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Exploring the Characterizations of Gelatin-Agar Bioplastics: An Eco-Friendly Alternative for Conventional Plastics

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ABSTRACT

In order to effectively combat the pervasive and worsening global crisis of plastic pollution, the integration of innovative and regenerable materials—characterized by their inherent biodegradability and compostability—as a sustainable substitute for petroleum-based plastics requires an exemplary shift. In this regard, bioplastics can be the best solution to mitigate the adverse impacts of conventional plastics. This research paper explores the potential of gelatin-agar bioplastic as a substitute for petroleum-based plastics. Agar is a polysaccharide which is used as a gelling agent, imparting mechanical strength to the bioplastic while gelatin is a protein which provides flexibility and structural integrity. Gelatin, agar, water, and plasticizer (glycerol) are combined with controlled heating, mixing, and solidification steps to create gelatin-agar bioplastic. After developing the bioplastic film, its biodegradability was tested, and it showed promising results. Almost 72% of a bioplastic sample was degrade by natural degradation process within 18 days observation. The bioplastic is transparent. The thickness of the bioplastic sample was in the range of 20 mm to 60 mm. The highest ultimate stress was .32MPa in tensile strength test experiment. The bioplastic films showed good water resistance behavior. The findings of the current study point to a wide variety of potential future uses and commercial applications.

Keywords: Bioplastic, Biodegradability, Plasticizer

1. Introduction

Plastic is an indispensable part of our day-to-day lives, used in a wide range of sectors, ranging from home to commercial purposes, due to its versatility and wide range of applications. The worldwide plastic manufacturing rate, which reached 360 million metric tons in 2018 and included 50% of SUP goods, has been influenced by rising demand for SUPs. According to estimates, just 9% of all plastic ever produced has been recycled, with the remaining 82% ending up in landfills, seas, and soil [1,2]. Decomposition of plastic can take anywhere between 10 and 1000 years and the decomposition depend on the material's makeup and environmental factors like sunshine exposure [3,4]

Since the pollution spreads from rivers to seas or oceans, plastics pose a serious threat to marine life. plastic debris is occasionally consumed by sea life. then toxins from the fish that people unintentionally eat enter their bloodstream. Any microplastic smaller than 5 mm in size is now considered to be one of the biggest threats to the marine ecosystem worldwide. They are so tiny that they may be readily thrown by themselves, and many aquatic creatures eat them because they resemble food. Then it begins to build up inside the stomach. Long-term consumption of microplastics may alter our chromosomes, which might result in infertility, obesity, and even cancer. The enormous amount of plastic trash in the oceans is endangering coral reefs and the wildlife that depends on them. According to estimates, the coral reefs in the Asia-Pacific are severely harmed as a result of rising plastic pollution, and by 2025, the damage will rise by 40%. The invasion of plastic must be stopped, as must the harmful consequences it has on the ecology and eventually the climate. Chemical approaches for plastic deterioration have been used for decades, but for a variety of reasons, the findings are not compelling. Chemical degradation is harmful to the environment since it leaves behind poisonous fumes and byproducts while only partially degrading polymers. As an alternative, recycling is utilized to combat plastic pollution by limiting manufacturing rates and reducing the amount of plastic trash produced. Treatment of plastic trash using pyrolysis and catalytic degradation techniques yields fuels, energy, and certain crucial industrial chemicals, however these processes are constrained and have significant efficiency shortcomings [5-8].

In search for sustainable solutions, gelatin-agar bioplastics can be a strong replacement for conventional plastics. Gelatin-agar bioplastics have a decreased environmental effect throughout their lifespan due to their natural source and biodegradable nature, which reduces concerns about the gathering of plastic waste. These bioplastics also have mechanical qualities that are equivalent to those of conventional plastics, making it possible to use them for a wide range of applications, including biomedical equipment and food packaging. These eco-friendly materials have the potential to revolutionize industries dependent on conventional plastics as scientific research and advancements in the area continue to grow, launching at a

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time when environmental responsibility and practicality coexist.

Gelatin, a mostly pure protein dietary component, is produced from collagen, which is the most prevalent and essential protein in the animal kingdom. The tertiary, secondary, and, to some extent, primary structures of native collagens are destroyed during the preparation of gelatin, specifically through the partial hydrolysis of collagen extracted from animal skin and bones, fish, and white connective tissue. Gelatin is a high-molecular-weight polypeptide and hydrocolloid. It has gained popularity among the general population and is used in a variety of culinary items due to its ability to thicken and gel [9-11].

Agarose and agaropectin combine to form the polysaccharide hydrocolloid known as agar in nature. Both the food and non-food businesses utilize it extensively, as do biotechnologies like tissue culture. Its extensive use is a result of its thickening and gelling properties. Various agar extraction techniques, depending on the source material and necessary grade, have been documented. The yield and quality of the agar are influenced by the temperature, alkali content, and extraction time. Studies are still required to optimize the extraction conditions in order to raise and improve the yield and quality of the agar, even if the general characteristics of the extraction process are understood [12-14].

Studies on the biodegradability of bioplastics have been conducted in a variety of environments, including compost, soil, and marine habitats. The biodegradation of bioplastics is aided by soil and compost, which are abundant in microorganisms. Environmental conditions are crucial in this process. Composting uses microbial action to turn organic waste into CO_2 and humus, although recycling and composting are the best options for recovering plastic. On the other hand, the slow decomposition of plastics causes problems with plastic accumulation in marine ecosystems, which can harm marine life and cause pollution. Nevertheless, even in aquatic systems, bioplastics—biodegradable polymers—offer a more sustainable alternative for ecosystems. [15,16].

The purposes of this study are to develop a more sustainable and environmentally friendly bioplastic material, explore the use of gelatin-agar bioplastics in different applications, and investigate the tensile strength, water resistance, and degrading characteristics of the bioplastic material. This study is unique in that it focuses on the creation of gelatin-agar bioplastics, which combine the flexibility of gelatin with the gelling qualities of agar to produce a flexible substance that overcomes the drawbacks of current bioplastics. This work examines the synergistic effects of combining these two natural polymers, which results in improved mechanical properties and biodegradability, in contrast to many studies that mainly examine single-component bioplastics. Additionally, the thorough assessment of the bioplastics' performance in terms of tensile strength, water resistance, and biodegradability in diverse environments offers insightful information that can guide future developments in sustainable materials applications.

The results of this research study will add to the developing body of knowledge on these bioplastics and give researchers, producers, and policymakers useful information in their search for sustainable materials. A number of experimental evaluations, including biodegradation research, mechanical testing, and water resistance tests, will be carried out in order to accomplish these goals. The significance of the findings will be examined in respect to the possibility of gelatin-agar bioplastics as an environmentally benign replacement for traditional plastics. This study intends to support current efforts to identify long-term solutions to the plastic pollution challenge by offering information on the gelatin-agar bioplastics' characteristics. The results of this study will help advance the development and use of environmentally conscious substances that can lessen the negative effects that traditional plastics have on the environment by giving researchers, regulators, and industry stakeholders useful information.

2. Methodology:

Chemical Compound Selection:

i. Agar: Agar was selected as the main component for this experiment. It was selected because it has the capacity to create a gel-like structure when mixed with water. It makes the bioplastic versatile, allowing it to be used in various applications. Agar was purchased from the local market in Khulna.
ii. Gelatin: Gelatin was selected as a binding material and hardening agent for this experiment. One of the main reasons for selecting gelatin is that it gives the bioplastic transparency. Gelatin was also purchased from the local food market in Khulna.
iii. Glycerin: In the experiment glycerin was used as a plasticizing agent which makes the bioplastic flexible and increase the tensile strength. It was purchased form a chemical shop in Khulna named City Scientific Khulna.

Apparatus Required:

i. Digital weighing scale
ii. Spatula
iii. Heater
iv. Beaker (1000 mL)
v. Spoon
vi. Tray
vii. Thermometer
viii. Measuring cylinder

Procedure for Synthesis of the Bioplastic:

i. At first, 500 mL of water was measured in measuring cylinder. Then the water was poured into the beaker, and it was placed on the heater. Then the water was heated for 5 minutes. A thermometer was placed in the beaker for observing the temperature.
ii. Agar and gelatin were measured in the digital weighing scale. 8.3 g Agar and 2.1 g Gelatin were added to the water and mixed the solution properly. The solution was stirred continuously to dissolve agar and gelatin properly. There would be residue on the beaker’s bottom if it was not stirred.
iii. After the solution became a little sticky, 15mL of glycerin was added and stirred the solution continuously.
iv. The solution was heated for 20-25 minutes. The highest recorded temperature was 97.2°C in the thermometer.

v. When the solution was concentrated and sticky enough, then the heating was stopped. Then the solution was poured into the tray.

vi. The tray was kept in light and air for 72 hours. When the film was completely dried, it was lifted from the tray.

vii. The above procedure was followed to make another sample.

Table 1: Composition of different sample.

Sample	Agar (g)	Gelatin (g)	Glycerin (mL)	Water (mL)
1	12.77	2.55	15	500
2	8.31	2.08	15	500

Here,
For sample 1, Agar: Gelatin = 5:1
For sample 2, Agar: Gelatin = 4:1

Analysis of film characteristics

Biodegradability, tensile strength, thickness, and water resistance of the bioplastic films were tested.

Biodegradability Test

At first the desired shape of the film was prepared. A required amount of soil was collected from the agricultural field and a container was filled with the prepared soil. Then the initial moisture content of the soil was measured and it was 26%. Initial weight of the bioplastic was measured. Then the bioplastic was buried in the prepared soil. The product's weight was observed for the interval of 3 days. The weight loss of the polymers was used to compute the degradation ratio.

Tensile strength Measurement:

Tensile test was performed at 34°C and relative humidity was 65±2%. A part of the film was cut off. Then the gauge length, width, and thickness of sample were measured by the slide caliper. The test was performed in Tinius Olsen tensile tester, The model was 25 ST. The samples were set to the machine and stress, strain, force, and position was recorded. Then stress vs strain, and force vs position graphs were plotted.

Thickness Test:

A slide caliper was used to measure the film's thickness.

Water Resistance Measurement:

By determining the proportion of weight gain caused by swelling, the water resistance test was used to evaluate the bioplastic's resistance to water. To do this, a swelling test was performed, which gauges how much the bioplastic film swells in the presence of water. The first step in the process was to weigh the bioplastic sample. After being completely submerged in water, the sample was left there for a whole day. The sample's ultimate weight was determined after this time. The weight variations of the bioplastic were monitored by repeating the same procedure five days later. The proportion of swelling and the bioplastic's water resistance may be ascertained by comparing the initial and final weights, which would offer important information about the material's water absorption and long-term durability.

Water Absorption (%) = $\frac{(X-Xo)}{Xo} \times 100\%$

Here,
Xo = initial sample weight (g)
X= weight of the sample after immersion

3. Result and Discussion:

Bioplastic Film:

After making the bioplastic film, the film looks like this

Figure 1: (a) Bioplastic film sample 1

Figure 1: (b) Bioplastic film sample 2

Note: For sample 1, Agar: Gelatin = 5:1
For sample 2, Agar: Gelatin = 4:1

Gelatin and agar were used to successfully create the bioplastic films in two different ratios: Sample 1 (Agar: Gelatin = 5:1) and Sample 2 (Agar: Gelatin = 4:1). According to Figure 1's depiction of the films' physical characteristics, both samples are transparent and have a smooth texture. The films' transparency implies that they can be applied to materials like packaging where visibility is crucial.

Biodegradability test:

Table 2: Results of Biodegradability test

Time (Day)	Weight (g)	weight loss (g)	weight Loss (%)
0	3.16	0	0.00
3	2.71	0.45	16.61
6	2.28	0.43	18.86
9	1.87	0.41	21.93
12	1.52	0.35	23.03
15	1.19	0.33	27.73
18	0.91	0.28	30.77

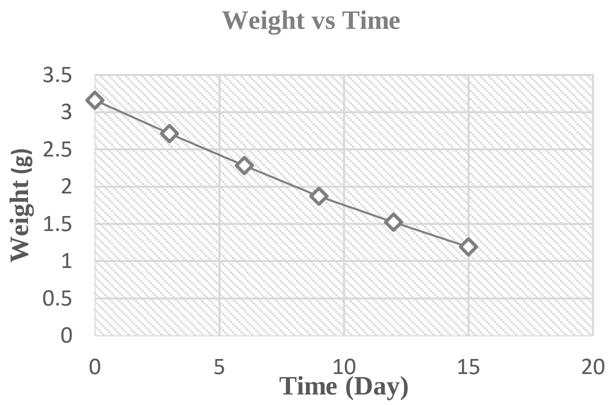

Figure 2: Weight vs time graph (Biodegradability test)

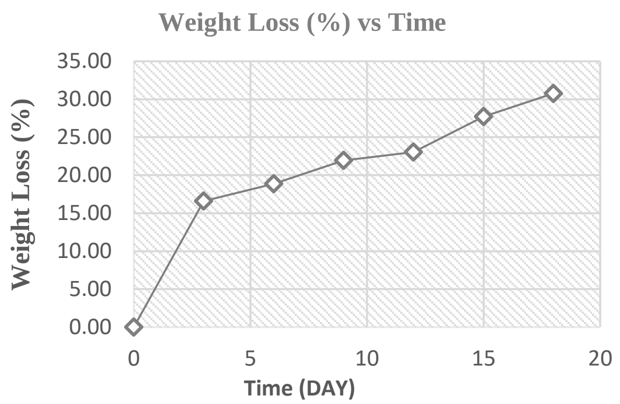

Figure 3: Weight Loss % vs Time graph (Biodegradability test) Tensile Strength.

Over the course of 18 days, the biodegradability of the bioplastic films was evaluated; Table 2 provides a summary of the findings. By day 18, the Sample's initial weight of 3.16 g had dropped to 0.91 g, representing a 30.77% overall weight loss. Effective degradation is indicated by the weight loss seen in both samples, which is essential for determining their environmental impact. The bioplastics are degrading over time, as shown by the weight vs. time graph (Figure 2), which shows a steady drop in weight for both samples. The materials must degrade in order to be deemed environmentally friendly, and the slow weight loss indicates that microbial activity is probably assisting in this process.

Mechanical Properties:

Table 3: Data for the mechanical properties of the bioplastics

Properties	**Sample 1**	**Sample 2**
Width (mm)	29.50	29.10
Thickness(mm)	0.41	0.58
Area (mm^2)	12.10	16.90
Modulus (MPa)	4.53	3.24
Ultimate Force (N)	3.81	4.52
Ultimate Stress (MPa)	0.32	0.27
Ultimate Strain (%)	8.47	7.64
Break Strain (%)	10.30	9.04
TE auto (%)	10.30	9.04

The results of tensile strength tests used to assess the bioplastics' mechanical qualities are shown in Table 3. Sample 2 had a lower modulus of 3.24 MPa than Sample 1, which showed a modulus of 4.53 MPa. This discrepancy suggests that Sample 1 is more rigid than Sample 2, which could be attributable to the film's higher agar content. Sample 1 needed 3.81 N of ultimate force to break, whereas Sample 2 needed 4.52 N. This implies that Sample 2 has a higher degree of flexibility because it can sustain a greater force before failing, even though it is less stiff. This finding is corroborated by the ultimate stress values, which show that Sample 1's ultimate stress was 0.32 MPa while Sample 2's was 0.27 MPa. This suggests that Sample 2 may be better suited for applications needing flexibility due to its higher ultimate force, whereas Sample 1 can withstand more stress before deforming. Additionally, the ultimate strain values reveal information about how the materials behave under stress. In Sample 2, the ultimate strain was 7.64% and the break strain was 9.04%, whereas in Sample 1, the ultimate strain was 8.47% and the break strain was 10.30%. According to these findings, Sample 1 can stretch farther before breaking, which is advantageous for uses requiring a certain amount of elongation.

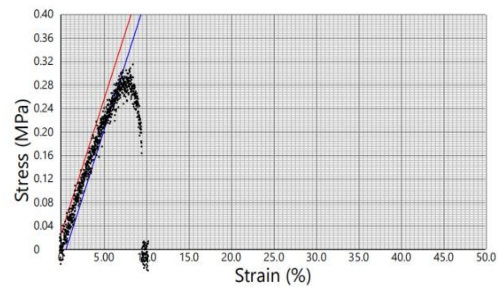

Figure 4: Stress vs Strain graph for sample 1 (tensile strength test)

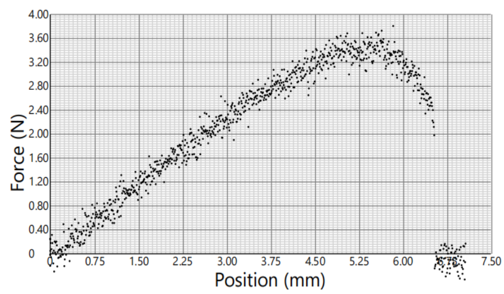

Figure 5: Force vs Position graph for sample 1 (tensile strength test)

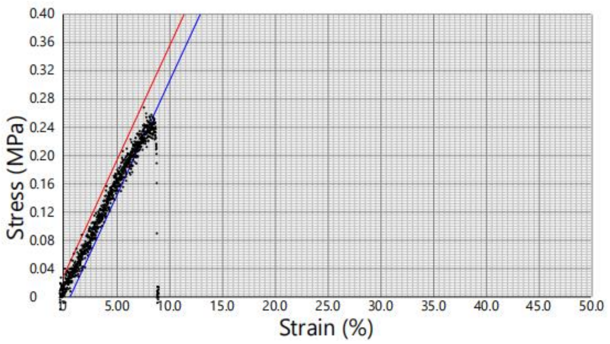

Figure 6: Stress vs Strain graph for sample 2 (tensile strength test)

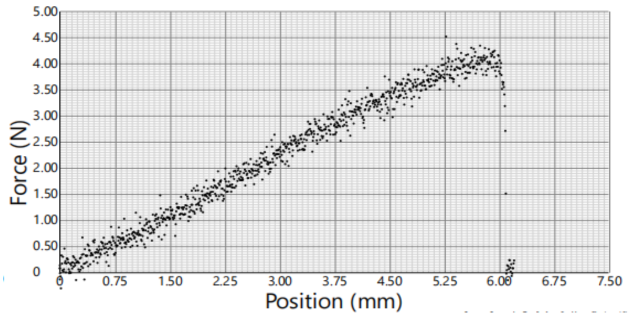

Figure 7: Force vs Position graph for sample 2 (tensile strength test)

The mechanical behavior of the samples is shown graphically in the stress vs. strain graphs (Figures 4 and 6). Sample 2's curve indicates more flexibility, whereas Sample 1's steeper slope indicates higher stiffness. The relationship between the applied force and the samples' positions during the tensile test is further demonstrated by the force vs. position graphs (Figures 5 and 7). A consistent reaction to applied stress is demonstrated by Sample 1, which displays a linear increase in force with position until failure. The force increases in Sample 2's graph, on the other hand, might be more gradual, indicating its capacity to absorb more energy before breaking. The trade-off between stiffness and flexibility is highlighted in this comparison of mechanical properties, enabling customized applications depending on particular needs.

Water Resistance:

Table 4: Results for water resistance test

Time(day)	Weight (g)		Water Absorption (%)	
	Sample 1	Sample 2	Sample 1	Sample 2
0	0.57	0.95		
1	0.87	1.33	52.63	40.00
2	0.95	1.38	9.20	3.76
3	0.96	1.40	1.05	1.45
4	0.97	1.41	0.52	0.71
5	0.97	1.42	0.52	0.71

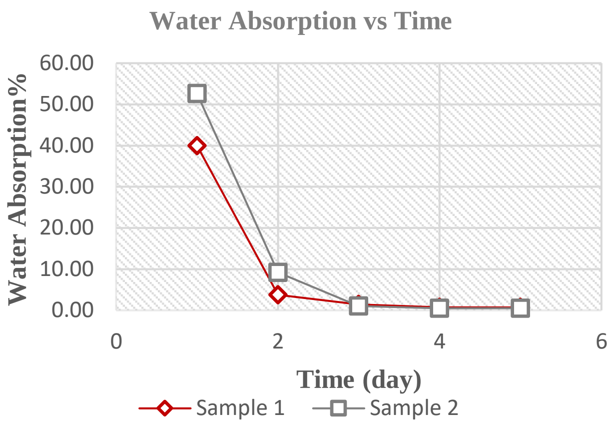

Figure 8: Water Absorption vs Time graph (water resistance test)

A five-day water absorption test was used to assess the bioplastics' water resistance; the results are shown in Table 4. On the first day, Sample 1's initial water absorption was 52.63%, whereas Sample 2's was lower at 40.00%. This suggests that Sample 1 is more prone to absorbing water, which could compromise its suitability for use in humid settings. Nevertheless, during the course of the five days, both samples showed a decline in their rates of water absorption. Sample 2's water absorption was 0.71% by day 5, whereas Sample 1's absorption dropped to 0.52%. This pattern implies that although the bioplastics absorb water at first, they eventually reach a saturation point, meaning that they can withstand moisture exposure without losing their structural integrity.

4. Conclusion:

The findings suggest that gelatin-agar bioplastics are promising substitutes for traditional plastics due to their advantageous mechanical, water-resistant, and biodegradable qualities. Agar and gelatin work together to improve the films' physical qualities while also promoting their environmental sustainability. The results indicate that these bioplastics can help reduce plastic pollution, and more research should concentrate on improving formulations and looking into new uses.

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