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A Comparative Study on Green Microalgae (*Chlorella sp.*) And Blue-Green Microalgae (*Spirulina sp.*) Properties as An Alternative for Bioplastic

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Abstract— The escalating environmental issues caused by the widespread use of conventional plastics have necessitated the exploration of sustainable alternatives. Algae-based bioplastics are gaining attention due to their potential to contribute to sustainable living due to their biodegradability and lower environmental impact. Therefore, this study investigates the properties of bioplastics derived from algae; Chlorella sp. and Spirulina sp. compared to the conventional plastic. This study compared algae-based plastic and conventional plastic based on various characteristics crucial for plastic applications, including moisture content, tensile strength (encompassing breaking strength and elongation), thickness, and water solubility. The findings reveal that conventional plastics exhibit the highest moisture content at 71.06 ± 2.23%, followed by Chlorella and Spirulina. It is worth noting that excess moisture content potentially leads to material degradation and a decrease in mechanical properties. On the other hand, Spirulina bioplastics demonstrate outstanding mechanical properties, with a remarkable tensile strength (3.837 ± 0.95N), elongation (102.50 ± 13.77 mm), and thickness (0.14 ± 0.449 mm), indicating better durability and resilience over both Chlorella bioplastics and conventional plastics. Moreover, Spirulina bioplastics show significantly greater solubility in hot (0.77 ± 0.10 mm^3s^{-1}) and tap water (0.82 ± 0.13 mm^3s^{-1}), outperforming Chlorella bioplastics and vastly surpassing conventional plastics exhibiting minimal solubility, indicating Spirulina has better environmental compatibility. This study provides preliminary findings that conclusively highlight the better performance of Spirulina-based

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bioplastics in several critical aspects, advocating their potential as a sustainable and environmentally friendly alternative to conventional plastics, aligning with sustainable living goals. Further comprehensive research is necessary to fully understand the potential of algae-based bioplastics as an alternative to conventional plastics.

Index Terms—*Algae, bioplastic, Chlorella, Spirulina*

I. INTRODUCTION

The world is increasingly pursuing innovative solutions that align with sustainability goals to address the critical issue of plastic waste pollution. Conventional plastics, primarily sourced from petroleum, have become a significant environmental concern due to their non-degradable nature, leading to widespread land, air, and water pollution [1]. The accumulation of these plastics not only contaminates ecosystems but also poses severe risks to marine life and human health, owing to the release of toxic chemicals when incinerated [2]

In response to this pressing global issue, research and development efforts have turned towards exploring sustainable alternatives to conventional plastics. One such promising avenue is the utilization of microalgae as a source for bioplastic production. While bioplastics can be sourced from various origins, including plants, animals, and microbes, each source has limitations, such as scarce biomass availability and cultivation challenges [3]. Microalgae, however, present a viable alternative for bioplastic production due to their abundant biomass, adaptability to diverse environments, and the possibility of cultivation in natural settings [4].

According to Dianursanti et al. (2019) [5], microalgae have the potential to act as fillers in the production of polymer matrix composites, which has garnered considerable attention. Incorporating microalgae as fillers would effectively reduce the cost and carbon footprint associated with polymer production. Therefore, this study explores the potential of microalgae-derived bioplastics as a sustainable and environmentally friendly alternative to conventional plastics.

Green microalgae, belonging to the Chlorophyta group, are autotrophic organisms that vary from single-celled to multi-celled forms and are commonly found in freshwater and marine environments [6]. These algae are abundant, widely distributed, and have a distinctive green colour due to chlorophyll b. Chlorophyta, being unicellular eukaryotes, have a unique cellular structure featuring a single chloroplast encased by two membranes, walls made of cellulose, and starch as their primary storage substance. They also contain several photosynthetic pigments, including carotene, xanthophyll, and chlorophylls a and b [7]. Green microalgae are found in water, inhabit soils and tree bark, and form symbiotic relationships with fungi to create lichens. One example of the green microalgae is *Chlorella sp.*

Blue-green algae, also known as cyanobacteria, are photosynthetic bacteria with photosynthetic machinery, utilizing the sun's energy to produce their food [8]. The moniker blue-green algae came about because of the colour, which was a by-product of the photosynthetic activity of the microbes. Notably, cyanobacteria thrive in various environments, including damp soil, freshwater, and marine settings, playing a pivotal role in nitrogen fixation [9]. One of the examples of blue-green algae is *Spirulina sp.*

Chlorophytes and cyanobacteria are great candidates for bioplastics because they can produce significant amounts of polyhydroxyalkanoates (PHA) [10], which are highly recommended for bioplastics production due to their ability to biodegrade through enzymatic activity [11]. Microalgae produce PHA as a natural carbon and energy storage molecule in response to nutritional deprivation in the presence of a carbon source [12]. In addition, microalgae biomass can be used directly for bioplastic production due to their small cell sizes or indirectly through the extraction of polyhydroxybutyrate (PHB) [13].

Spirulina sp. and *Chlorella sp.* are the most common microalgae utilized for bioplastic manufacture because of their tiny cell size [11]. This enables the conversion to bioplastics without prior treatment which minimizes waste production and makes scalable production more cost-effective. In this study, the microalgae that will be used are *Chlorella sp.* (green microalgae) and *Spirulina sp.* (blue-green microalgae).

The main objective of this study is to compare microalgae's ability to be used as a bioplastic material with conventional plastic. The study aims to compare the properties of algae-based bioplastic and conventional

plastic comprehensively. By achieving these objectives, this study seeks to provide insights into the potential of algae as a viable source for bioplastic production and its environmental implications.
The scope of this study will encompass the comparison of the bioplastic potential of algae and conventional plastic, focusing on their respective properties. While this research endeavors to provide valuable insights into the potential of microalgae as a viable source for bioplastic production, it is essential to acknowledge its limitations. This is just a preliminary study, and the availability of resources for bioplastic production and the scope of the study will not extend to address large-scale production and commercialization aspects of algae-based bioplastics. These limitations will be considered throughout this study to ensure a comprehensive and accurate assessment of the potential of microalgae-derived bioplastics.

II. METHODOLOGY

Preparation of Bioplastics

In this study, pure *Chlorella* and *Spirulina* algae in powdered form were utilized for bioplastic production, significantly reducing the logistical and financial challenges of using fresh algae. This approach not only simplifies the production process by eliminating the need to cultivate fresh specimens but also ensures consistency in the quality and concentration of the algae, which is crucial for the bioplastic's properties. Powdered algae are more cost-effective and scalable, enhancing the economic viability of the production process.
For comparison, both algal-based bioplastic and conventional petrol-based plastic were prepared. The preparation method was adapted from the study by Azmin et al. (2022) [14] with some adjustment. Table 1 shows the ingredients for both plastics.

Table 1. Bioplastic and conventional petrol-based plastic ingredients

Bioplastics	Conventional petrol-based plastic
2.25g sorbitol	4.5g sorbitol
2.25g gelatin	2.25g gelatin
75ml 2% glycerol solution	75ml 2% glycerol solution
2.25g algae samples	

Sorbitol, a widely accessible, non-toxic, and inexpensive plasticizer, is added to enhance the elasticity and water vapor permeability of the material [15]. Gelatine is included for its stabilizing, emulsifying, and thickening properties, as well as its ability to bind water, consequently improving water solubility by attracting and binding water molecules [16]. Additionally, glycerol is used as a plasticizer to increase flexibility [5].
The ingredients for each algal biomass bioplastic and conventional petrol-based plastic were mixed well and heated to 95°C. The mixture was then stirred, and once it reached 95°C, the heat was removed while continuing to stir. After that, the mixture was poured into a dried pan and spread to dry. The dried bioplastic was then separated from the pan for further analysis. The prepared bioplastic film was then analyzed for its properties and compared with conventional plastic.
The tests utilized in this study were slightly modified from a study conducted by Hanry and Surugau (2020) [17]. Fig 1 shows the diagram of the tests conducted.

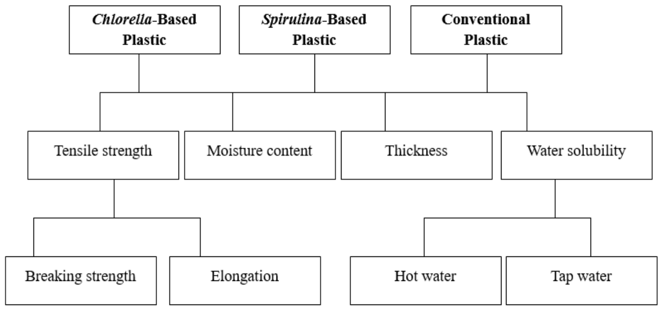

Fig 1: Diagram of the bioplastics properties tests conducted

A. Thickness

The thickness of the bioplastic was measured using a thickness gauge. This instrument facilitates the measurement by securely holding the bioplastic material between the stylus and the anvil. The gauge applies a consistent pressure by positioning the bioplastic workpiece between these components, ensuring an accurate measurement. The thickness value is then directly read from the device.

B. Tensile strength

The tensile test conducted included breaking strength and elongation. Breaking strength determines the maximum load at which the sample can maintain its shape before breaking, while elongation is the maximum strain it can endure. The tensile strength was tested using Testometric Machine M350-10CT. The strips were hooked on a spring balance and were pulled until it tore apart.

C. Moisture Content

The weight loss of films was measured to determine the moisture content of each bioplastic. The bioplastic samples were cut into square pieces of 2.0cm^2, accurately weighed, and the initial weight was recorded. These samples were then heated in an oven at 105°C for 24 hours, and the final weight was recorded. Each film treatment was replicated five times to ensure accuracy. The moisture content was calculated using the formula below:

$$\text{Moisture Content (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

D. Water solubility

The solubility test aimed to determine the rate at which a biofilm dissolves. The tests were conducted using 125 mL of two different solvents, tap water and water heated to 90°C, to explore the effects of temperature on dissolution. Each solution was continuously stirred at 200 rpm to ensure uniformity in the testing process. The time taken for the samples to dissolve was recorded. The solubility rate was calculated using the formula:

Solubility = $\underline{\text{Sample sizes (mm}^3\text{) x Thickness (mm)}}$ time (s)

III. RESULT AND DISCUSSION

The findings of this study reveal that conventional plastics exhibit the highest moisture content, measuring at 71.06 ± 2.23%, closely succeeded by *Chlorella* bioplastic with a moisture content of 70.82 ± 3.87%, and *Spirulina* bioplastic presenting the lowest moisture content at 65.17 ± 2.11%. However, it is noteworthy that there was no significant difference in moisture content between *Spirulina* and *Chlorella* bioplastics and conventional plastics. Fig 2 graphically illustrates these differences in moisture content among the plastics.

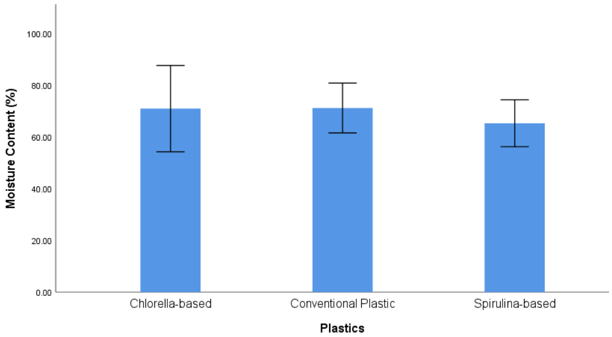

Fig 2: The mean of moisture content of the different plastics

As noted by Listyarini et al. (2020) [18], moisture content in bioplastics is a crucial factor influencing their water absorption and flexibility. *Spirulina* and *Chlorella* bioplastics are highlighted for their lower tendency to absorb water, contributing to a more stable and predictable performance under various environmental conditions. Generally, lower moisture content leads to better stability and preservation of mechanical properties like elasticity and firmness. Therefore, *Spirulina* bioplastics, which have minimal moisture content, are more likely to offer enhanced durability and reliability for various applications.

The durability of bioplastic packaging material is crucial for withstanding load-bearing pressure. This durability can be assessed by examining the physical and tensile properties of the bioplastic, including its thickness and tensile strength [19].

Fig 3 shows the mean thickness of the plastics. *Spirulin*a-based plastic demonstrates a significantly higher mean thickness (0.14 ± 0.449 mm) compared to *Chlorella*-based plastic (0.09 ± 0.35 mm) and conventional plastic (0.05 ± 0.24 mm).

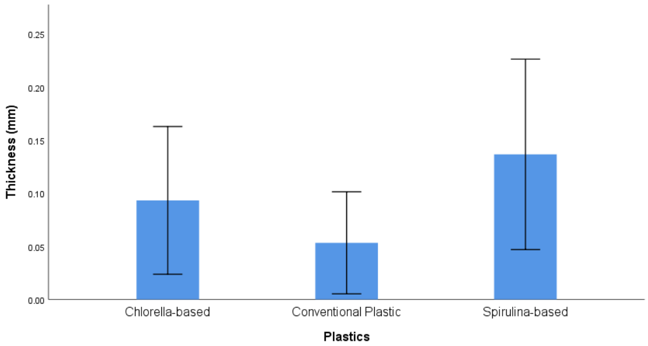

Fig 3: The mean thickness of the plastics

The results indicates that *Spirulina*-based plastic not only surpasses its *Chlorella*-based plastic, in terms of thickness but also significantly exceeds the thickness of conventional plastic materials. The thickness of a material can be crucial for its application, as it impacts the material's strength, durability, and overall performance in various uses.

Fig 4 shows the comparison of breaking strength of conventional plastic, *Chlorella* and *Spirulina*-based plastic. *Spirulina* excels in tensile properties, with the highest breaking strength (3.837 ± 0.95N) surpassing both *Chlorella* (2.793 ± 0.54N) and conventional plastic (1.84 ± 0.62N).

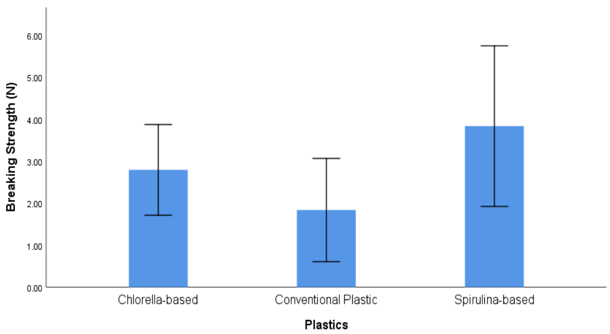

Fig 4: The mean of breaking strength of the different plastics

A breaking strength test is a method of determining the maximum load at which the specimen can maintain its shape before breaking. In this study, *Spirulina*, with a breaking strength of 3.837 ± 0.95N, showcases better strength, far exceeds that of *Chlorella*, which has a breaking strength of and is notably higher than that of conventional plastic. The high breaking strength of *Spirulina* can be attributed to its unique cellular structure and composition, which may provide it with enhanced tensile properties compared to *Chlorella* and plastic.

The elongation properties of different plastics are depicted in Fig 5. As illustrated, *Spirulina*-based bioplastic emerges as the standout materials, boasting an elongation at a break of 102.50 ± 13.77 mm. This figure greatly surpasses the elongation values recorded for *Chlorella*-based bioplastic, which stands at 69.17 ± 28.14 mm, and conventional plastic, which exhibits a lower elongation at a 60.00 ± 16.07 mm break.

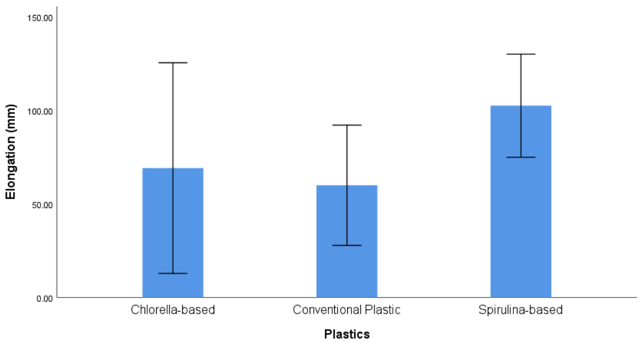

Fig 5: The mean of elongation properties of different plastics

Elongation is the maximum strain a material can endure before breaking. The better elongation performance of *Spirulina* bioplastic shows its enhanced capacity to withstand stretching forces without breaking. The comparison with *Chlorella* and conventional plastics highlights the potential of *Spirulina sp.* as a more adaptable and resilient material. It supports the argument for *Spirulina's* suitability in replacing conventional plastics in specific applications, making it a compelling choice for industries aiming to reduce their ecological footprint without compromising material performance.

Fig 6 shows the solubility of plastic in different water temperature conditions. *Spirulina* bioplastic demonstrates better solubility in hot and tap water, with values of 0.77 ± 0.10 mm^3s^{-1} and 0.82 ± 0.13 mm^3s^{-1}, respectively. This contrasts with *Chlorella* bioplastic, which shows solubility values of 0.70 ± 0.24 mm^3s^{-1} in hot water and lower solubility in tap water (0.39 ± 0.18 mm^3s^{-1}). Conventional plastic, on the other hand, exhibits minimal solubility in both hot (0.36 ± 0.90 mm^3s^{-1}) and tap water (0.10 ± 0.51 mm^3s^{-1}).

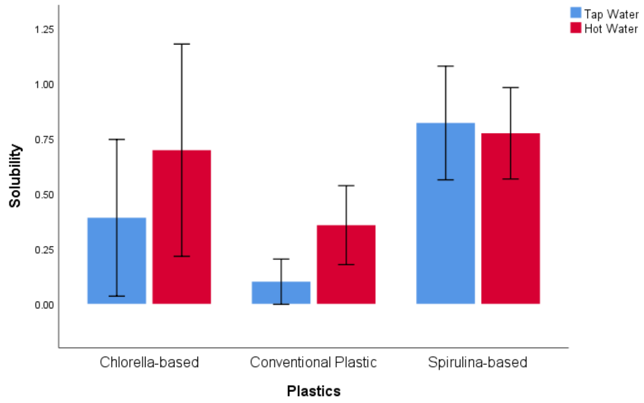

Figure 6: Mean solubility of plastic in different water temperature conditions.

The high water solubility of these films allows them to biodegrade in water systems like oceans, lakes, and drainage [20]. Bioplastics that dissolve more efficiently can be broken down more rapidly, reducing their persistence in the environment and minimizing pollution. *Spirulina* exhibits the highest solubility and has the most potential to be a sustainable and environmentally friendly alternative to conventional plastics.

CONCLUSION

In conclusion, the comparative study of green microalgae (*Chlorella sp.*) and blue-green microalgae (*Spirulina sp.*) for bioplastic production has provided valuable insights, with *Spirulina*-based bioplastics demonstrating better mechanical properties. The importance of this work lies in its potential to revolutionize the plastic industry by offering a renewable and biodegradable alternative. The exceptional properties of *Spirulina*-based bioplastics suggest a wide range of applications, including packaging materials, disposable cutlery, and agricultural mulches. Additionally, the study paves the way for further research into optimizing production processes and exploring the potential of other microalgae species for bioplastic development. This work underscores the viability of microalgae-derived bioplastics, particularly Spirulina, in contributing to sustainable living and addressing the environmental challenges posed by conventional plastics. It's important to note, however, that this is a preliminary study, and further research is needed to fully understand the potential and limitations of microalgae-derived bioplastics for various applications.

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