Project ID: EAEV093T

Algae as a Resource for Bioplastic Production: Evaluating Species-Specific Characteristics & Biodegradability of *Closterium, Chlorella, Scenedesmus, Volvox, Spirogyra, Saccharina Latissima,* & *Alaria*

By: Pretom Chowdhury, Madison Bennett & Joseph Jeong

Forest Hills High School

Abstract

Plastic pollution, with an annual human ingestion rate of approximately 1.38 million grams, calls for sustainable alternatives. This study investigates the development of biodegradable bioplastics from algae as a means to reduce environmental impact and combat climate change. Exploring the creation of bioplastics using two types of algae, green and brown, each processed through distinct chemical methods. Farming green algae under controlled conditions to optimize biomass production, followed by the extraction of biopolymers through flocculation. Brown algae bioplastics were developed by mixing dried algae with water, glycerol, and cornstarch. The aim was to evaluate the biodegradation, tensile strength, and melting point of these bioplastics, hypothesizing that *Saccharina Latissima* (brown algae) would exhibit superior properties. For biodegradation, an analytical scale and water immersion were used; tensile strength was measured using calipers and a spring meter; the melting point was determined with a hot plate and thermometer. The Data confirmed that *Saccharina Latissima* bioplastics had a biodegradation rate of 1.2% per day, a tensile strength of 0.6 MPa, and a melting point of 65°F, surpassing those of green algae bioplastics. The high alginate content in brown algae contributes significantly to the enhanced film-forming capabilities, flexibility, and transparency of the bioplastics. These bioplastics, with their varied properties, can potentially replace conventional plastics in numerous applications, ranging from water bottles to industry-level PVC pipes. This research underlines Saccharina Latissima's potential as a sustainable alternative to traditional plastics, offering promising prospects for environmental conservation.

Algae as a Resource for Bioplastic Production: Evaluating Species-Specific Characteristics & Biodegradability of Closterium, Chlorella, Scendesmus, Volvox, Spirogyra, Sugar Kelp, & Alaria

About 368 million tons of plastic was produced globally in 2019 The global production of plastic in the year 2019 was approximately 368 million metric tons. (World Economic Forum*)*. Every week, on average it is estimated that an average of about 5 grams of microplastics are consumed in a week. This may not sound like a lot but this means that billions of people are consuming 260.7 grams (0.57 Lbs) of plastic within a year. And out of this percentage, this means that yearly as a species about 1,384,615.38 grams of plastic is ingested yearly. By the year 2050, companies will be producing three times as much plastic as we do today (Agenda 2019).

There are many multiple types of plastics, such as Polyethylene, which is used for packaging film and insulation (Britannica 2023). High-density polyethylene (HDPE) poses greater decomposition challenges owing to its robust and durable nature (Acme Plastics). Microplastics from these polymers course through the bodies of almost every organism, and they contain particles that can carry harmful chemicals and pollutants such as PCBs (Polychlorinated biphenyls) and dioxins. These compounds these which store themselves in animal fat and have been linked to skin conditions such as chloracne, liver problems, elevated blood lipids (fats), cancer, and reproductive problems (Plastics and Human Health | Plastics and the Environment Series, n.d.). Furthermore, plastics can persist in the environment for hundreds of years, gradually breaking down into microplastics that can be ingested by smaller organisms, eventually entering the food chain. This takes a massive toll on aquatic ecosystems all over the globe, impacting at least 267 species (Mulhern, 2022).

Biodegradable plastics are materials that naturally deteriorate, allowing environmental elements - including microorganisms - to digest and break them down (Environmental 2022). These plastics reducecontribute to reducing greenhouse gas emissions and the use of fossil fuels as bioplastics are made from renewable biological sources, that absorb carbon dioxide from the atmosphere. These bioplastics are also designed to be biodegradable because when they decompose they release less carbon dioxide compared to traditional plastics reducing their long-term environmental impact. (Ahmed 2022)

Made from bio-based products such as seaweed, sugar beets, or other plants, they eliminate the need for environmentally harmful fossil fuels (World 2022). Research into At the University of Bath in England, innovations in bioplastics as a viable, sustainable materialenvironmentally isare underway, particularly in creating polycarbonate from sugars and carbon dioxide for use in bottles, lenses, and

DVDs. This method is both cost-effective and environmentally friendly (Cho 2017). This is done by fermenting the sugars into lactic acid. These molecules are chemically bonded together through polymerization to form long polymer chains, creatingthis creates the PLA found in plastics. Creating an eco-friendly alternative to plastics. (Williams et al., 2009b)

How can this issue be addressed before it has a more significant impact on the ecosystems? There are 172,578 species of algae in the world (Algaebase n.d). Algae produce substances called biopolymers that can effectively be used to create various items, including medicines and food packaging (Alazaiza 2023). Seaweed can be microscopic or enormous plants providing many benefits as food and to their habitat (NOAA 2023). With the help of additives, these biopolymers can be manipulated to produce biodegradable plastics. Instead of breaking down into smaller, more harmful particles that have existed for hundreds of years, bioplastics formed from algae and seaweed possess the ability to be consumed by microorganisms, bacteria, and fungi. This process, called biodegradation, is facilitated by enzymes produced by microorganisms, ultimately leading to the conversion of biodegradable plastic into environmentally benign substances.

Algae have various real-world applications, such as transportation and power plant fuel generation. They can produce transportation fuel. Furthermore, algae can generate renewable energy, which can be used in conjunction with power plants to reduce carbon emissions and increase energy efficiency. Algae are converted into biodegradable plastics by a variety of chemical procedures that involve the extraction of biopolymers from the algae. However, because of human activity, the same algae can become detrimental to the environment, starting a process called eutrophication.

Water bodies, such as lakes or rivers, become enriched with excessive nutrients, like nitrogen and phosphorus, usually due to agricultural runoff or sewage discharge. This overload of nutrients stimulates the rapid growth of algae, and seaweed aquatic plants, creating algal blooms. When these marine algae die and decompose, oxygen is consumed, leading to oxygen depletion in the water, which can harm aquatic life and result in "dead zones." By removing the selected algae from the water to create biopolymers, it is possible to address two critical issues (Sustainable Resource and Waste Management, Hamburg University of Technology and Cinar). Algae and seaweed can be farmed and harvested, buying a small portion of algae and cultivating it to make bigger amounts of algae is possible, leaving very little need for big habitats that will cost a lot. First, it helps mitigate eutrophication by reducing the excess algae, preventing oxygen depletion and the negative consequences for aquatic ecosystems. Second, during algal growth, these organisms absorb carbon dioxide (CO_2) from the atmosphere through photosynthesis. Using the algae to produce biopolymers locks this captured CO_2 within the plastic, thus sequestering carbon and contributing to carbon emissions reduction, ultimately helping combat climate change. Likely, algae will not be able to completely replace plastic in the near future but this is a step in the correct direction into finding different solutions. (*Eutrophication: Causes, Consequences, and Controls in Aquatic Ecosystems | Learn Science at Scitable*, 2023)

Using bioplastics as an alternative to traditional plastics is a viable method for reducing carbon footprint. Bioplastics decompose faster and are less toxic since they do not contain bisphenol A (BPA), a hormone disruptor found in many plastics (Cho, 2017). Decomposition of bioplastics can occur within weeks to months and they can be broken down in water. Made from biomass, bioplastics are compostable, breaking down into carbon dioxide, water, and inorganic compounds without leaving toxic residue. Compared to traditional plastics like polyethylene and HDPE, bioplastics produce significantly fewer greenhouse gas emissions. There is no net increase in carbon dioxide as they decompose into the same carbon from which they were made (Cho, 2017). Plastic production accounts for 1 to 3 percent of U.S. greenhouse gas emissions; replacing them with biodegradable plastics could decrease this figure by almost 25% (Posen, 2017).

In pursuit of environmentally-friendly bioplastic production, two species of brown seaweed have been chosen for their different characteristics and potential: *Alaria esculenta* and *Saccharina Latissima* .

Seaweed can be used for a plethora of things, some being fertilizers for foods, bioplastics, textiles, supplements, and carbon sinks (Macleod 2023). Seaweed produces various kinds of polysaccharides like agar, carrageenan, and alginate which can be used in the development of biopolymers, biopolymers derived from seaweed are renewable, biodegradable, and biocompatible with the environment (Jumaidin 2018). Like the algae, the Seaweed will have a different chemical process to extract these biopolymers to be further processed into plastics.

Alaria esculenta is a member of the seaweed species commonly known as winged kelp that grows in the nutrient-rich, cool waters of the northern Atlantic. Its strong adaptability in the varied marine realms makes it a good choice for sustainable harvesting. It has a high growth rate and an especially large amount of alginates, which are polysaccharides used in making bioplastic. Alginates extracted from *Alaria esculenta* are well-known for their gelling, stabilizing, and thickening properties that a successful bioplastic must have. Furthermore, *Alaria esculenta* can be harvested in a way that does not damage the environment. Therefore it becomes an economically viable renewable resource upon which to maintain production of bioplastic into the future.

Another brown seaweed species with great potential in the production of bioplastics is *Saccharina Latissima* , also called sugar kelp. It is common in the cold waters of the North Atlantic, and its rapid growth and high yield make it prized as a biomass-energy resource. *S. Latissima* is thick in laminarin and fucoidan, polysaccharides that show useful characteristics for bioplastic preparation after processing. These include film-forming capabilities and biodegradability--two key properties in the search for environmentally friendly substitutes for plastic. The culture of *Saccharina Latissima* can fit into environmental aquaculture systems, providing a stable and nonpolluting source of raw material supply.

On the other hand, green algae, including various species such as *Chlorella*, *Closterium*, *Volvox*, *Scenedesmus*, *Spirogyra*, are diverse and environmentally favored organisms that have great potential applications in sustainable bioplastic production due to their fast growth, high biomass yield, and rich biopolymer content, which is a more realistic and green alternative to conventional plastics.

The well-known alga, *chlorella* is a single-cell alga that is highly valued for its high growth factor and great lipid, and carbohydrate content. Such biochemical components are necessary for carrying out the process of bio-polymer synthesis, and thus, the value of *chlorella* in the production of bioplastics and other biopolymers is all the more evident. Its fast growth and high protein composition under different environmental conditions make it a good sustainable source in bioplastic manufacturing. Furthermore, its capability of carbon dioxide sequestration and wastewater has brought it closer to being regarded as an eco-friendly material resource.

Scenedesmus is characterized by high lipid accumulation, an important constituent for bioplastic production.The lipids from *scenedesmus* can be further converted into biopolymers that can be used in making biodegradable plastics. This alga's potential in carbon capture and bioremediation adds to its environmental sustainability, positioning it as a green alternative in the realm of bioplastics.

Of all charophytes, *spirogyra* is distinct because of its filamentous morphological nature and high level of polysaccharides, especially cellulosic matter. This polymer can be grown and used as a material to develop bioplastic during industrial production. The simplicity surrounding cultivation and processing of *spirogyra* as a source of bioplastic makes *spirogyra* an accessible, cost effective, and eco-friendly alternative to traditional plastic materials.

The advantages of *volvox* include its colonial organization and ease in collecting and processing. The carbohydrates in *volvox* can be converted to biopolymers that are essential in bioplastic production. Its enormous rounded colonies consisting of millions of cells give a plentiful supply of biomass that helps the big scale bioplastic manufacture process.

Closterium, in turn, have a unique structure of their cells that is mainly represented by their cell wall containing several polysaccharide types. These polysaccharides are important building blocks for bioplastic production as they provide a sustainable renewable source for this initiative. The ability of *closterium* to withstand different environmental conditions makes it a candidate for fast manufacturing of bioplastics.

Multiple scientists have been working in this field; the concept of converting marine algae into bioplastics was a collective effort within the community and each scientist made specific contributions towards the field. Looking through photosynthesis, the Dutch designer's Eric Klarenbeek and Maartje

Dros have examined findings that show that algae could be used as a production material by cultivating aquatic algae, then drying and processing them into a material used to 3D print starch-based plastics. (Morris, 2017).

Additionally, Franziska Kratzl, a graduate research assistant in TUM, finds in her research that the CO2 is fixed throughout the process of photosynthesis, making building factors for bioplastics; bioplastics can decompose back into carbon dioxide. Because CO2 is used in a way that doesn't interfere and compete with our food supply, the making of bioplastics isn't damaging to the environment (Kratzl, 2022). Kratzel's study highlights that microalgae hold great promise as a biomass source for bioplastic manufacturing, as it avoids competition with food resources.

Unlike bioplastics, which come from biofuels (algae becomes biofuel) that are renewable, conventional plastics come from fossil fuels that are unrenewable; unrenewable fossil fuels make unrenewable plastics. David K. A. Barnes, another researcher, notes that because these conventional plastics end up becoming debris, and at a substantial rate, this debris mostly ends up in the ocean; this debris consists of an abundance of microplastics. Such debris increased in the oceans as the years went by. (Barnes, 2009). To further support this, Colin Barrow, a researcher and author of Marine Nutraceuticals and Functional Foods, discovered that since the composition of the biopolymers, the microalgae make is high in carbohydrate, lipid, and protein content, the most effective biofuel would be microalgae. Microalgae are more than capable of producing vast amounts of all those essential substances, so they prove to be a better biofuel than lignocellulosic (dry plant matter) biomass (Barrow, 2007). It'd be effective to test which microalgae of the green algae group would make the most effective bioplastic.

Axel Barett, founder and editor of BioplasticsNews.com, notes that in 2019 ASU (Arizona State University) researcher Taylor Weiss a notable algae researcher, claimed that these bioplastics are classified as biodegradable, which solves the issue of breaking down petroleum-based plastics (artificial organic polymers). (Barrett, 2019). Additionally, Renee Cho, a contributor to the Columbia Climate School, mentioned that using algae for bioplastic production holds significant promise for lowering manufacturing expenses (Cho, 2017). In essence, all these studies show that algae are useful and unharmful biofuel for turning carbon dioxide into bioplastics and oxygen, which reduces CO2 emissions and leads to an eco-friendly environment.

As the use of plastic becomes detrimental to society scientists have been searching for alternatives such as biopolymers which are large molecules made up of repeating subunits called monomers, derived from living organisms. Unlike synthetic polymers, which are derived from petrochemicals, biopolymers are typically renewable and biodegradable. Synthetic polymers tend to break down slowly through processes like mechanical weathering, oxidation, and, in some cases, hydrolysis. Chemical bonds in synthetic polymers resist rapid degradation, leading to persistent plastic waste. While biopolymers break down more readily due to their natural origin and chemical structures. Enzymatic action by microorganisms can cleave the biopolymer chains into simpler compounds, facilitating biodegradation into natural byproducts. Biopolymers can be modified and engineered to exhibit specific properties, such as flexibility, strength, and biodegradability, to suit a wide range of applications.

With these properties, researchers are constantly searching for the perfect combination and algae species with the favored traits to create biopolymers suited for mass production. While biopolymers have many advantages, it's important to note that their adoption still faces challenges, such as cost-effectiveness, scalability, and addressing specific performance requirements for different applications.

Hypothesis:

In this study, we examined biodegradation and physical properties of bioplastics due to different species of algae in a rigorous manner. Two hypotheses are at the core of our research. The null hypothesis (**Ho**) posits a uniformity among species: It is predicted that *Chlorella*, *Closterium*, *Volvox*, *Scenedesmus*, *Spirogyra*, *Saccharina Latissima,* and *Alaria Esculenta* will have the same rate of biodegradability of bioplastics, same melting points, and plasticity. In contrast to this, our alternative hypothesis (**Ha**) predicts that *Saccharina Latissima* will have the biggest rate of biodegradability of bioplastics, plasticity, and lowest melting point. This speculation is based on the specific biological processes of *Saccharina Latissima*, which we think to endow advanced bioplastic degradation capabilities.

Methods

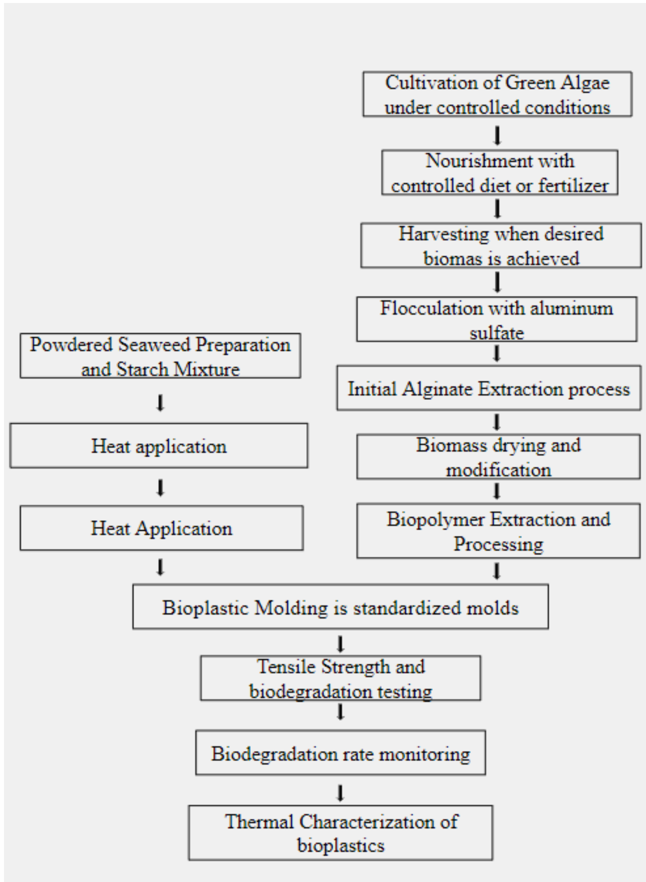


Figure 1: This is a methodological chart representing the steps in which we turn the algae into plastics

Materials

-One bin to hold all the Tupperware 55x40x14 cm, Six Tupperware 12x8x7 cm, 50 mL Distilled water for each Tupperware, 50 mL Mineral water for each Tupperware, coffee filters, spectrophotometer, 5 beakers 500 mL, pipettes, cuvette, analytical/precision scale, Newton spring meter, hotplate, calipers, heat insulating glove, Airstones for each 100ml Tupperware container, Aerator for each 100ml Tupperware container, Thermometer, Gloves, Goggles, Glycerol, Aluminum Sulfate, Corn Starch, *Closterium*, *Chlorella*, *Scenedesmus, Volvox, Spirogyra, Saccharina Latissma, Alaria esculenta*

Design and Procedure

By farming algae rich in biopolymers like alginate or protein in Chlorella, Closterium, Volvox, Scenedesmus, and Spirogyra then extracting the biomass from the water through flocculation, a process of coagulation; it is possible to cultivate algae under controlled conditions, optimizing factors like same number of fluorescent light bulbs, temperatures of 22°C, and nutrient supply of .25 mL of fertilizer per week to maximize biomass production. The containers are covered with parafilm to capture the evaporated water.

The green algae such as Closterium, Volvox, Chlorella, Scenedesmus, and Spirogyra, which served as the independent variables, were divided into separate containers, each filled with dechlorinated water. (*Figure 2*) These algae cultures were nourished with a controlled diet of spirulina to facilitate the bioaccumulation of biopolymers. The rate and extent of biodegradation were monitored, recorded, and expanded on for real-world applications. Additionally, fertilizer "*API Leaf Zone*" was placed in all environments to stimulate algae growth. Though fertilizers containing nitrogen and phosphorus may affect the biodegradation of bioplastics, the results may vary depending on the type of bioplastic. Specifically for alginate-based bioplastics, nitrogen and phosphorus fertilizers may accelerate biodegradability and promote the consumption of bioplastics in the environment. After the algae cultures had reached the desired biomass concentration, biopolymers were extracted from the algae through flocculation. Biomass concentration was measured by examining the sample's absorbance values; these values were correlated to the number of cells per volume or dry weight.

The initial process included alginate extraction, biopolymer modification through esterification, and the cross-linking of proteins, including structural, storage, and enzymatic proteins such as lysine, arginine, glutamic acid, and aspartic acids. These proteins, along with glycoproteins, lectins, mycosporine-like amino acids, and phycobiliproteins, are robust and abundant. They are capable of forming a stable matrix when modified and interact effectively with other biopolymers.

This method encountered significant challenges due to the unexpected drying and hardening of the algae. The initial step involved mixing harvested algae biomass with a calcium chloride ($CaCl_2$) solution to extract alginate found in the cell walls of brown algae, followed by precipitating the alginate with 95% ethanol (C_2H_6O). However, the drying out of algae compromised the effectiveness of this process, as the reduced moisture content likely hindered the full extraction and precipitation of alginate. The subsequent esterification step, meant to enhance the hydrophobicity and water resistance of alginate by reacting it with sulfuric acid, and the modification of proteins through cross-linking with glutaraldehyde ($C_5H_8O_2$) , were also affected. The intended modifications require a certain degree of moisture to facilitate chemical reactions properly; the dry, hardened state of the algae likely impeded the effective interaction of these chemical agents with the alginate and protein molecules.

The experiment began amid the flocculation process whereby 0.2 grams of aluminum sulfate ($Al_2(SO_4)_3$) was meticulously added into six different groups of green algae. The Alum undergoes hydrolysis to form aluminum hydroxide precipitates and sulfate ions. The chemical reaction can be represented as: $Al_2(SO_4)_3 \rightarrow 2AI(OH)_3 = 3SO^2{}_4$

This step was very important also, in causing the agglomeration of algae particles, so that they settled down to the bottom of these containers which in turn made water clear above the container. Thus, as soon as the algae underwent the sedimentation process, filtration was done using coffee filters fixed firmly in six different beakers to avoid cross-contamination. Filtration occured one to two times per sample. Each group was filtered into its designated beaker, effectively separating the algae from the liquid.

With the remainder of the experimental groups, it was decided to modify the initial methods to one that accommodated the dry and hardened component of the green algae. Subsequently, 0.1 grams of algae from each group were carefully ground into a fine powder using mortar and pestle; a preliminary step that enables successful extraction of biochemical components from the cells of green algae after powdering. This algal powder was then transferred to a beaker where a solution was prepared by adding water (H_2O), starch((C6H10O5)n) (where n represents the number of glucose molecules present), glycerol ($C_3H_8O_3$), and ethyl alcohol mixed in that order with each reagent dose at 0.5 grams. To solubilize and interact the components with the given solution, the addition of water was essential to establish an aqueous medium. As a viscosity modifier, starch was used to aid in the stabilization of the final product and acted as the primary biopolymer matrix. When mixed with water, it gelatinizes, absorbing water and swelling to form a paste that entraps and is predicted to bind the other components. The glycerol was taken as a plasticizer to make it flexible and reduce brittleness after being solidified. Ethyl alcohol functioned as a solvent and also facilitated the evaporation process during the heating step.

Each mixture was stirred until uniformity occurred, and the components were evenly distributed across the mass. First, the compiled mixture was subjected to heating on a 60 degrees Celsius hot plate. The hot air activation that promoted gelling formed part of the controlled heating which also facilitated the fast evaporation of ethanol transforming the mixture from a liquid to a semi-solid state.

To prepare brown seaweed, 50g of powdered seaweed was mixed with 300ml of water. The powdered form increased the surface area for hydration, particularly of the alginates, which were mainly composed of mannuronic acid (M) and guluronic acid (G) units (C_6H8O6). To prepare the starch mixture, 250 grams of starch were dissolved in 500 ml of water. The polysaccharides from the starch interacted with the water, breaking down into smaller molecules and forming a gel-like structure upon exposure to heat, providing a backbone in bioplastics. The mixture was heated and stirred until near boiling point, causing hydration and swelling of the starch and creating a viscous solution. The gelling process involved letting the mixture sit until it became jello-like, which included the gelatinization of starch. Glycerol

($C_3H_8O_3$) was added as a plasticizer; glycerol intercalated between the polymer chains, reducing intermolecular hydrogen bonding and increasing flexibility. As the mixture cooled, the polymers solidified, forming a stable structure.

For the formulation of bioplastics, standardized molds were a prerequisite to maintain consistency of shape and size. In order to achieve this, Poland Spring water bottle caps were used because they were uniform in size and were readily available. One by one, the algae mixtures were poured into the offered caps acting as molds, giving rise to the bioplastic materials. Once shaped like caps, these bioplastics were gently extracted from the caps.

The second step of the process was the cutting of the organic plastics whereby molded bioplastics were sectioned into smaller, equal samples for testing. By using a box cutter, each molded bioplastic was divided into four equal quadrants. It was done so that each sample would have the same physical properties and dimension, hence, comparability of their characteristics would be possible in succeeding analysis.

However, an exception was noted on the processing of the bioplastic derived from Alaria which came in a type of brown algae. The Alaria-based bioplastic showed a markedly high hardness that was detrimental to the cutting process. Consequently, the division of the Alaria bioplastic was approached with caution, and deviations from the uniform quadrants were recorded.

After the molding and cutting of the test samples, the bioplastic samples proceeded to the drying stage. Then this period was key to acquiring the specified consistency; hence, all of the bioplastics were untouched for a day with controlled environment so that each sample obtained a rock hard consistency perfect for the mechanical test.

When the bioplastics were dried, the bioplastics were undertaken for tensile strength evaluations. The first step of this analysis was used to find out the area of cross-sections of all the bioplastic samples. The cross-sectional area of the samples was one of the main parameters in determining the tensile strength, for which the use of calipers or a micrometer to accurately measure the width and depth was mandatory.

Finally, upon using a caliper to calculate and record its respective cross-sectional areas, each bioplastic was carefully fixed to the spring meter individually. The tensile testing started with the application of moderate force, implemented in the spring meter, to stretch each bioplastic until the first sign of material failure could be recognized owing to the emergence of a crack.The force applied at the point of cracking was measured in newtons (N) and meticulously documented.

The final phase of the procedure involved the calculation of tensile stress. The net force recorded by the spring meter at the point of failure was divided by the cross-sectional area of the bioplastic sample.

The determination of this simple calculation gave the tensile stress of the bioplastic expressed in newtons per square millimeter (N/mm^2) and used as a measure of the bioplastics' tensile strength.

After the composition of tensile strengths, the study directed toward the rate of biodegradation of the bioplastic samples. This evaluation was crucial in understanding the environmental impact of the bioplastics. The process commenced with the accurate weighing of the samples of each bioplastic prior to the biodegradation test using an analytical/precision scale. These values were registered as initial masses supplied for each specimen.

The bioplastics were subsequently immersed into a regulated biodegradation atmosphere of water, for natural decomposition. The time of exposure was tightly controlled and recorded. After the expiry of the assigned time of biodegradation (3 days), the samples were retrieved and weighed again in order to determine its weight at this point. This element was one of the major critical steps needed to determine the level of mass loss due to the biodegradation process.

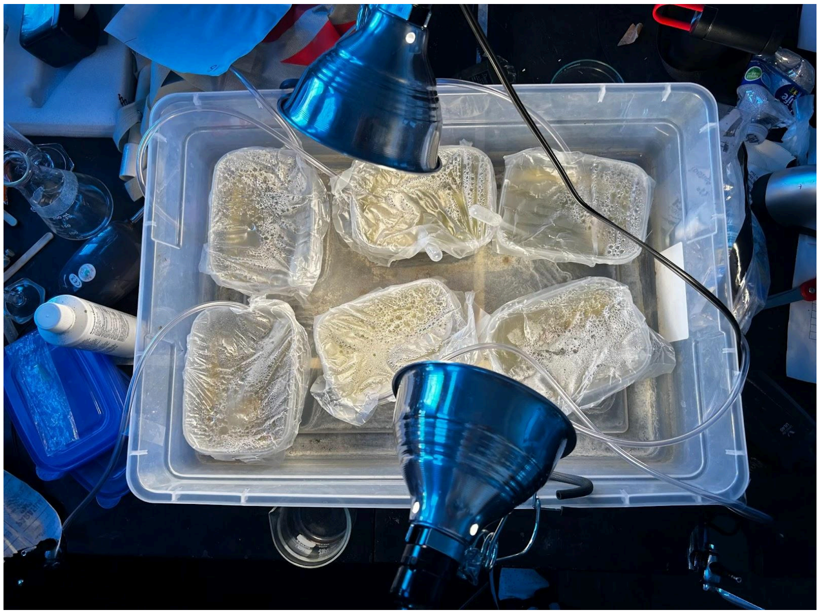
The formula

$$Biodegradation\ rate\ (\%\ Per\ Day) = \left(\frac{initial\ mass - Final\ Mass}{Initial\ Mass}\right) \mathrm{X} \left(\frac{100}{Time\ In\ Days}\right)$$

records the decimal rate of bioplastic degradation in the experiment, leading to elimination of an approximate decimal percentage that accounts for the rate of biodegradation per day. The initial mass refers to the original weight of the bioplastic, before the experiment, and the final mass the same substance after the biodegradation period. The time is given in the number of days which is the period of the bio-degradation of the experiment (which was 3 days).

The last stage of the experiment was the measurement of each bioplastic sample's melting point. This test was crucial for determining thermal characterization of the bioplastics that is necessary in assessment of their performance at different temperatures. The samples of bioplastics were separately added in different volumes of water inside beakers. The beakers were thereafter placed on a heating hot plate, selected for its facility with having a steady and adaptable source of heat. The surface of the hot-plate was warmed at a rate as slow as possible by careful temperature regulation with a thermometer. The target was to set the heat-up as gradually as possible to a level high enough for the bioplastic to start melting.

The exact time when each sample of bioplastic started to melt down was carefully noted. At this point, the temperature of the hot plate was recorded in degrees Celsius; this temperature is known as the melting point of the bioplastic. It is important to note that the melting point is the temperature taken under the conditions of this experiment whereby the bioplastic melts from solid to liquid state.



\

Figure 2: Algae Cultivation Setup

Results

Diagrams

Species	**Melting point C °**	**Plasticity (MPa)**	**Rate of biodegradability (% Per day)**
Closterium	81°	0.43 MPa	1.18%
Chlorella	75°	0.37 MPa	1.10%
Scenedesmus	77°	0.40 MPa	1.02%
Volvox	76°	0.36 MPa	1.10%
Spirogyra	71°	0.40 MPa	0.99%
Saccharina latissima	65°	0.60 MPa	1.21%
Alaria	71°	0.4625 MPa	0.98%
Composite	75°	0.55 MPa	1.04%

Figure 2

Figure 3 shows the general averages of each green algae. The melting point, the Tensile Strength, and the Biodegradability of each plastic. The average is rounded to the hundredth, there were 4 trials for each algae group, each tested on their melting point, plasticity, and biodegradation. The melting point of *Saccharina latissima* is 65°, tensile strength 0.60 MPa, and a mass loss of 1.21% per day.

Species	Group 1	Group 2	Group 3	Group 4
Closterium	3.626	3.234	4.998	5.096
Chlorella	3.234	3.136	3.724	4.214
Scenedesmus	2.744	2.548	4.802	5.586
Volvox	3.822	3.332	3.626	3.430
Spirogyra	2.744	4.018	4.410	4.508
Saccharina latissima	4.606	5.586	7.154	6.174
Alaria	4.836 (3.038)	6.350 (4.900)	3.375 (4.410)	5.428 (5.782)
Composite	5.390	4.802	5.292	6.076

Figure 4 shows the net forces of each bioplastic group, rounded to the nearest thousandth; proportions were set in open and close parentheses to find the net forces of *Alaria* if it was 9.8mm^2 in cross-sectional area

Species	Group 1	Group 2	Group 3	Group 4
Closterium	9.8mm^2	9.8mm^2	9.8mm^2	9.8mm^2
Chlorella	9.8mm^2	9.8mm^2	9.8mm^2	9.8mm^2
Scenedesmus	9.8mm^2	9.8mm^2	9.8mm^2	9.8mm^2
Volvox	9.8mm^2	9.8mm^2	9.8mm^2	9.8mm^2

Spirogyra	9.8mm^2	9.8mm^2	9.8mm^2	9.8mm^2
Saccharina latissima	9.8mm^2	9.8mm^2	9.8mm^2	9.8mm^2
Alaria	15.6mm^2	12.7mm^2	7.5m^2	9.2mm^2
Composite	9.8mm^2	9.8mm^2	9.8mm^2	9.8mm^2

Figure 5 shows cross-sectional areas of each group.

Species	Group 1	Group 2	Group 3	Group 4
Closterium	0.5 g	0.5 g	0.5 g	0.5 g
Chlorella	0.5 g	0.5 g	0.5 g	0.5 g
Scenedesmus	0.5 g	0.5 g	0.5 g	0.5 g
Volvox	0.5 g	0.5 g	0.5 g	0.5 g
Spirogyra	0.5 g	0.5 g	0.5 g	0.5 g
Saccharina latissima	0.5 g	0.5 g	0.5 g	0.5 g
Alaria	0.5 g	0.5 g	0.5 g	0.5 g
Composite	0.5 g	0.5 g	0.5 g	0.5 g

Figure 6 shows all initial masses of each algae group expressed in grams

Species	Group 1	Group 2	Group 3	Group 4
Closterium	.498425 g	.49835 g	.497975 g	.4982
Chlorella	.49829 g	.49835 g	.498605 g	.49817 g

Scenedesmus	.498515 g	.498485 g	.49844 g	.49847 g
Volvox	.49844 g	.49847 g	.49805 g	.498455 g
Spirogyra	.498395 g	.49859 g	.49844 g	.498635 g
Saccharina latissima	.49817 g	.498335 g	.49796 g	.49829 g
Alaria	.498305 g	.49865 g	.49856 g	.49862 g
Composite	.498335 g	.49841 g	.498455 g	.498575 g

Figure 7 shows all final masses of each algae group expressed in grams

Species	Group 1	Group 2	Group 3	Group 4
Closterium	0.105	0.110	0.135	0.120
Chlorella	0.114	0.110	0.093	0.122
Scenedesmus	0.099	0.101	0.104	0.102
Volvox	0.104	0.102	0.130	0.103
Spirogyra	0.107	0.094	0.104	0.091
Saccharina latissima	0.122	0.111	0.136	0.114
Alaria	0.113	0.090	0.096	0.092
Composite	0.111	0.106	0.103	0.095

Figure 8 shows all biodegradation rates (% per day) for all algae groups; formula from figure 11 was used; all groups are rounded to the nearest thousandth

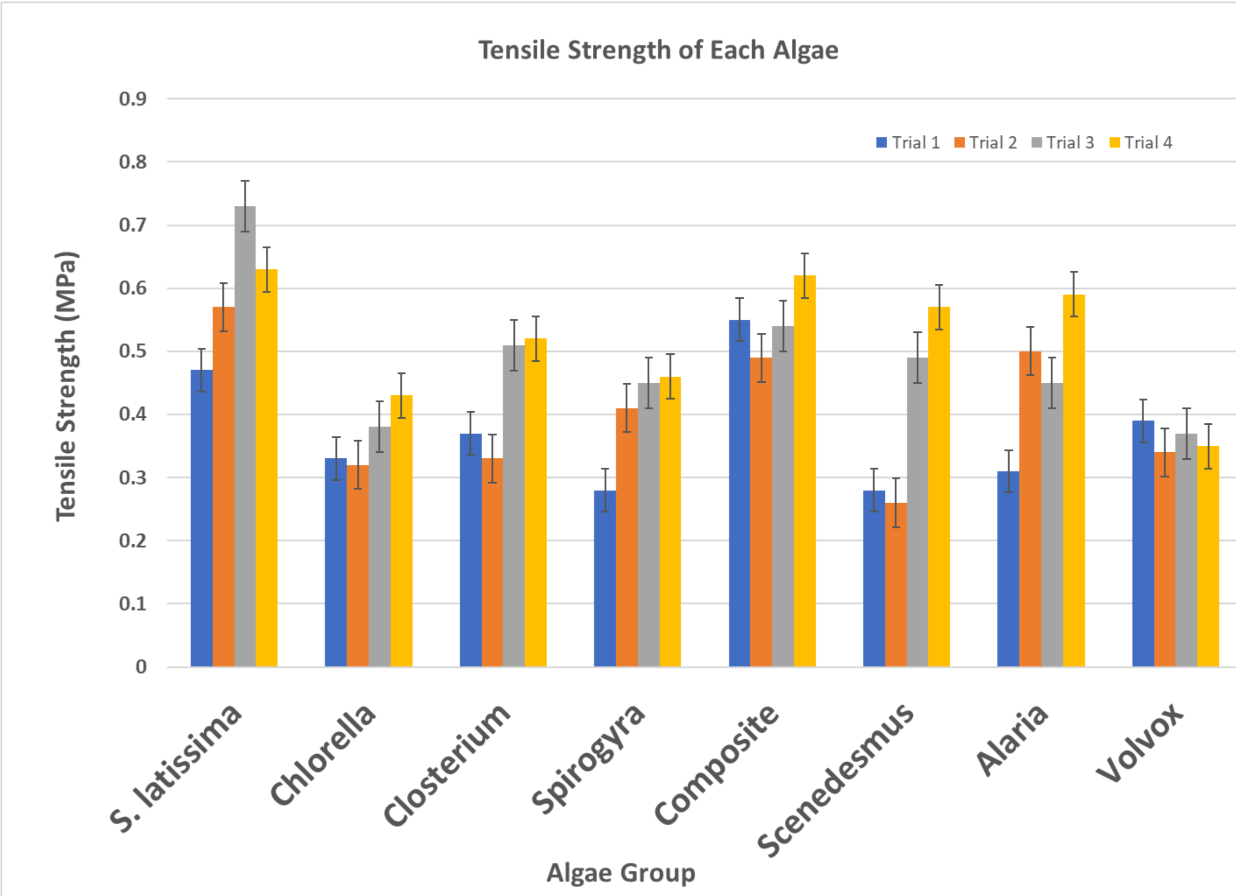


Figure 9 Tensile Strength Graph

Figure 9: Demonstrates the Tensile strength measured in MPa, with error. Tensile strength was measured in newtons using the hanging scale, then divided by the cross-sectional area, to get the Tensile strength which is measured in MPa, an equation shown in Figure 10, seeing how much tension the plastics can face before ripping. The highest tensile strength was *Saccharina Latissima*, with a Tensile strength of 0.6 MPa, and the lowest was Chlorella with 0.365 MPa.

$$Tensile\ Strength\ (MPa) = \frac{Maximum\ Force\ (N)}{Cross\text{−}Sectional\ Area\ (mm^2)}$$

Figure 10 Tensile Strength Formula

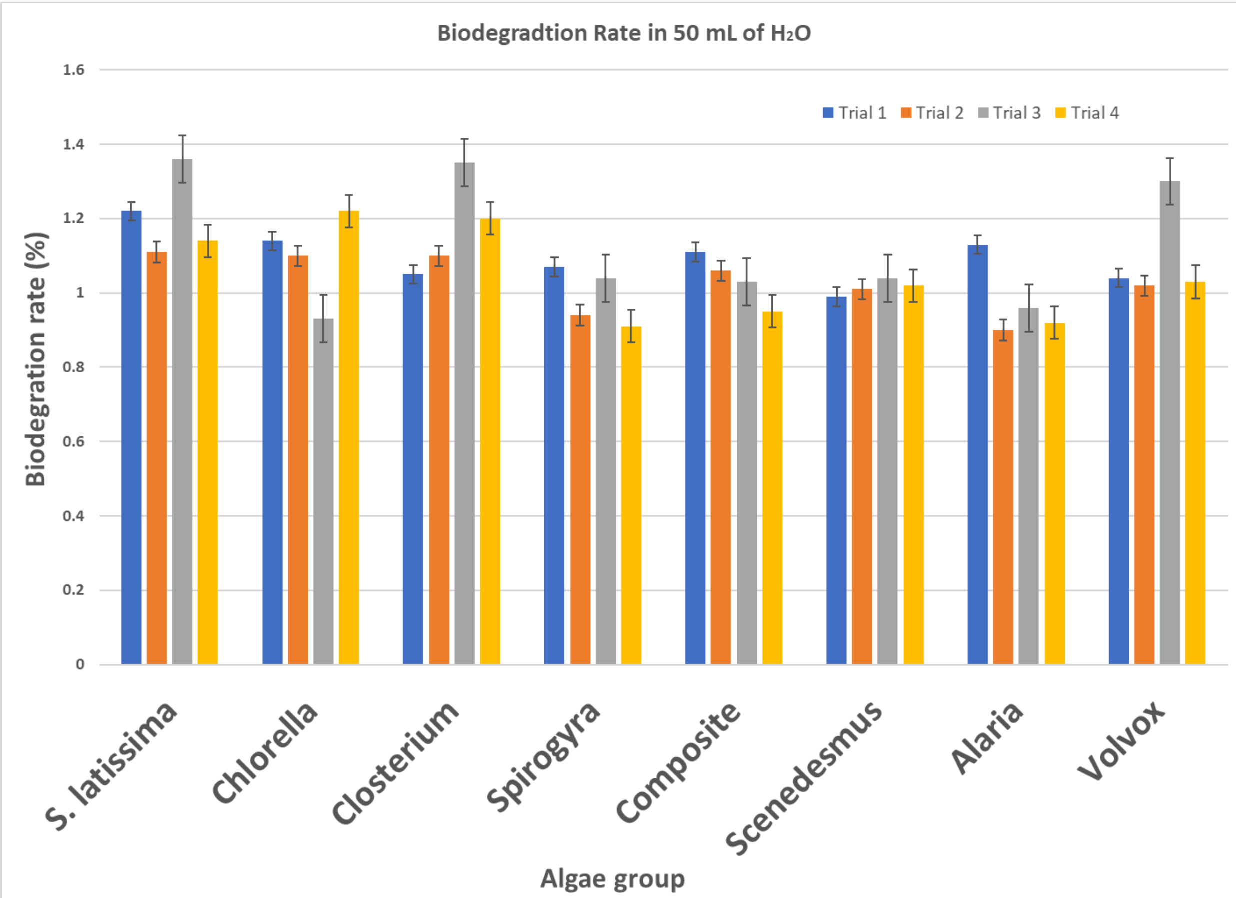


Figure 11 Biodegradability graph

Figure 11 shows the percentage of biodegradability scaled up from 3 to 30 days, so all values were multiplied by 100. The average percentage of biodegradability for each species was roughly 1% per day. Figure 12 showcases how we were able to calculate the amount degradation rate per day, subtracting the Initial mass by the Final mass divided by the initial, then multiply by 100/the 30 days it was taken to get rate of biodegradation per day, *Saccharina latissima* has a biodegradability of 1.2075% which is higher than the rest, the lowest biodegradability with being *Alaria* losing only 0.9775% of their mass every day.

$$Biodegradation\ rate\ (\%\ Per\ Day)\ =\ \left(\frac{initial\ mass - Final\ Mass}{Initial\ Mass}\right) \mathrm{X} \left(\frac{100}{Time\ In\ Days}\right)$$

Figure 12 Biodegradation Rate Formula

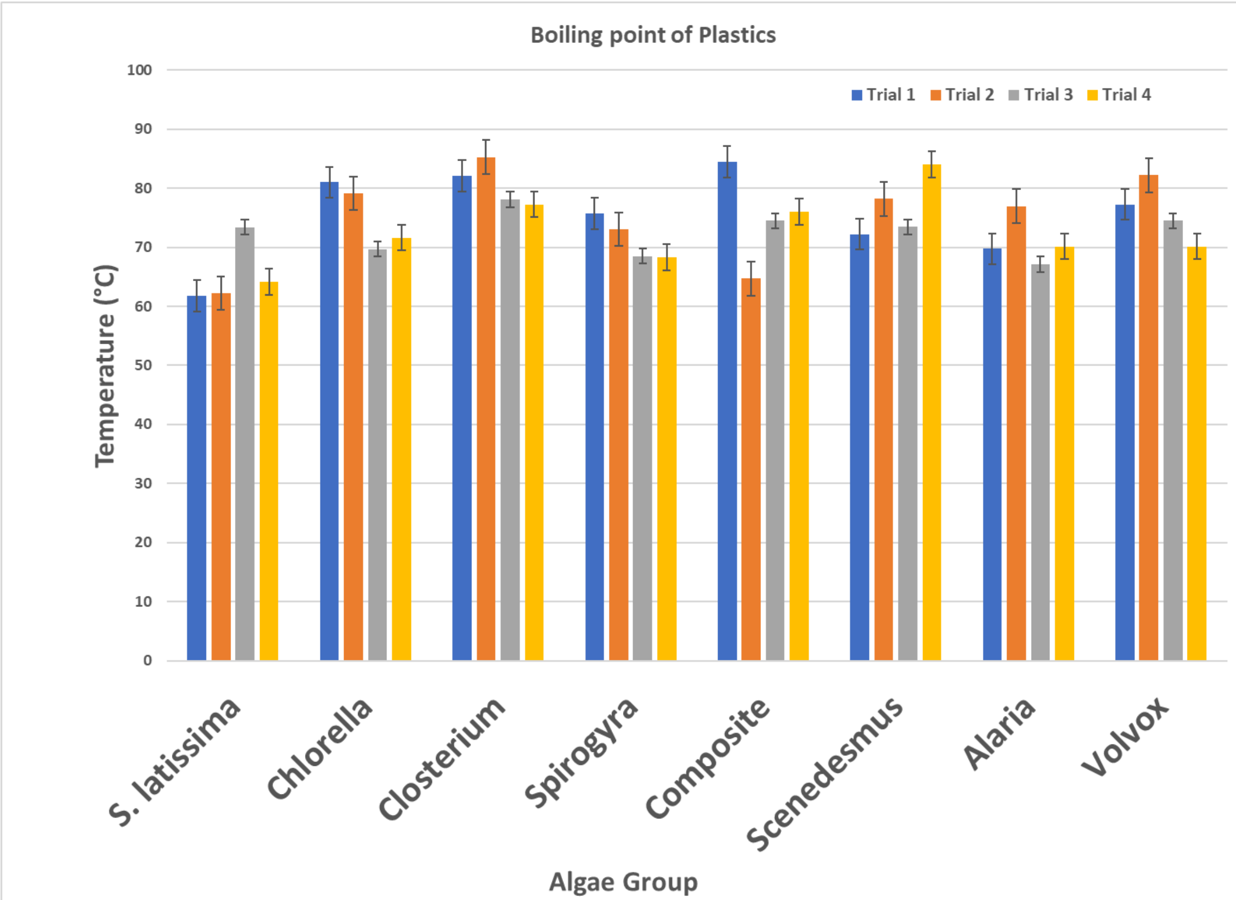


Figure 13 Melting point of the algae

Figure 13: Represents the melting point of the algae. The melting point was measured by putting the algae into a beaker filled with water that is heated by a hotplate. A thermometer was stuck inside the beaker to see at what point the algae would start to melt inside of the beaker. This was recorded in Celsius; the highest of them all was *Closterium* with a melting point of 81°, and the lowest of them all was *Saccharina Latissima* having a melting point of 65°.

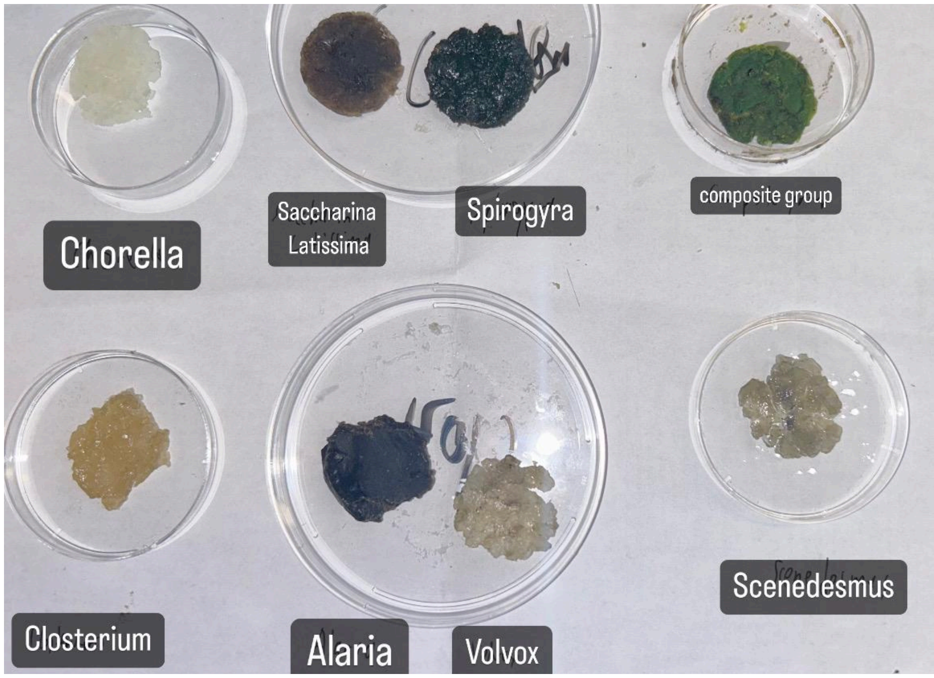


Figure 14: Bioplastics in the shape of a Poland spring water bottle cap, all of the same weight.

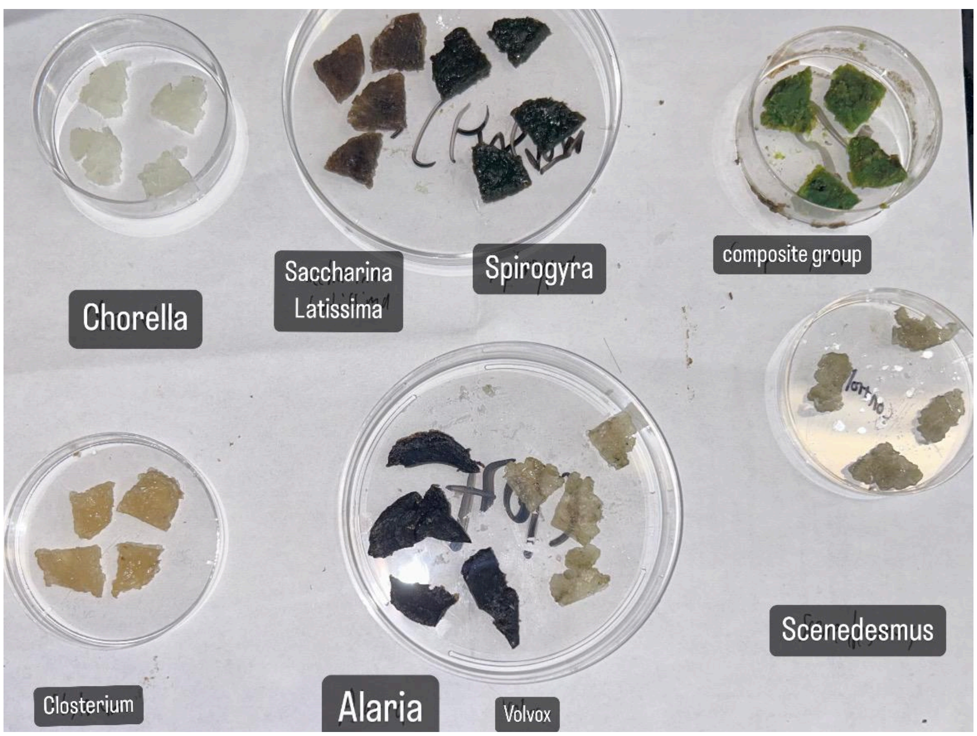


Figure 15: Bioplastics are cut into 4 approximately equal pieces, except *Alaria*; each piece was approximately 0.5 grams.

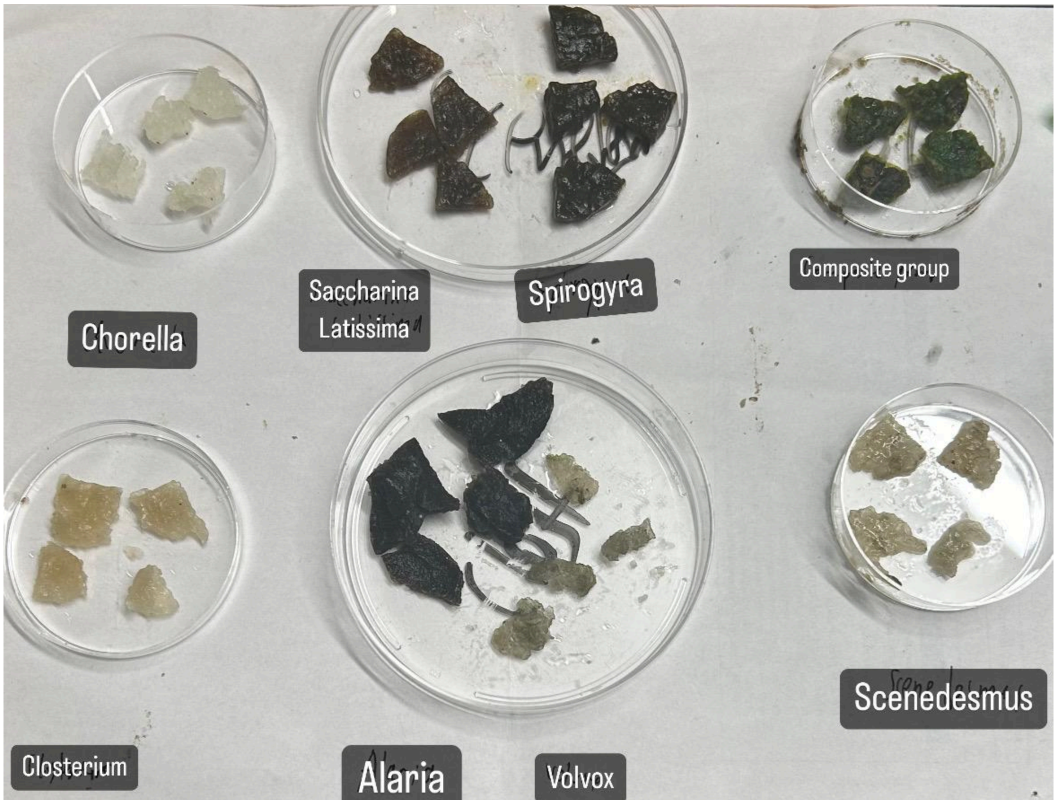


Figure 16 Illustrates the degradation of bioplastics after one month of immersion in water.

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
Saccharin	4	2.4	0.6	0.011867
Chlorella	4	1.46	0.365	0.002567
Closteriur	4	1.73	0.4325	0.009358
Spiro	4	1.6	0.4	0.006867
Composit	4	2.2	0.55	0.002867
Scenedes	4	1.6	0.4	0.023667
Alaria	4	1.85	0.4625	0.013692
Volvox	4	1.45	0.3625	0.000492

ANOVA

ce of Varic	SS	df	MS	F	P-value	F crit
Between (	0.210997	7	0.030142	3.378484	0.011844	2.422629
Within Gr	0.214125	24	0.008922			
Total	0.425122	31				

Figure 17: Above provides the P-value of Biodegradability, showing a low p-value of 0.03, making the data for biodegradability statistically significant.

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Saccharin	4	2.4	0.6	0.011867		
Chlorella	4	1.46	0.365	0.002567		
Closteriur	4	1.73	0.4325	0.009358		
Spiro	4	1.6	0.4	0.006867		
Composit	4	2.2	0.55	0.002867		
Scenedes	4	1.6	0.4	0.023667		
Alaria	4	1.85	0.4625	0.013692		
Volvox	4	1.45	0.3625	0.000492		
ANOVA						
ce of Varic	SS	df	MS	F	P-value	F crit
Between	0.210997	7	0.030142	3.378484	0.011844	2.422629
Within Gr	0.214125	24	0.008922			
Total	0.425122	31				

Figure 18: Provides a P value of Tensile Strength, a P value of 0.01, making the data for average tensile strength statistically significant.

Anova: Single Factor						
SUMMARY						
Groups	Count	Sum	Average	Variance		
sL	4	261.55	65.3875	29.64089		
Chlorella	4	301.49	75.3725	30.66949		
Closteriur	4	322.77	80.6925	13.91383		
Spiro	4	285.65	71.4125	13.11856		
Composit	4	299.75	74.9375	65.89383		
Scenedes	4	307.94	76.985	28.95017		
Alaria	4	284.01	71.0025	17.58329		
Volvox	4	304.16	76.04	25.39427		
ANOVA						
ce of Varic	SS	df	MS	F	P-value	F crit
Between	601.903	7	85.98614	3.055054	0.019048	2.422629
Within Gr	675.493	24	28.14554			
Total	1277.396	31				

Figure 19: Provides the P value of Tensile Strength, a P value of 0.02, making the data for average temperature statistically significant.

Discussion

This study investigates the production of bioplastics from seaweed (*Saccharina Latissima* and Alaria *esculenta*) and various green algae (*Closterium, Chlorella, Scenedesmus, Volvox,* and *Spirogyra)*, focusing on the differences in their biopolymer compositions and the resultant bioplastic properties. The research reveals that the enhanced plastic-like characteristics of bioplastics from *Saccharina Latissima* and *Alaria esculenta*, as compared to green algae, are primarily attributable to the high alginate content in seaweeds. Alginates, with their unique molecular structure, significantly improve the film-forming properties, flexibility, and transparency of bioplastics (Kaczmarek 2020). This superiority is further augmented by the increased surface area provided by the powdered form of seaweed, facilitating better interaction and integration of alginates into the bioplastic matrix (Rosado 2021). This feature contrasts starkly with green algae, which may not offer the same level of uniformity and integration due to their differing biopolymer composition.

The relationship between melting point, plasticity, and biodegradability in water significantly influences the behavior of bioplastics. The melting point, representing the transition from solid to liquid, is intimately connected with plasticity, the material's ability to deform under stress. Lower melting points, often associated with higher plasticity, render bioplastics more malleable and easily moldable. This characteristic gains importance in water environments, where the materials can experience enhanced softening and deformability. This heightened plasticity, in turn, facilitates interactions with water, potentially promoting microbial colonization and accelerating enzymatic breakdown, thereby expediting biodegradation. Water, acting as a medium for microbial activity, becomes a crucial factor in this process. However, the nuanced interplay of these factors relies on the specific composition of the bioplastic, the surrounding environmental conditions, and the presence of microorganisms in the water. In essence, the intertwined characteristics of melting point and plasticity exert a profound influence on the biodegradability of bioplastics within water environments.

The research explores the relationship between various algae species, specifically *Chlorella, Scenedesmus, Closterium, Volvox, and Spirogyra,* as well as a Control Group, in comparison with the optical data obtained from a spectrophotometer. This data includes absorbance and transmittance values, which serve as indicators of algae growth, the biomass present in a given area, and the lipid content of each species. The study utilized spectrophotometer readings to gain insights into the growth patterns and overall health of the algae population. By analyzing the absorbance data, we can assess the density of the algae, which correlates to biomass. In contrast, the transmittance values offer a perspective on the clarity of algae suspensions, indicating the size and distribution of particles, which are also crucial in determining biomass concentration. Additionally, the lipid content, essential for bioplastic production, varies among different algae types, significantly influencing their suitability for various plastic applications.

Higher absorbance values indicate more robust algae growth. Spirogyra, with the highest mean absorbance of 0.3, suggests vigorous growth and significant biomass accumulation, which is crucial for bioplastic production. A substantial source of biopolymers is required to ensure the feasibility of creating these plastics. Closterium displays a mean absorbance of 0.24, while Chlorella and Scenedesmus each have a mean value of 0.23, demonstrating their capability to grow in a controlled environment. The Control group, comprising a mixture of all the algae species, shows a mean absorbance of only 0.20, which is the second lowest next to Volvox's 0.18. This indicates that these algae groups are not growing as rapidly as the others.

Transmittance, a value that represents how much optical light can pass through a substance, is typically related to biomass density. Generally, lower transmittance suggests denser biomass. The control group, which had all the green algae in the environment, showed high biomass, as indicated by its 54% transmittance. Volvox had a transmittance of 55%, Scenedesmus had a transmittance of 56%, and Chlorella had a transmittance of 57%, placing it in the middle between the highest and lowest transmittance values, indicating all have a significant amount of biomass. The highest transmittance is seen in Spirogyra, at 59%, suggesting it has the lowest amount of biomass among all the groups.

Comparative analysis between seaweed (specifically *Saccharina Latissima* and *Alaria esculenta*) and various green algae (such as *Closterium, Chlorella, Scenedesmus, Volvox,* and *Spirogyra*) reveals distinct advantages in the use of seaweed, attributable to its unique biochemical composition. Central to seaweed's superior performance in bioplastic production is the presence of alginates, a biopolymer consisting of mannuronic acid (M) and guluronic acid (G) units (($C_6H_8O_6$) (Tang 2014). These alginates exhibit gel-forming properties due to their block copolymer structure (Consist of distinct blocks or sequences of one type of monomer, followed by blocks of another monomer). Moreover, the powdered form of seaweed significantly increases the surface area for hydration and interaction, ensuring a more homogeneous distribution of alginates within the bioplastic matrix, leading to improved film-forming properties and mechanical strength.

In contrast, the bioplastic production process from green algae involves the use of aluminum sulfate ($Al_2(SO_4)_3$) for flocculation. The chemical reaction involving the dissociation of aluminum sulfate and the hydrolysis of aluminum ions to form aluminum hydroxide ($Al(OH)_3$) is crucial for the aggregation of algae cells. However, this process does not inherently contribute to the enhancement of the bioplastic's properties. The molecular structure of alginates in seaweed, characterized by their block copolymer nature, provides superior structural properties compared to the simpler polysaccharides found in green algae. Furthermore, the powdered form of seaweed ensures a uniform distribution of alginates and better interaction with added components such as starch, leading to a more consistent bioplastic quality. The synergistic interaction of starch gelatinization and glycerol plasticization in seaweed bioplastics further enhances the overall properties of the bioplastic, a phenomenon less evident in the experimental green algae bioplastics.

Variations in the bioplastic properties among different green algae are linked to their structural differences. For instance, filamentous algae like Closterium and Spirogyra, characterized by longer polymer chains, contribute to the strength of the bioplastics but may lack uniformity compared to the bioplastics derived from seaweed.

Potential sources of error include the variability in the biochemical composition of both seaweed and green algae due to environmental conditions, and measurement inaccuracies in determining melting point, plasticity, and biodegradability. To mitigate these challenges, the study proposes the standardization of cultivation conditions for both seaweed and green algae and the use of calibrated and precise instruments for measuring bioplastic properties.

The research contributes substantially to the advancing field of bioplastics, providing valuable insights into how different algae can be utilized for sustainable material production. The environmental implications of this research are profound, underscoring the importance of exploring diverse algal sources for environmentally friendly alternatives to conventional plastics.

These reactions demonstrate the transformation of algae-derived biopolymers into a bioplastic material. The changes in chemical structures due to reactions like cross-linking and esterification are pivotal in imparting the bioplastic with characteristics such as mechanical strength, flexibility, and water resistance, mirroring those of conventional plastics while being environmentally friendlier.

The development of bioplastics from seaweed presents a sustainable alternative to traditional plastics, offering significant environmental benefits by reducing pollution and reliance on fossil fuels. Seaweed-based bioplastics, with their enhanced properties, can be tailored for various applications, ranging from packaging to biomedical uses, algae-derived bioplastics offer a myriad of benefits and hold significant potential for widespread adoption in everyday items, including water bottles, plastic bags, and various other products. First and foremost, these bioplastics are sourced from renewable and abundant marine resources, mitigating the reliance on fossil fuels for traditional plastic production. This aspect alone contributes to reducing greenhouse gas emissions and environmental degradation associated with fossil fuel extraction and plastic manufacturing. Furthermore, algae bioplastics are biodegradable and can be composted, addressing the critical issue of plastic pollution in landfills and oceans. Unlike conventional plastics that persist for centuries, algae-derived bioplastics break down into natural components, minimizing their environmental impact.

Another advantage of algae-based bioplastics is their versatility and adaptability in manufacturing processes. They can be engineered to exhibit various desirable properties, such as flexibility, transparency, and durability, making them suitable for a wide range of applications. Water bottles made from algae bioplastics, for instance, can be designed to be lightweight and robust, ensuring that they meet consumer needs while also being eco-friendly. Plastic bags produced from algae bioplastics can be durable, reducing the need for single-use plastics and contributing to a sustainable future. Moreover, algae bioplastics are generally considered non-toxic and safe for food contact, expanding their potential use in food packaging and food service items.

As the demand for sustainable alternatives to conventional plastics continues to grow, the expansion of algae-derived bioplastics in everyday items holds significant promise. With advancements in research and technology, these bioplastics can become more cost-effective and readily available, making them a competitive choice for manufacturers. The adoption of algae bioplastics in water bottles, plastic bags, and other products can help reduce the carbon footprint associated with plastic production, leading to a cleaner and healthier environment. It also aligns with consumers' increasing awareness of environmental issues and their preference for eco-friendly options. Governments and industries around the world are recognizing the urgency of addressing plastic pollution, and algae bioplastics represent a viable solution to this global challenge, paving the way for a more sustainable and eco-conscious future.

While commendable efforts were invested in reducing errors and controlling for fluctuating factors within the project, there is room for improvement in terms of equipment. For instance, when employing the capillary tube method to determine the melting points of plastics, our team utilized a hot plate to melt the bioplastics. Although we exercised meticulous care in measuring these melting points to attain maximum accuracy, some irregularities inevitably arose that were not as precise as those achievable with more specialized techniques such as a melting point apparatus or differential scanning calorimetry. The limitations of the hot plate setup became apparent in the precision of our results.

Furthermore, the equipment used for cultivating algae could potentially have affected the growth rate, given that lighting conditions are a significant factor influencing algae growth. In our setup, we manually controlled the turning on and off of lights at different times of the day, introducing variability into the growth conditions. This manual approach, while resource-conscious, may not have provided the consistent and controlled lighting conditions that specialized equipment designed for algae cultivation can offer. Therefore, investing in improved equipment for both the melting point determination and algae cultivation processes could significantly enhance the accuracy and reliability of our experimental outcomes, ultimately contributing to the overall success and rigor of the project.

With improved tools and extended cultivation periods, the potential to grow a larger quantity of green algae could be realized. Moreover, it is advisable to conduct experiments to identify the most suitable algae species, given their affordability and rapid proliferation. Extending the growth phase could yield more detailed insights. Apropos the growth rates of algae, a primary challenge encountered during the experiment was the slower-than-expected growth rate of these algae. Despite the fact that algae is usually known as a fast-growing organism, the observed growth rates in our experimental set-up were not large enough to obtain the biomass in the provided time frame. The limitation affected our ability to collect a sufficient biomass necessary for bioplastic production. Because only a minimum of the algae was harvested, the bioplastics derived from green algae were miniaturized in size. The small quantity of production limited the possibility to form bioplastics in the form of larger objects; therefore, this limited the practical application of our findings as well as the testing of mechanical properties like tensile strength, biodegradability and the physical property of melting point.

As noted earlier, our experiment focused only on a few species of brown and green algae; our goal was to examine which algae grow fastest in cultivation and create the most biodegradable bioplastic, which we were only able to do to a certain extent. It can be considered to continue this research by looking more widely at a greater array of diverse species of algae, including red algae, that have biopolymers to find not only specific fast-growing algae that create the ultimate biodegrading plastic but also one that exhibits the properties of conventional plastics.

Regarding future experiments, our team came to think seriously about our algae cultivation methodology. During the cultivation period, even as our team was strenuously raising these algae on a six-week cycle, data could be collected at a substantial and accurate rate if we extended it to three or four months. Changing the time frame in this way could bring more meaningful results and strengthen the statistical significance of this experiment. The establishment of more algae farms around the world undoubtedly contributes to making bioplastic alternatives more feasible and sustainable on a global scale. Algae farming, also known as algae cultivation or aquaculture, involves the controlled growth of algae in specialized facilities, such as ponds, photobioreactors, or open-water systems. These farms are key to the large-scale production of algae biomass, serving as the primary feedstock for algae-derived bioplastics. Expanding these farming operations ensures a steady supply of raw materials, thereby reducing production costs and enhancing the economic competitiveness of bioplastics in comparison to traditional petroleum-based plastics. Moreover, algae cultivation is highly resource-efficient, as many algae species grow rapidly and thrive in diverse environmental conditions, including wastewater and brackish water. This reduces concerns about resource scarcity and land-use conflicts as algae farming doesn't compete with food crops for arable land or freshwater resources. Additionally, the remarkable ability of algae to capture carbon dioxide from the atmosphere and convert it into organic matter through photosynthesis plays a significant role in mitigating climate change, as expanding algae farms would contribute to carbon sequestration efforts. Furthermore, algae farming can be integrated with organic waste streams such as agricultural runoff or industrial wastewater, addressing pollution concerns by treating and recycling waste while simultaneously producing biomass for bioplastics. This approach represents a sustainable and circular resource management strategy. Besides its environmental benefits, the establishment of algae farms also promotes regional economic development, generating employment opportunities and fostering innovation in both rural and urban areas. Finally, as algae-derived bioplastics become more accessible due to increased biomass supply, they are likely to find applications not only in everyday items but also in various industrial sectors, including automotive, construction, and electronics. This expansion of the bioplastics market can further incentivize investment in algae farming, driving progress towards a more environmentally responsible and economically viable future.

The relationship between melting point, plasticity, and biodegradability in water significantly influences the behavior of bioplastics. The melting point, representing the transition from solid to liquid, is intimately connected with plasticity, the material's ability to deform under stress. Lower melting points, often associated with higher plasticity, render bioplastics more malleable and easily moldable. This characteristic gains importance in water environments, where the materials can experience enhanced softening and deformability. This heightened plasticity, in turn, facilitates interactions with water, potentially promoting microbial colonization and accelerating enzymatic breakdown, thereby expediting biodegradation. Water, acting as a medium for microbial activity, becomes a crucial factor in this process. However, the nuanced interplay of these factors relies on the specific composition of the bioplastic, the surrounding environmental conditions, and the presence of microorganisms in the water. In essence, the intertwined characteristics of melting point and plasticity exert a profound influence on the biodegradability of bioplastics within water environments.

Plastics have become a ubiquitous presence in our daily lives, serving a wide range of purposes across various industries. In the aerospace sector, plastics are valued for their ability to reduce weight. The construction industry favors them for their affordability and durability. Additionally, plastics are critical in the medical field, utilized in essential items such as syringes and blood bags (BPF n.d). These materials share the versatile properties of conventional plastics, being easily moldable and applicable in numerous contexts. Exploring different algae species could reveal which ones are most effective at containing liquids while remaining biodegradable in water and environmentally friendly.

Conclusion

Our research focused on exploring the potential of brown and green algae for bioplastic production, with a special emphasis on species-specific characteristics and their biodegradability. Through extensive experimentation and analysis, our study aimed to identify an algae species offering an environmentally conscious alternative to conventional plastics. *Saccharina latissima,* or sugar kelp, a type of brown algae, emerged as a frontrunner, demonstrating superior biodegradability, plasticity, and a lower melting point compared to its counterparts.

We reject the null hypothesis and accept the alternative hypothesis, instead of accepting the alternative. We hypothesized that *Saccharina Latissima* would have the highest biodegradability of plastics, plasticity, and melting point. *Saccharina latissima*, brown algae alternatively known as sugar kelp, which underwent the same process of plasticization as Alaria, showed a greater rate of biodegradability percentage per day and stronger tensile strength. Corn starch expands the cell walls of the algae, and using a plasticizer like glycerol gives the *Saccharina latissima* its plastic-like properties. Our data was significant; biodegradability had a P value of 0.03, tensile strength had a P value of 0.01, and Melting point P value of 0.02. All had a P value lower than 0.05 making the data statistically significant, this can be due to the cornstarch and polysaccharides making the cell walls stronger thus making the plastics stronger.

While cultivating our algae, we did not see many results as to its growth. The growth of the algae was very stagnant, sometimes not showcasing growth, and other times, showing a big burst in the microalgae population. The absorbance and transmittance of the data were tested but proved that there were little to no changes that were significant to showcase the data. When harvesting the algae, there was a very minimal amount that was able to be processed, it was less than a pea size amount of algae, so the method originally was changed to the current to showcase better results. The making of plastic algae underscores the potential of *Saccharina latissima* and other algae species as sustainable sources for bioplastic production. Challenging the current process of making plastics that harm our environment, marks a significant step towards environmental sustainability.

Works Cited

King, C. (2021). Why We Need To Understand the History of Plastic Before We Can Tackle The Problem. *Plaine Products*. https://www.plaineproducts.com/why-we-need-to-understand-the-history-of-plastic-before-we-can-tackle-the-problem/#:~:text=The%20Rise%20of%20Plastic&text=Plastic%20began%20to%20be%20mass,into%20a%20variety%20of%20forms.

Alazaiza, M., Albahnasawi, A., Eyvaz, M., Maskari, T. A., Nassani, D. E., Amr, S. S. A., Abujazar, M. S. S., & Bashir, M. (2023a). Green bioprocessing of Algae-Derived biopolymers. *encyclopedia.pub*. https://encyclopedia.pub/entry/40346

NOAA. What is seaweed? 01/20/23, https://www.eurekaselect.com/article/86286 , accessed on 12/16/23.

Macleod, Catriona. "Can Seaweed Save the World? Well, It Can Certainly Help in Many Ways, Says Researcher." Phys.org, 10 Mar. 2023, https://phys.org/news/2023-03-seaweed-world-ways.html.

Jumaidin, Ridhwan, et al. "Seaweeds as Renewable Sources for Biopolymers and its Composites: A Review." Current Analytical Chemistry, vol. 14, no. 3, 2018, pp. 249-267, https://www.eurekaselect.com/article/86286.

Sustainable Resource and Waste Management, Hamburg University of Technology, and Senen Cinar. "Bioplastic Production From Microalgae: A Review." *International Journal of Environmental Research and Health*, no. PMC7312682, May 2020, www.ncbi.nlm.nih.gov/pmc/articles/PMC7312682.

AlgaeBase :: Listing the world's algae. (n.d.). https://www.algaebase.org/

Barrett, A. (2021, February 1). *ASU researcher uses algae to make biodegradable plastic*. Bioplastics News. https://bioplasticsnews.com/2019/04/15/asu-researcher-uses-algae-to-make-biodegradable-plastic/

Bioplastics from blue-green algae for the climate. (n.d.). TUM School of Engineering and Design. https://www.ed.tum.de/en/ed/news-single-view-start/article/bioplastics-from-blue-green-algae-for-the-climate/#:~:text=Franziska%20 Kratzl%20 uses%20blue-green,and%20addressing%20the%20climate%20crisis

Cho Renee The Truth About Bioplastics. Columbia Climate School - State of the Planet, 13 Dec. 2017, https://news.climate.columbia.edu/2017/12/13/the-truth-about-bioplastics/ Accessed Accessed (2023, December 18)

Guiry, M. D. (2012). HOW MANY SPECIES OF ALGAE ARE THERE? *Journal of Phycology*, *48*(5), 1057–1063. https://doi.org/10.1111/j.1529-8817.2012.01222.x

Hughes, V. a. P. B. M. (n.d.). *How long it takes everyday items to decompose – The Waste Management & Recycling Blog*. https://www.forgerecycling.co.uk/blog/how-long-it-takes-everyday-items-to-decompose/

Kartik, A., Akhil, D., Lakshmi, D. V., Gopinath, K. P., Arun, J., Sivaramakrishnan, R., & Pugazhendhi, A. (2021). A critical review on production of biopolymers from algae biomass and their applications. *Bioresource Technology*, *329*, 124868. https://doi.org/10.1016/j.biortech.2021.124868

Loctier, D. (2023, January 31). Meet the French researchers using microscopic algae to tackle plastic pollution. *Euronews*. https://www.euronews.com/green/2023/01/31/meet-the-french-researchers-using-microscopic-algae-to-tackle-plastic-pollution

Morris, A., & Morris, A. (2022, January 12). Dutch designers convert algae into bioplastic for 3D printing. *Dezeen*. https://www.dezeen.com/2017/12/04/dutch-designers-eric-klarenbeek-maartje-dros-convert-algae-biopolymer-3d-printing-good-design-bad-world/

Mulhern, O. (2022). How many marine animals die from plastic each year? *Earth.Org*. https://earth.org/data_visualization/how-many-marine-animals-does-ocean-plastic-kill/

Plastic Oceans - Future Agenda. (2019, March 18). Future Agenda. https://www.futureagenda.org/foresights/plastic-oceans/

Environmental Business Review *Environmental Benefits Of Biodegradable Plastics." Environmental Business Review,* (2022 November 14) www.environmentalbusinessreview.com/news/environmental-benefits-of-biodegradable-plastics-nwid-86.html. Accessed (2023, December 18)

Ahmed, Shahid, et al. *Recent Advances in Biodegradable Polymers for Sustainable Applications*. Nature News, Nature Publishing Group, 2022, www.nature.com/articles/s41529-022-00277-7. Accessed (2023, December 18)

World Wild Life *Is Biodegradable and Compostable Plastic Good for the Environment? Not Necessarily* World Wildlife Fund,08 April 2022 www.worldwildlife.org/blogs/sustainability-works/posts/is-biodegradable-and-compostable-plastic-good-for-the-environment-not-necessarily. Accessed (2023, December 18)

Plastic pollution. (n.d.). UNEP - UN Environment Programme. https://www.unep.org/plastic-pollution#:~:text=Every%20day%2C%20the%20equivalent%20of,polluting%20lakes%2C%20rivers%20and%20seas

Sreenikethanam, A., & Bajhaiya, A. K. (2022). Algae Based Bio-Plastics: Future of Green Economy. In *IntechOpen eBooks*. https://doi.org/10.5772/intechopen.100981

The Editors of Encyclopaedia Britannica. (2023, September 8). *Polyethylene (PE) | Properties, Structures, Uses, & Facts*. Encyclopedia Britannica. https://www.britannica.com/science/polyethylene

The problem of marine plastic pollution. (n.d.). Clean Water Action.

What is High Density Polyethylene (HDPE)? | Acme Plastics. (n.d.). https://www.acmeplastics.com/what-is-hdpe

Posen, I. D., Jaramillo, P., Griffin, W. M., Matthews, H. S. *Greenhouse Gas Mitigation for U.S. Plastics Production: Energy First, Feedstocks Later.* Environmental Research Letters, vol. 12, no. 3, 2017, p. 034024, 16 March 2017 https://iopscience.iop.org/article/10.1088/1748-9326/aa60a7 (2023, December 18)

Wang N.S. (n.d.). *Measurements of cell biomass concentration*. https://user.eng.umd.edu/~nsw/ench485/lab9c.htm

Frank, D. S., & Matzger, A. J. (2019). *Effect of polymer hydrophobicity on the stability of amorphous solid dispersions and supersaturated solutions of a hydrophobic pharmaceutical*. Molecular Pharmaceutics, *16*(2), 682–688. https://doi.org/10.1021/acs.molpharmaceut.8b00972

Jilong Wang a, Yan Liu a, Xintian Zhang a, Syed Ehsanur Rahman c, Siheng Su b, Junhua Wei c, Fuda Ning d, Zhonglue Hu e, Raul Martínez-Zaguilán f, Souad R. Sennoune f, Weilong Cong g, Gordon Christopher c, Kun Zhang a, Jingjing Qiu c *3D printed agar/ calcium alginate hydrogels with high shape fidelity and tailorable mechanical properties* 17 November 2020 https://www.sciencedirect.com/book/9780123969835/natural-and-synthetic-biomedical-polymers Accessed December 18 2023

K. Muylaert , L. Bastiaens , D. Vandamme , L. Gouveia *5 - Harvesting of microalgae: Overview of process options and their strengths and drawbacks* 23 June 2017 https://www.sciencedirect.com/science/article/abs/pii/B9780081010235000054

Plastics Applications, https://www.bpf.co.uk/plastipedia/applications/Default.aspx. Bdf Accessed 20 December 2023.

Nandiyanto, Asep Bayu Dani. 4 March 2020 *"MECHANICAL AND BIODEGRADATION PROPERTIES OF CORNSTARCH-BASED BIOPLASTIC MATERIAL* IPME RAS, 2020, www.ipme.ru/e-journals/MPM/no_34420/MPM344_09_nandiyanto.pdf. 20 December 2023