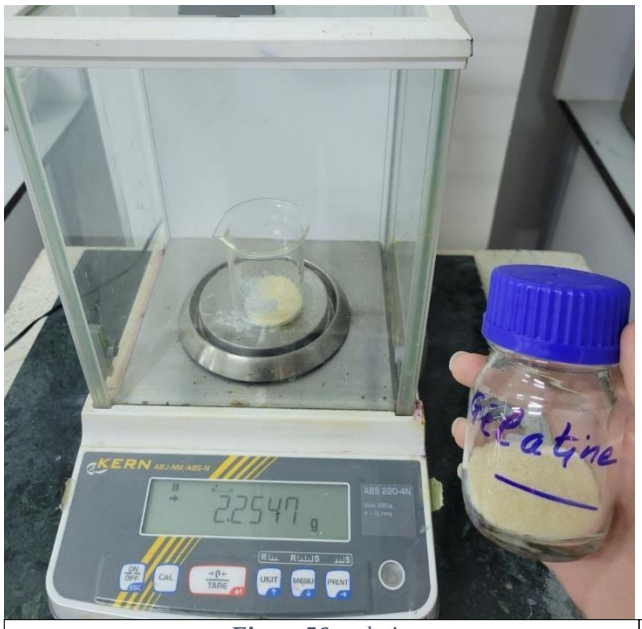


Figure 56: *gelatin*

Figure 57: *adding the ingredients*

Then the solutions were stirred while heated at 95ºC for 1h. The mixture was poured into a silicone mold, spread into thin layers and left to dry in an ambient temperature for 3 days.

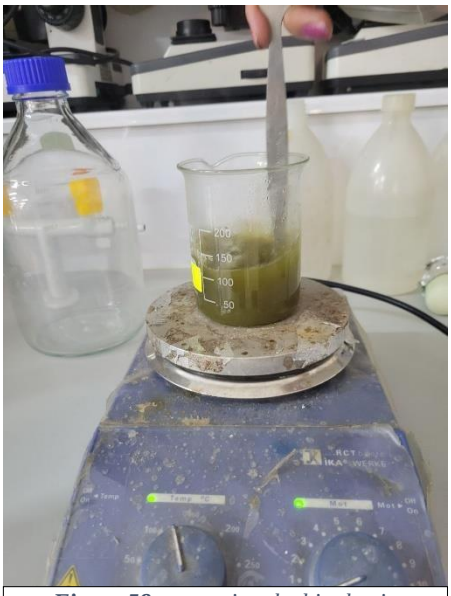


Figure 58: *preparing the bioplastic*

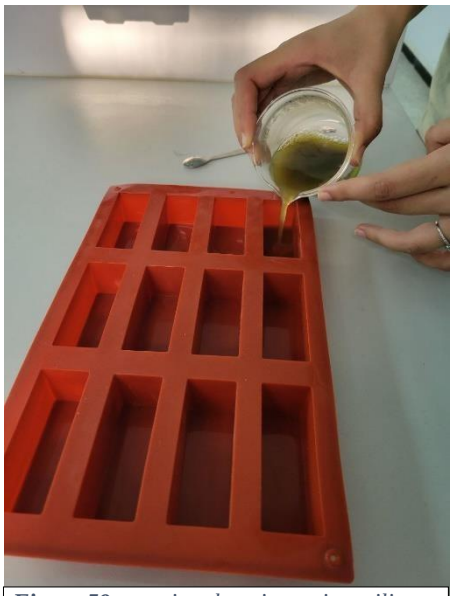


Figure 59: *pouring the mixture in a silicone mold*

After drying, the bioplastic was removed from the silicone mold and underwent qualitative analysis.

Figure 60: *bioplastic sample after drying*

To compare the biodegradability rate, we prepared another bioplastic using the same ingredients excluding spirulina.

Figure 61: *preparing another bioplastic*

4.4 Biodegradability test using soil burial

4.4.1 Material

- Bioplastic films
- Soil

4.4.2 Mathod

Figure 62: *bioplastic buried in the soil*

Biodegradable behavior of bioplastics can be determined using soil burial degradation test. The extent of damage of bioplastics can be analyzed using degradation percentage. The prepared bioplastics were weighed. Then the samples were buried into the ground. The degradation rate of samples was calculated from the weight loss of the sample over time. The final mass of samples was measured after 7 days. The degradation of the test samples was calculated as in Equation 1 **(Vasile et al., 2018).**

$$Degradation\ (\%) = \frac{Initial\ weight - final\ weight}{Initial\ weight} \times 100 \qquad (1)$$

4.5 Elongation test

4.5.1 Material

- Bioplastic
- Ruler

4.5.2 Mathod

Figure 63: initial length

Figure 64: final length

An elongation test measures the ability of a material to undergo deformation under tensile stress, specifically determining how much it can stretch before breaking. Tensile stress was applied manually by gradually increasing tension until the specimen ruptured. Post-rupture, the final length was measured directly with the ruler from the original mark to the point of rupture. This test is crucial for assessing the ductility and flexibility of materials, such as bioplastics. The elongation percent was calculated using Equation 2 **(Kuhn and Medlin, 2000).**

$$Elongation\ (\%) = \frac{final\ length - initial\ length}{initial\ length} \times 100 \qquad (2)$$

CHAPTER III: Results and discussions

The aim of this chapter is to present the results obtained from cultivating Spirulina, extracting Polyhydroxybutyrate (PHB) in the form of crystals, relate them to our initial hypothesis, discuss and demonstrate this microalga 's bioplastic potential, and finally harvesting and drying the microalgae to create bioplastic films.

1 Cultivation

The cultivation experiments in this study have provided valuable insights into the growth and adaptation of Spirulina platensis under controlled conditions. Starting from the initial seeding in K marine medium to the ongoing maintenance in the aquarium setup, we observed consistent and healthy growth. This success is primarily attributed to the careful management of key environmental factors. We maintained a steady temperature of 30°C and adjusted the pH to between 9 and 10 using NaOH or HCl. These conditions were crucial for creating an optimal environment for Spirulina to thrive.

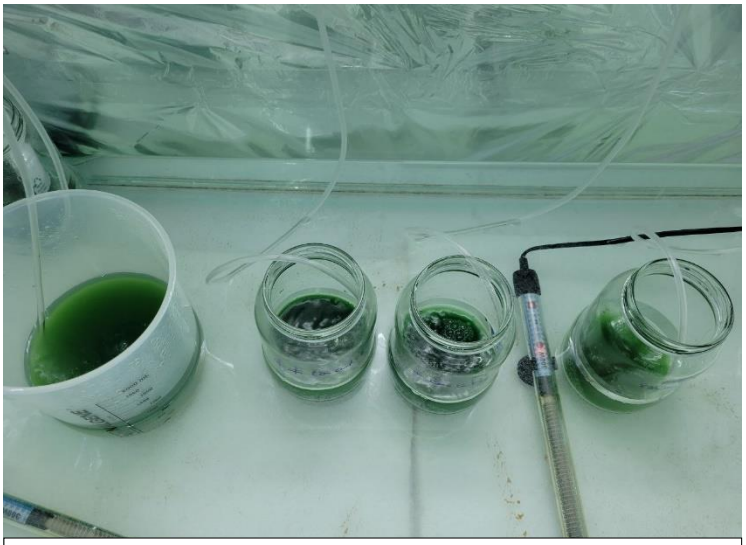


Figure 65: *initial seeding*

A key part of the cultivation experiment was transitioning to the LMK culture medium, which allowed us to assess Spirulina's adaptability to different nutrient compositions. By introducing LMK medium in various quantities while keeping conditions like pH and temperature consistent, we could closely monitor growth responses and biomass productivity. Following each transition, we observed sustained growth rates and the development of healthy characteristics in the Spirulina cultures.

Based on visual examinations of spirulina cultivated in the LMK medium, it was observed that spirulina exhibited superior growth compared to when cultivated in commercially purchased

K marine medium. Microscopic analysis confirmed this observation by revealing dense populations of filamentous structures and vibrant blue-green pigmentation, indicative of robust biomass proliferation in the LMK medium.

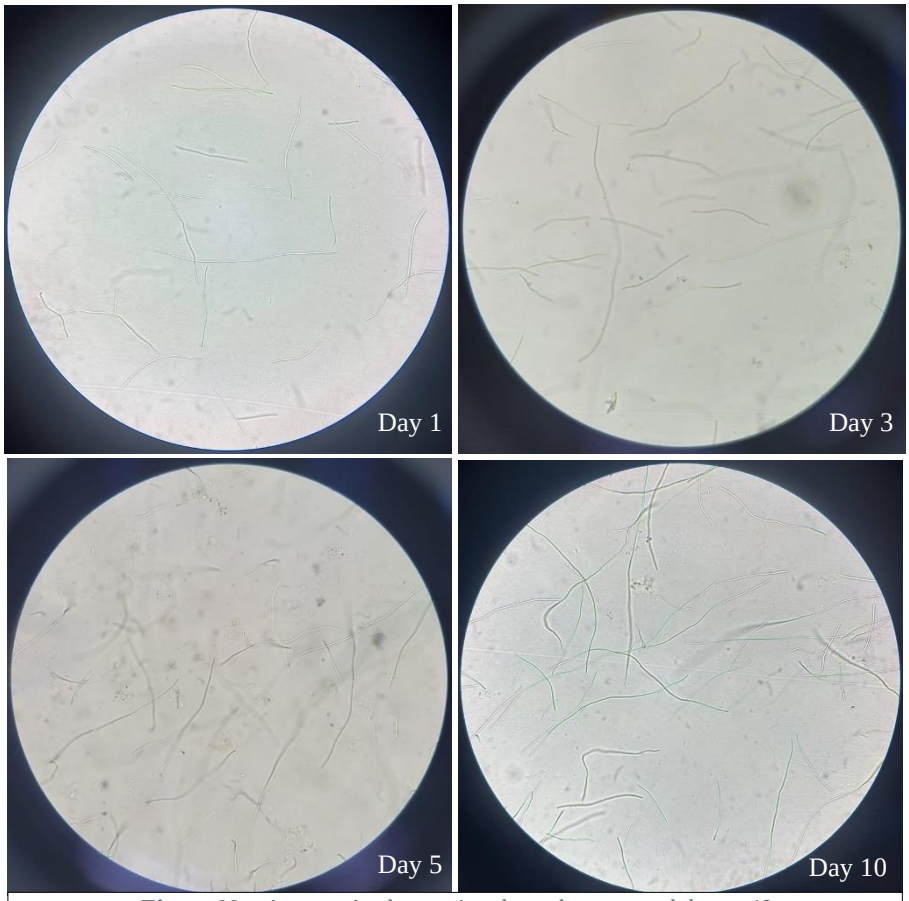


Figure 66: *microscopic observation throughout several days ×40*

Figure 67: *microscopic observation of spirulina filament on the 10th day ×100*

2 Extraction of Polyhydroxybutyrate (PHB)

After concentrating and drying the Spirulina cells, we proceeded with chemical treatment, utilizing 2N HCl to disrupt the cell walls. This process resulted in a thickened mixture, indicating the release of cellular contents. Due to its hydrophobic nature, PHB (polyhydroxybutyrate) does not dissolve in water but exhibits a strong affinity for non-polar solvents like chloroform, facilitating its dissolution during subsequent steps.

Following the methodology outlined in the article “Production of bioplastic using Spirulina platensis and comparison with commercial plastic” **(Maheswari and Ahilandeswari, 2011),**

Prior to introducing sulfuric acid, we conducted microscopic observations of the tube contents. These observations revealed PHB molecules in crystalline form, confirming their presence in Spirulina platensis.

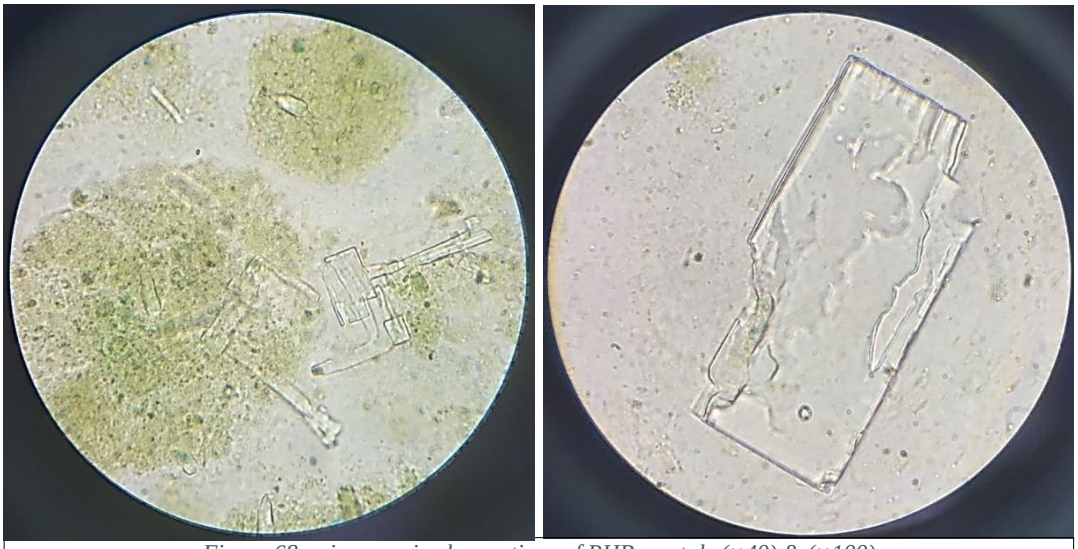


Figure 68: microscopic observations of PHB crystals (×40) & (×100)

The detection of Polyhydroxybutyrate (PHB) crystals in Spirulina platensis cultures signifies the microorganism's capability to synthesize bioplastics. PHB, a type of polyhydroxyalkanoate (PHA), serves as an intracellular storage compound for carbon and energy in various microorganisms. The presence of PHB crystals in our microscopic analysis validates Spirulina's capacity to produce this valuable biopolymer under suitable conditions.

Moreover, the ability of Spirulina to accumulate PHB underscores its metabolic adaptability. PHB synthesis typically occurs in response to environmental stresses such as nutrient limitation or excess carbon sources. This metabolic strategy allows Spirulina to store carbon and energy reserves for future use, ensuring its survival under fluctuating environmental conditions and offering potential biotechnological applications **(A and G, 2024).**

The ability of Spirulina to synthesize PHB highlights its potential as a sustainable source of bioplastic, offering an environmentally friendly alternative to petroleum-based plastics. PHB is known for its biodegradability, biocompatibility, and thermoplastic properties, making it an attractive material for a wide range of applications, from packaging to medical devices. The capacity of Spirulina to accumulate PHB adds value to this already versatile microalga **(Maheswari and Ahilandeswari, 2011).**

However, it is important to emphasize that the precise quantification of PHB in the 10 ml Spirulina sample used in our experiment has not yet been achieved. To accurately determine

the PHB content, an additional analytical step involving the conversion of PHB to crotonic acid esters following depolymerization with sulfuric acid is commonly employed for PHB quantification in microbial samples. This derivatization process allows for the subsequent detection and quantification of PHB content using analytical techniques such as spectrophotometry. Currently, our progress in this analysis is contingent upon the availability of crotonic acid, essential for detecting the precise amount of PHB within the Spirulina culture.

3 Bioplastic production

The Spirulina powder was mixed with gelatine and glycerol solution to form a dough-like consistency. This mixture was then spread into thin layers and kept to dry in an ambient temperature for 3 days.

Spirulina bioplastic was successfully produced. The bioplastic property of Spirulina is due to polyhydroxy butyrate content in algal cells therefore it played a role as a biopolymer, the bioplastic binders also played a crucial in its mechanical properties. The bioplastic sheet was appeared in a light-yellow green colour, it exhibited good flexibility and tensile strength and it showed potential for use in various applications. The successful production of strong and biodegradable bioplastic materials using Spirulina validates its potential as a sustainable alternative to conventional plastics.

3.1 Biodegradability test

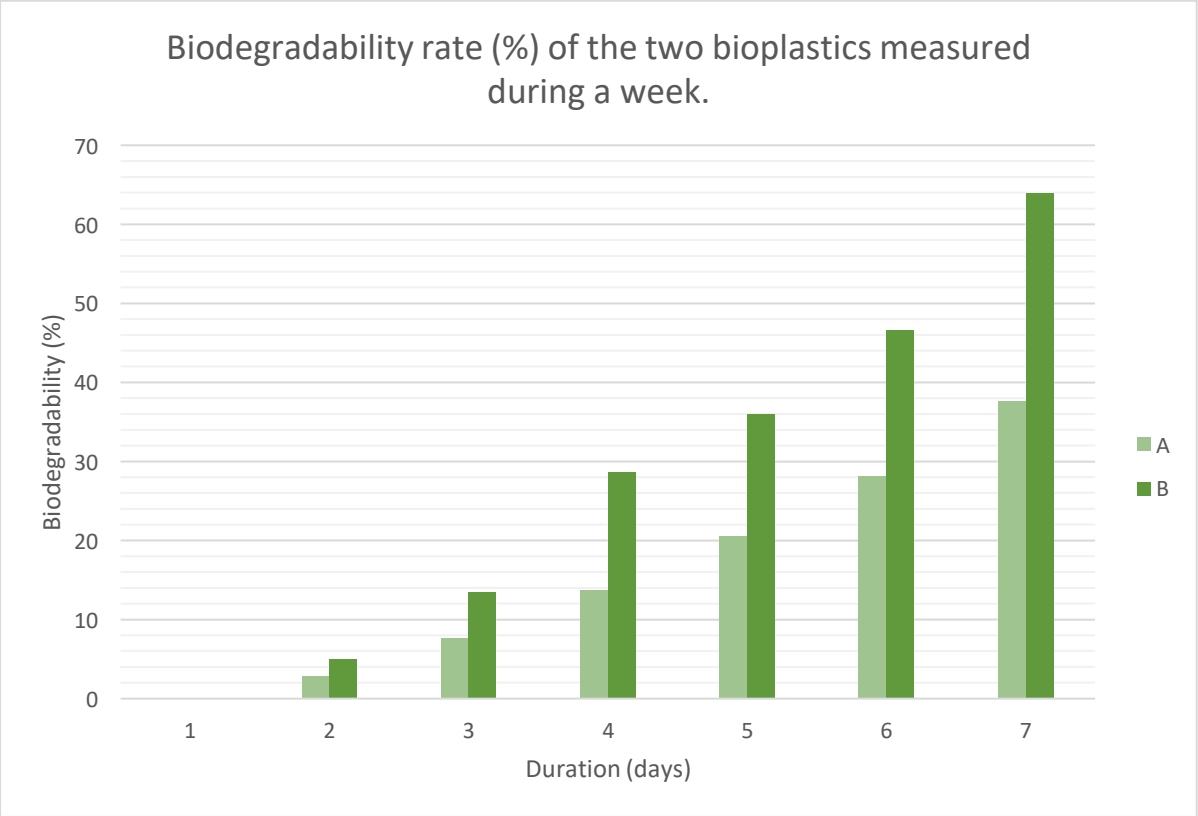
The mass of the samples was measured each day for a week, the biodegradation rate of Spirulina bioplastic and commercial bioplastic was calculated over 7 days using Equation 1. Based on the results shown on table below, both types of bioplastics were found to be biodegradable, with the Spirulina bioplastic showing a higher rate of degradation.

Table 5: *Biodegradability rate (%) of the two bioplastics measured during a week*

Bioplastic/period	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
A	0%	2.8%	7.7%	13.8%	20.5%	28.2%	37.6%
B	0%	5%	13.5%	28.7%	36%	46.6%	64%

A: The bioplastic produced using only glycerol and gelatin

B: The bioplastic produced using glycerol, gelatin and spirulina



The biodegradation study revealed significant differences in the breakdown rates between Spirulina bioplastic and commercial bioplastic. Over seven days, the commercial bioplastic, composed of only glycerol and gelatin, exhibited a moderate degradation rate with a 37.6% weight loss. In stark contrast, the Spirulina bioplastic, which included glycerol, gelatin, and Spirulina, demonstrated a much faster degradation, achieving 64% breakdown within just seven days. This accelerated degradation can be attributed to the inclusion of Spirulina, which likely enhances the bioplastic's susceptibility to microbial attack due to it contenting PHB.

Several bacterial species found in the soil, such as *Pseudomonas*, *Bacillus*, and *Moraxella*, have a significant impact on the degradation of bioplastics. The biodegradation test provides the rate of degradation percentage of bioplastics. The final mass of the samples was measured after six days. Both types of bioplastics were found to be biodegradable, with the Spirulina bioplastic showing a higher rate of degradation.

3.2 Elongation test

The elongation test was conducted to evaluate the ductility and flexibility of the Spirulina-based bioplastic. The initial length of the specimen was measured to be 7 cm. After the application of tensile stress until the point of rupture, the final length was recorded as 10 cm.

Using the elongation Equation 2, the elongation percentage was approximately 42.86%, which indicates a significant ability of the Spirulina-based bioplastic to undergo deformation before breaking. This level of elongation demonstrates the material's flexibility and ductility. This affirms the effectiveness of using glycerol and gelatin as binders, which enhance the mechanical properties of the bioplastic. The high elongation percentage reflects the successful incorporation of these binders, resulting in a material that is not only flexible but also robust enough to be considered a viable alternative to conventional plastics. This significant elongation capacity suggests potential for further optimization and application in industries that demand high-performance, biodegradable materials.

Conclusion

This study has successfully demonstrated the potential of *Spirulina platensis* as a sustainable feedstock for the production of bioplastic materials. By leveraging the microalgae's ability to accumulate polyhydroxybutyrate (PHB), we have developed a novel bioplastic film with promising properties.

The cultivation of Spirulina under controlled conditions allowed us to optimize its growth and biomass production. Microscopic analysis confirmed the presence of PHB crystals within the Spirulina cells, validating its capacity to synthesize this valuable biopolymer.

The production of bioplastic films using Spirulina, resulted in a material with excellent flexibility and elongation properties. Compared to a commercial bioplastic, the Spirulina-based bioplastic exhibited a significantly higher rate of biodegradation, highlighting its enhanced susceptibility to microbial degradation.

These findings underscore the potential of Spirulina as a sustainable and eco-friendly alternative to conventional petroleum-based plastics. The ability to produce bioplastic materials using this microalga offers a promising alternative to petroleum-based plastics.

Further optimization of the bioplastic formulation and scale-up of the production process will be crucial next steps to enhance the mechanical and thermal properties of the Spirulina-based bioplastics. Exploring potential applications in various industries, such as packaging, textiles, and composites, will also be essential to drive the widespread adoption of this renewable and biodegradable material. Continued research and innovation in this field hold the promise of a future where plastic waste is minimized.

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BUSSINESS MODEL CANVA

Production of bioplastics from spirulina

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Introduction

The Business Model Canvas (BMC) is a powerful tool for structuring and analyzing the key elements of a business model. It helps understand the fundamental aspects of a business and assess its potential for success. In our project, we will use the BMC to visualize and analyze the key elements of a new innovative product, bioplastic derived from Spirulina, highlighting its remarkable properties for sustainable production.

Our project has emphasized the multiple properties and benefits of Spirulina in creating bioplastics. As a rich source of nutrients, vitamins, and minerals, this renewable marine resource offers an opportunity to create natural and sustainable formulations. By integrating Spirulina into our products, we contribute to an eco-friendlier approach and reduce our dependence on synthetic ingredients, which is essential for a more responsible and sustainable production process.

We use the Business Model Canvas (BMC) to understand and visualize the different key elements of our business model. This includes identifying our customer segments, defining our value proposition, determining our distribution channels, designing our customer relationships, structuring our revenue streams, recognizing our key resources, defining our key activities, selecting our strategic partners, and analyzing our cost structure.

Chapter 01: Project Introduction

The Project Idea

The idea for this project emerged from increasing awareness of environmental issues caused by traditional petroleum-based plastics. Studies have shown that over 300 million tons of plastic are produced annually worldwide, with a large portion ending up in landfills or oceans. Meanwhile, Spirulina platensis, a nutrient-rich microalga, has shown great potential for bioplastic production. This idea developed through research indicating that spirulina-based bioplastics are biodegradable and can reduce the carbon footprint. These bioplastics will serve as eco-friendly alternatives to traditional plastics, meeting the growing demand for sustainable and environmentally friendly solutions.

We chose **SARL Blue-Green Bioplastics** as a name of our startup, our activity is registered in the **National Centre of Commerce CNC** under the code **104203**. This code attests its activity: Manufacture of basic plastic materials and synthetic resins.

Our company is located in **National School of Marine Science and Coastal Planning (ENSSMAL) laboratories.**

SARL Blue Green Bioplastics is a fledgling Algerian company that specializes in the production and distribution of sustainable bioplastics derived from algae. Founded recently, the startup's core mission is to develop eco-friendly packaging and material solutions that address pressing environmental concerns. Leveraging advanced technologies, the company designs innovative bioplastic formulations with superior technical properties, while ensuring they are biodegradable and environmentally friendly. Blue Green Bioplastics primarily targets companies in Algeria's food packaging and medical sectors, offering them a much-needed sustainable alternative to traditional plastics. Backed by its technical expertise, strong commitment to sustainability, and strategic industry partnerships, the startup aims to establish itself as a leading player in the country's burgeoning biomaterials market.

SARL Blue Green Bioplastics logo:

***Figure 1**: our company's logo*

Proposed Values Offered by SARL Blue Green Bioplastics:

As an Algerian startup company, SARL Blue Green Bioplastics offers innovative bioplastics using Spirulina platensis, addressing the need for sustainable and eco-friendly alternatives to traditional plastics. Our bioplastics are designed to meet or exceed customer expectations in terms of durability, strength, and biodegradability. We provide flexible production processes that allow for the customization of bioplastics to meet specific client needs, including adjustments in properties like rigidity and durability. Our tailored bioplastics help clients achieve specific tasks, such as creating an eco-friendly packaging. Our products are designed to meet specific client requirements, ensuring functionality and aesthetic appeal. By optimizing our production processes and using renewable resources, we aim to lower production costs, making our bioplastics competitively priced and accessible. We offer safer bioplastics for the environment and human health, reducing exposure to harmful chemicals. We strive to make sustainable bioplastics available to customers who previously lacked access to such eco-friendly options, expanding our market reach. Our bioplastics are user-friendly and compatible with existing manufacturing processes, ensuring a smooth transition to sustainable materials.

Team of SARL Blue Green Bioplastics:

Our team at SARL Blue Green Bioplastics consists of highly qualified members, each bringing distinct and complementary skills to our innovative project of producing bioplastics from Spirulina platensis.

Safia Louglaithi: Leads scientific research and bioplastic formulation development. She also oversees technical communication and product marketing.

Skills and Qualifications: Marine biotechnology engineer specializing in research and development of innovative bioplastic formulations.

Training: Project management, time study and team management, intellectual property.

Bendacha Hiba: Manages Spirulina cultivation and optimizes bioplastic production processes. She develops strategic partnerships and explores market opportunities.

Skills and Qualifications: Marine biotechnology engineer, expert in Spirulina cultivation and sustainable production process optimization.

Training: Business Model Canvas (BMC), finance and negotiation, quality labels.

Interaction and Communication Modes:

We promote open and collaborative communication within our team. We hold regular meetings to discuss project progress, challenges, and decisions. Additionally, we utilize digital tools such as instant messaging platforms and project management tools for remote collaboration and task tracking.

This organizational structure enables us to effectively leverage our complementary skills and work cohesively towards the common goal of developing sustainable and innovative bioplastic solutions from Spirulina platensis.

Project Objectives:

At **SARL Blue Green Bioplastics,** our main objective is to take the lead in bioplastics production in Algeria. We are dedicated to develop and manufacture environmentally friendly bioplastic solutions using Spirulina. Our project focuses on implementing advanced technologies to make production processes efficient and cost-effective. We prioritize the use of renewable resources and biodegradable materials to minimize our environmental footprint.

In the short term (1-2 years), our aim is to establish a presence in the local market by forming partnerships and targeting niche segments interested in sustainable products. Over the medium term (3-5 years), we plan to expand our market reach across Algeria and neighboring regions, capturing a significant share of the bioplastics market. Looking ahead (5-10 years), our vision is to solidify our leadership in bioplastics production in North Africa. We will achieve this by scaling up production capacity, fostering continuous innovation, and forming strategic partnerships. These objectives reflect our commitment to sustainable practices and meeting the growing demand for eco-friendly alternatives in Algeria and beyond.

Key Activities:

Research and Development (R&D):

- Conducting ongoing research to enhance the bioplastic properties of Spirulina platensis.
- Developing new bioplastic formulations and applications to meet market demands.
- Innovating and improving production processes to increase efficiency and reduce costs.

Procurement:

- Sourcing high-quality Spirulina from local and sustainable suppliers.
- Procuring other necessary raw materials and additives for bioplastic production.

Production:

- Mixing and formulating raw materials under controlled conditions.
- Utilizing advanced manufacturing equipment to produce bioplastics.
- Monitoring and optimizing the production process to ensure high-quality output.

Quality Control:

- Conducting regular chemical and microbiological tests to ensure product quality and safety.
- Validating production batches to meet industry standards and regulatory requirements.

Packaging and Distribution:

- Packaging bioplastics using eco-friendly and sustainable materials.
- Managing inventory and logistics to ensure timely delivery to customers.
- Establishing and maintaining distribution channels, including direct sales, partnerships, and online platforms.

Marketing and Sales:

- Developing and implementing marketing strategies to promote bioplastics.
- Engaging with potential customers and partners through various channels, including social media, trade shows, and industry events.
- Building and maintaining relationships with key customers and stakeholders.

Customer Support:

- Providing technical support and product information to customers.

- Handling customer inquiries, feedback, and complaints to ensure satisfaction.

Sustainability Initiatives:

- Continuously improving production processes to minimize environmental impact.
- Implementing sustainable practices throughout the supply chain.
- Educating customers and the public about the benefits of bioplastics and sustainability.

Regulatory Compliance:

- Ensuring all products and processes comply with relevant industry standards and regulations.
- Staying updated on regulatory changes and adapting practices accordingly

Collaboration and Partnerships:

- Collaborating with research institutions, industry partners, and other stakeholders to drive innovation.
- Establishing partnerships for distribution, marketing, and joint research projects.

Project Delivery Schedule:

Table 1: *The stages and duration of our project*

Equipement	**La réalisation**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Phase 01	**Planification et Développement**	**X**	**X**					
Phase 02	**Production et Commercialisation**			**X**	**X**			
Phase 03	**Gestion des Ressources et des Partenariats**					**X**		
Phase 04	**Gestion des Relations Client**						**X**	
Phase 05	**Évaluation et Amélioration**							**X**

Chapter 02: Innovative aspects

Domains and natures of Innovation:

New Technologies: Using the microalgae Spirulina platensis as the raw material for bioplastic production, which is an innovative approach in Algeria.

New Products: Creating a 100% biodegradable and bio-based bioplastic to replace conventional petroleum-based plastics, and improving the performance of the bioplastic in terms of strength, flexibility, and biodegradability.

New Markets: Targeting a new category of environmentally-conscious consumers seeking sustainable alternatives to non-biodegradable plastics. As well as joining a new market segment in Algeria, where bioplastics have not yet been widely adopted.

Chapter 03: Strategic Market Analysis

Market Segmentation:

Food Packaging Companies in Algeria: This target food and beverage packaging manufacturers in Algeria who are seeking more sustainable and eco-friendly packaging solutions. Blue Green Bioplastics' advanced bioplastic materials with their superior technical properties and environmental credentials are well-positioned to meet the demands of this segment.

Medical and Pharmaceutical Sector: Beyond food packaging applications, Blue Green Bioplastics' bioplastic products also have significant potential for use in the medical and pharmaceutical industries due to their biocompatibility and biodegradability. This represents an attractive diversification opportunity for the company.

Environmentally-conscious Algerian Consumers: There is a growing consumer segment in Algeria that is increasingly aware of and concerned about environmental issues. These consumers are more receptive to purchasing products made from sustainable, biodegradable materials like Blue Green Bioplastics' offerings.

Measurement of the intensity of competition:

The competitive landscape for bioplastics spans both the international and Algerian markets, presenting a mix of challenges and opportunities for our startup company. In the international market, direct competitors like Arkema and Total Corbion PLA face weaknesses such as

higher production costs, limited brand awareness in developing regions like Algeria, and supply chain constraints for their specialized bioplastic products. These international players also struggle with a lack of diverse product portfolios beyond their core bioplastic materials, limiting their ability to comprehensively address customer needs. Meanwhile, the indirect competition from global giants like Dow and Tetra Pak, while having strong brand recognition, are hampered by higher costs, slower innovation, and perceived trade-offs between functionality and sustainability - areas where a cost-competitive, locally-produced bioplastics solution can differentiate. Within the Algerian market specifically, the indirect competition from established petrochemical and plastics producers like Sonatrach and Hanwa Algerie also presents vulnerabilities, including their heavy reliance on fossil fuel-based feedstocks, limited expertise in bioplastics innovation, and potential cultural and operational barriers in the local market. By leveraging our company's ability to offer a wide range of tailored, cost-effective and environmentally-friendly bioplastic solutions, we can navigate this competitive landscape and establish a strong presence in both internationally and in Algeria.

Marketing strategy:

The marketing strategy of Blue Green Bioplastics is designed to establish the startup as a leading provider of competitively-priced, sustainable bioplastic solutions in the market. By leveraging cost-control measures and advanced production technologies, the company aims to offer flexible pricing structures that cater to the diverse needs of its customers. To facilitate efficient product distribution and order management, Blue Green Bioplastics will utilize a user-friendly digital application platform, ensuring timely delivery and streamline logistics. The promotional efforts will focus on raising awareness about the benefits of bioplastics through targeted marketing campaigns, both online and offline, as well as active participation in industry events and trade shows. Recognizing the importance of customer service and feedback, the company will integrate a customer-centric approach, incorporating a feedback system within the digital platform to promptly address any concerns or complaints. Furthermore, the startup will continuously invest in research and development to expand its bioplastics product portfolio and stay ahead of evolving market demands. By integrating these key elements into its marketing strategy, Blue Green Bioplastics is poised to position itself as a competitive and customer-focused provider of high-quality, environmentally-friendly bioplastic solutions, driving growth and success in the industry.

Our Facebook page:

https://www.facebook.com/share/i1HLH8Dg2dAC2d8h/?mibextid=qi2Omg

Channels of distribution:

In our distribution channels strategy, we plan to implement a multi-faceted approach to reach our target market effectively. Firstly, we will focus on establishing a strong online presence through an e-commerce platform to directly sell our bioplastic products to environmentally conscious consumers. Additionally, we aim to collaborate with wholesale distributors to reach retailers and businesses in need of sustainable packaging solutions. Partnering with eco-friendly retailers will allow us to showcase our bioplastic products in stores and online platforms dedicated to green products. Furthermore, we intend to participate in industry trade shows and eco-friendly events to raise awareness and promote our bioplastic to a specialized audience. By diversifying our distribution channels and leveraging strategic partnerships, we aim to expand our market reach and establish a strong presence in the sustainable packaging industry.

Relationship with customers:

Personalized Customer Service: We trained our team to deeply understand the unique needs and challenges of each client regarding bioplastics and we provide customized solutions based on the specifics of each business and product to ensure that our clients are fully satisfied. Feedback and Co-creation: We established open communication channels to collect client feedback and suggestions. Also, we will involve clients in the development of our products by regularly soliciting their ideas.

Loyalty Program: We Established an attractive loyalty program that rewards loyal clients (discounts, exclusive benefits, etc.) and we offer incentives to encourage referrals and repeat purchases.

Chapter 04: Production and Organization Plan:

Key Resources:

Raw Materials (Spirulina): Spirulina is the primary and distinctive ingredient in our bioplastic products. This microalga is rich in nutrients, particularly proteins and polysaccharides, making it an ideal sustainable alternative to traditional plastics. We source

our spirulina locally from sustainable farms to ensure quality and minimize environmental impact.

Production Facility: Our production facility is equipped with several technologies and adheres to strict quality standards. It includes specialized equipment for bioplastic formulation, mixing, molding, and quality control. The facility operates under sustainable practices, utilizing energy-efficient processes and minimizing waste generation.

Technology and Equipment: Essential equipment for our bioplastic production includes bioreactors for algae cultivation, extruders for polymer processing, injection molding machines, and quality control instruments such as spectrophotometers and rheometers. These technologies enable precise control over material properties and ensure consistency in product quality.

Skilled Workforce: Our team comprises biotechnologists, polymer chemists, and production specialists dedicated to bioplastic innovation. With expertise in algae cultivation, polymer synthesis, and bioplastic processing, we ensure the development and production of high-quality bioplastics that meet industry standards and customer expectations.

Manufacturing Process: Our bioplastic production process involves several key steps:

Raw Material Sourcing: Procurement of high-quality spirulina from selected suppliers.

Bioplastic Formulation:

- Precise weighing and mixing of ingredients according to our proprietary formula.
- Controlled blending under specified conditions (temperature, humidity) to achieve desired material properties.
- Regular quality checks throughout the formulation phase to ensure consistency and performance.

Extrusion and Molding:

- Extrusion of bioplastic compounds through specialized machines to form pellets or sheets.
- Injection molding or compression molding to shape bioplastic into final products, such as packaging containers or films.
- Integration of additives for enhancing bioplastic properties, such as flexibility or UV resistance.

Quality Assurance:

- Comprehensive testing of bioplastic samples for mechanical strength, thermal stability, and biodegradability.
- Analysis of microbial and chemical properties to ensure product safety and compliance with regulatory standards.
- Validation of production batches before packaging and distribution.

Packaging and Distribution:

- Aseptic filling of bioplastic products into eco-friendly packaging materials.
- Sealing and labeling of packaged bioplastics with detailed product information and sustainability certifications.
- Distribution through established channels, including direct sales, partnerships with retailers, and online platforms.

Workforce:

At the beginning of the project, we will start with a team of four people (the two founders, a secretary, and a technician). Within 1 year, we will recruit additional skilled personnel to support the growth and development of the project.

Key Partners:

Spirulina Suppliers:

SARL K marine – Alger

+213 542 28 17 71

Khraicia, Algiers.

Financing:

National bank of Algeria BNA

+213 77 11 44

08 Makid Building -16040 Hussein day street – Algiers

Delivery Company:

Yalidine Express

+213 0982 30 80 80

Kaidi activity area, lot N63, Bordj El Kiffan, Algeries

bioplastics Ingredients Supplier:

SARL ALGER Chemistry

+213 555 06 01 00

Saliba city, lot N33 industrial zone, Oued smar, Algiers.

Analyse SWOT

The SWOT analysis is a strategic method that examines the strengths, weaknesses, opportunities, and threats of a company or project. Strengths represent internal advantages, while weaknesses identify internal points of vulnerability. Opportunities are external elements that can be beneficial, and threats are external elements that can pose risks. The benefits of SWOT analysis include identifying key factors influencing performance, assisting in strategic planning, improving decision-making, facilitating internal communication, and managing risks. This tool is essential for entrepreneurs as it helps them better understand their environment, leverage their strengths, and prepare for potential challenges. By contributing to the development of a strong strategy and risk minimization, it increases the chances of success.

Table 2: Analyse SWOT

Strengths	**Weaknesses**
1. Innovative use of Spirulina platensis for bioplastics	1. High initial costs for research and development
2. Strong commitment to sustainability and eco-friendly practices	2. Dependence on consistent supply of high-quality Spirulina
3. Expertise in bioplastic production and advanced manufacturing	3. Limited market awareness and brand recognition
4. Potential for high-quality, biodegradable products	4. Complexity in scaling production processes
5. Ability to target environmentally-conscious consumers and businesses	5. Potential regulatory challenges and compliance requirements
Opportunities	**Threats**
1. Growing market demand for sustainable and biodegradable materials	1. Intense competition from established bioplastic manufacturers
2. Potential to expand into various industries (packaging, automotive, etc.)	2. Fluctuations in raw material prices and availability
3. Increasing consumer awareness and preference for eco-friendly products	3. Rapid technological advancements by competitors
4. Government incentives and regulations promoting sustainable materials	4. Economic downturns affecting consumer and business spending
5. Opportunities for strategic partnerships and collaborations	5. Potential negative environmental impacts of large-scale algae harvesting

Chapter 5: Financial plan

Table 3: costs and expenses

Item	Cost	Frequency	Total annual cost (DA)
Rent	200.000 DA/Month	Monthly	2.400.000 DA
Tanks	100.000 DA/unit	One time	100.000 DA
Centrifuge	300.000 DA/unit	One time	300.000 DA
pH meter	250.000DA /unit	One time	250.000 DA
Thermometer	20.000DA/unit	One time	20.000 DA
Balance	100.000DA/unit	One time	100.000 DA
Thermal resistence	100.000DA/unit	One time	100.000 DA
Mixer	50.000 DA/unit	One time	50.000 DA
spectrophotometer	375.000DA /unit	One time	375.000 DA
Spirulina	200.000 DA/Month	Monthly	2.400.000 DA
Spirulina nutrients	150.000 DA/Month	Monthly	1.800.000 DA
Chemicals	500.000 DA/Month	Monthly	6.000.000 DA
Oven	350.000 DA/Unit	One time	350.000 DA
Other equipements	500.000 DA	One time	500.000 DA
Maintenance for cultivation	100.000 DA/Month	Monthly	1.200.000 DA
Salaries	60.000 DA/Month (*2) + 40.000 DA /Month (*1)	Monthly	1.440.000 DA 480.000 DA = 1.920.000 DA
Advertising	300.000 DA/Month	Monthly	3.600.000 DA
Distribution	500.000 DA/Month	Monthly	6.000.000 DA
Electricity and water	200.000 DA/Month	Monthly	2.400.000 DA
			48.840.000 DA

Fixed Costs:

Fixed costs are those that do not change with the level of production or sales. They include:

- Rent: 200,000 DA/month
- Salaries: 1,920,000 DA/month
- Advertising: 300,000 DA/month
- Maintenance: 100,000 DA/month
- Electricity and water: 200,000 DA/month
- Other fixed costs related to equipment and setup

Variable Costs:

Variable costs change with the level of production. These could include:

- Raw materials (e.g., Spirulina nutrients, chemicals): 850,000 DA/month
- Distribution costs: 500,000 DA/month
- Other production-related costs that vary with sales volume.

Total Costs:

Monthly Fixed Costs

Total Fixed Monthly Costs = 200,000 DA (Rent) + 1,920,000 DA (Salaries) + 300,000 DA (Advertising) + 100,000 DA (Maintenance) + 200,000 DA (Electricity and water) = 2,720,000 DA

Monthly Variable Costs

Total Variable Monthly Costs = 850,000 DA (Raw materials) + 500,000 DA (Distribution) = 1,350,000 DA

Total Monthly Costs:

Total Monthly Costs = Total Fixed Monthly Costs + Total Variable Monthly Costs = 2,720,000 DA + 1,350,000 DA = 4,070,000 DA

Total annual costs: Total monthly costs × 12 = 48,840,000 DA

Price estimation

$$Cost\ per\ unit = \frac{Total\ monthly\ costs}{Number\ of\ units\ produced} = \frac{4{,}070{,}000}{10000} = 407\ DA/unit$$

Selling Price = Cost per unit + gross margin = 407 + 20% = 508.75 DA/unit

Monthly Revenue: Selling Price per Unit × Number of Units Sold = 508.75 DA/unit × 10,000 units = 5,087,500 DA

Annual Revenue: Monthly Revenue × 12 = 5,087,500 DA/month × 12 = 61,050,000 DA

Annual Profits: Annual Revenue − Total Annual Costs = 61,050,000 DA − 48,840,000 DA = 12,210,000 DA

The prototype:

Spirulina based bioplastics offer a sustainable and eco-friendly alternative to traditional petroleum-based plastics. The key components of these bioplastics include Spirulina powder, produced from the nutrient-rich microalga known for its biodegradability and beneficial properties. This powder is combined with a bioplastic base, stabilizers for durability, and molding agents for shaping the material into various products.

The production process begins with the utilization of Spirulina powder, where the nutrient-rich powder is incorporated into the bioplastic mixture. The Spirulina powder is blended with the bioplastic base, stabilizers to create a uniform composition. Molding agents are used to shape the bioplastic material into desired forms such as packaging, utensils, or containers. The bioplastic is then allowed to dry and solidify, with finishing touches applied for smooth surfaces and textures.

The prototype features of Spirulina based bioplastics include their biodegradability, which reduces environmental impact and promotes sustainability. The nutrient-rich properties of Spirulina enhance the material with beneficial nutrients, offering potential health benefits in addition to eco-friendliness. The customizable design allows for the incorporation of colorants to meet specific aesthetic preferences, making the bioplastics versatile for a wide range of applications in various industries.

Figure 2: *our prototype*

Table 6: our business model canvas

<table>
<tr>
<td rowspan="2">Key partners:

Spirulina Suppliers

SARL K Marine - Alger

Financing

BNA

Delivery Company

Yalidine

Ingredient Suppliers

SARL Alger Chemistry</td>
<td>Key activities:

Primary activities

Production of bioplastics from Spirulina

Secondary activities

- Installation and maintenance of production equipment

- Marketing strategy

- Distribution and logistics</td>
<td rowspan="2">Value proposition:

- Sustainable and eco-friendly alternatives to traditional plastics

- safer bioplastics for the environment and human health, reducing exposure to harmful chemicals

- Biodegradable and environmentally friendly bioplastics

- Scientifically proven effectiveness</td>
<td>Customer Relationship:

-Personalized Customer Service:

-Feedback and Co-creation

- Loyalty Program</td>
<td rowspan="2">Market Segment:

- Food Packaging Companies in Algeria

- Medical and Pharmaceutical Sector

-Environmentally-conscious Algerian Consumers.</td>
</tr>
<tr>
<td>Key Resources:

- Raw Material: Spirulina algae

- Production site

- Technology and equipment

- Workforce

- Marketing and sales agent</td>
<td>Distribution:

- Online e-commerce platform.

- Social media platform (Facebook).

- Collaborations.</td>
</tr>
</table>

Abstract:

This thesis investigates the potential of spirulina for the production of bioplastics within the field of marine biotechnology. Spirulina, a nutrient-rich microalgae, is examined for its properties and applications in bioplastic manufacturing. The document addresses the definition, types, advantages, and disadvantages of both conventional and bioplastics, and particularly emphasizes the use of bioplastics derived from microalgae. It focuses on the cultivation of *Spirulina platensis* and demonstrates the feasibility and potential of using spirulina as a sustainable alternative to traditional petroleum-based plastics, contributing to the advancement of environmentally friendly bioplastic materials.

Key words: Bioplastics, Microalgae, Spirulina platensis, Polyhydroxybutyrate (PHB), Cultivation techniques, Environmental impact.

Résumé:

Cette thèse explore le potentiel de la spiruline pour la production de bioplastiques, dans le cadre de la biotechnologie marine. La spiruline, une microalgue riche en nutriments, est étudiée pour ses propriétés et son application dans la fabrication de bioplastiques. Le document couvre la définition, les types, les avantages et les inconvénients des plastiques et des bioplastiques, ainsi que l'usage des bioplastiques à partir de microalgues. En particulier, il se concentre sur la culture de *Spirulina platensis*, ses conditions de croissance, et les techniques de culture nécessaires et sa utilisation dans des applications de bioplastiques.

Mots clés : Bioplastiques, Microalgues, Spirulina platensis, Polyhydroxybutyrate (PHB), Techniques de culture, Impact environnemental.

نبذة مختصرة:

تستكشف هذه الأطروحة إمكانية استخدام السبيرولينا في إنتاج البلاستيك الحيوي ضمن مجال التكنولوجيا الحيوية البحرية. السبيرولينا، وهي نوع من الطحالب الدقيقة الغنية بالمغذيات، تُدرس لخصائصها وتطبيقاتها في تصنيع البلاستيك الحيوي. يغطي المستند تعريف وأنواع وفوائد ومساوئ البلاستيك والبلاستيك الحيوي، بالإضافة إلى استخدام البلاستيك الحيوي المستخلص من الطحالب الدقيقة. وتركز الأطروحة بشكل خاص على زراعة سبيرولينا بلاتينسيس وظروف نموها والتقنيات الزراعية اللازمة لتعظيم إنتاجها لاستخدامها في تطبيقات البلاستيك الحيوي.

الكلمات الدالة : لبلاستيك الحيوي, الطحالب الدقيق ,السبيرولينا بلاتنسيس ,بولي هيدروكسي بيوتيرات ,(PHB) تقنيات الزراعة, التأثير البيئي.