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Review Article

Agar-Based Biodegradable Plastic: A Sustainable Alternative to Petroleum- Derived plastics

Akash Jyoti Boruah[1*]

[1]Dept. of Botany, Jorhat Kendriya Mahavidyalaya, Kenduguri, Jorhat- 785010, Assam, India

*Corresponding Author: Tel.: 09365249041

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Abstract— Plastic pollution is a primary environmental issue, leading to the seeking for sustainability. This research inquires the possibilities of bioplastics, including agar-based bioplastic, where ethanol is utilizing as a plasticizer, to develop an eco- friendly and flexible, degradable substance. Agar, a natural polysaccharide extracted from red algae, promotes as a remarkable biodegradable polymer. To tackle this issue, ethanol serves as a plasticizer to enhance flexibility and mechanical strength by altering the internal configuration of the agar matrix. The bioplastic was formed by dissolving agar in warm water, contained ethanol, and allowing the mixture to cool and form into thin sheets. The findings indicated that ethanol increased the material's elasticity, while keeping its environmentally friendly characteristics. It also offered minimal resistance to water, a frequent drawback in bioplastics. Additionally, decomposition tests verified that the bioplastic degrades naturally, positioning it as a promising substitute for synthetic plastics. This research emphasizes the promise of agar bioplastic with ethanol as a plasticizer for uses such as packaging and single-use products. Later studies may enhance the pattern and explore the methods for large-scale production. By assuming biodegradable materials, we can minimize plastic waste and protecting the environment as well.

Keywords— Agar based bioplastic, plasticizer, eco-friendly, green packaging, polymer, environment

1. Introduction

1.1 Background and Significance

Plastics have become an important part of our modern society due to their varied applications, stability, and affordability. These are used widely in Household packaging, medical equipment, construction, and other industries. However, the over dependence on petroleum-based plastics has led to a critical environmental crisis. These synthetic plastics are non-biodegradable, taking hundreds of years to decompose, and their aggregation has resulted in significant pollution across land and marine ecosystems. Now, the harmful impacts of increasing plastic waste on biodiversity, human health, and the overall environment have driven researchers toward sustainable alternatives.

Among the many solutions being explored, these biodegradable plastics derived from any natural sources have obtained attention. Because, these bioplastics offer an eco-friendly alternative, as they decompose naturally and without releasing toxic byproducts. One important biopolymer in this field is agar, which is a polysaccharide extracted from red algae (Rhodophyta). Agar has a great gel-forming properties and is widely used in food, pharmaceuticals, and research.

Agar-based bioplastics have been derived as a sustainable alternative to petroleum- based plastics, due to they are non-toxic to nature and have ability to degrade in the environment within a short period. However, pure agar films tend to be rigid and fragile. This limitation has alerted the need for modifications of agar-based bioplastics to improve the mechanical properties.

One common way to improving the flexibility of bioplastics is the use of plasticizers. These are the substances added to polymers to increase their flexibility, by reducing their intermolecular forces. Traditional plasticizers, such as phthalates, are often toxic and pose health risks. Therefore, in the production of bioplastics, selecting an eco-friendly, safe plasticizer is important. Ethanol, which is a widely available and biodegradable solvent, has shown this potential. Ethanol can modify the hydrogen bonding interactions in agar, increasing the mobility of polymer chains and making the bioplastic more flexible.

The significance of developing an agar-based bioplastic with ethanol prolongs beyond environmental concerns. Plastic pollution is not only an ecological issue but also an economic, public health challenge. The plastic waste leads to soil and water contamination, imbalance ecosystems, and even enters the human food chain. Many governments and environmental organizations are now pushing for biodegradable alternatives, banning the single-use plastics, and encouraging the production and development of sustainable packaging materials. Agar-based bioplastics could provide a viable alternative in this case.

Additionally, the production of agar- based bioplastics support the blue economy, emphasizes sustainable use of ocean resources for economic growth. Agar is extracted from seaweed, which is an abundant and renewable resource that does not compete with food crops, in case of land use. So, seaweed farming is considered environmentally beneficial, as it helps in carbon sequestration, marine biodiversity, and provides economic opportunities for communities. By utilizing agar, we not only address plastic pollution but also raise the sustainable marine resource management.

Several studies have explored the possibility of agar-based bioplastics, but have challenges also in optimizing their properties for large-scale application. Furthermore, factors such as water resistance, thermal stability, and cost-effectiveness must be evaluated to make agar-based bioplastics a commercially viable solution.

In summary, the development of agar-based biodegradable plastics with ethanol as a plasticizer is a promising step toward sustainable innovation. It addresses critical issues related to regular plastic pollution, and offers an environmentally safe alternative, aligns with global efforts to modulation toward biodegradable materials. However, further research and technological advancements are needed to improve its mechanical properties and explore its full potential.

1.2 Objective and Scope of Study

1.2.1 Objectives

The key objectives include:

1. Developing an optimized method for producing agar-based bioplastic with ethanol as a plasticizer.
2. Examining the tensile strength, elongation at break, and flexibility of the bioplastic.
3. Evaluating the impact of ethanol on the hydrophilic nature of agar-based plastic.
4. Investigating the decomposition rate of the bioplastic under natural environment.

1.2.2 Scope of Study

This study focuses on the development and analysis of agar-based bioplastics, particularly underline the role of ethanol as a plasticizer. The research covers:

- **Material selection and preparation** – The study involves agar as the primary polymer and ethanol as the plasticizer, with water as the solvent.
- **Processing techniques** – The bioplastic will be produced through a simple solution-casting method to form flexible degradable films.
- **Property evaluation** – The mechanical properties, water absorption, and biodegradability of the bioplastic will be tested using standard methodologies.
- **Environmental impact** – The potential benefits of agar-based bioplastics in reducing plastic waste and supporting sustainability will be discussed.
- **Limitations and future research** – The study acknowledges the current limitations in agar-based bioplastics and search areas for further improvement.

2. Related Work

Agar-based bioplastics have attracted considerable interest as eco-friendly substitutes for traditional plastics because of their biodegradability, renewability, and minimal environmental footprint. An increasing amount of research emphasizes their possible uses, especially in the packaging sector. Hernández et al. (2022) conducted a study on biopolymer films made from agar-glycerin, where they systematically analyzed the mechanical properties of these films, including strength, elasticity, and ductility. Their research showed that precise optimization of ingredient levels can produce bioplastics with characteristics ideal for biodegradable packaging, establishing agar as a flexible option for sustainable alternatives [1].

The development and analysis of bioplastics made from agar powder were investigated in the Science of Advanced Materials (2024). This research highlighted the notable enhancements in flexibility and strength obtained by refining the formulation of agar-based bioplastics. The researchers also emphasized the remarkable biodegradability of these bioplastics in soil burial tests, stressing their environmental advantages and possibilities for widespread use [2].

A different novel method was examined in a 2022 study released in Polymers, which investigated the creation of agar-alginate membranes for packaging food. The research showed improved mechanical characteristics, biodegradability, and suitability for food preservation applications by merging agar with alginate. This collaborative method demonstrated the adaptability of agar when paired with different biopolymers to meet various industrial requirements [3].

Hassan et al. also advanced the field by highlighting the market potential of agar-based bioplastics for everyday applications. Their study showed that agar-based bioplastics can provide durability and functionality similar to traditional plastics, making them appropriate for daily use and minimizing environmental harm [4]. Likewise, the Journal of Emerging Technologies and Innovative Research (2019) emphasized how effortlessly microorganisms break down agar-agar-based bioplastics, which is an essential aspect of their environmental suitability [5].

Together, these studies demonstrate that agar-based bioplastics have the potential to transform the packaging and consumer product sectors. Their ability to biodegrade, mechanical characteristics, and compatibility with other biopolymers position them as strong alternatives to synthetic plastics. Nonetheless, in spite of these progressions, obstacles persist in increasing production and enhancing mechanical traits to satisfy the requirements of industrial uses. Future studies should aim to improve the cost-efficiency and scalability of agar-based bioplastics while investigating their possible uses in areas beyond packaging, including agriculture, medicine, and electronics. This in-depth analysis highlights the significant impact of agar-derived bioplastics in enhancing sustainability and tackling the worldwide plastic waste issue.

3. Experimental Method

3.1 Materials and Preparation of Agar-Based Bioplastic

3.1.1 Materials Used

The production of agar-based bioplastic requires carefully selected ingredients to gain the desired mechanical and biodegradable properties. The primary materials include:

Agar Powder: Agar, a natural polysaccharide derived from red algae (Rhodophyta), is the main polymer. It provides the structural ground substance for the film due to its excellent gelling properties.

Ethanol (C_2H_6O): Ethanol acts as a plasticizer, to improve the flexibility and mechanical properties of the bioplastic. It modifies the intermolecular interactions in the agar- based matrix, and enhancing elongation properties.

Distilled Water: Water serves as a solvent to dissolve agar and aid in the homogeneous mixing of all ingredients.

Table 1: Quantity of the materials

Sl No	Ingredients/ Materials	Amount
1	Agar Powder	4 grams
2	Distilled Water	200 ml
3	Ethanol	8 ml

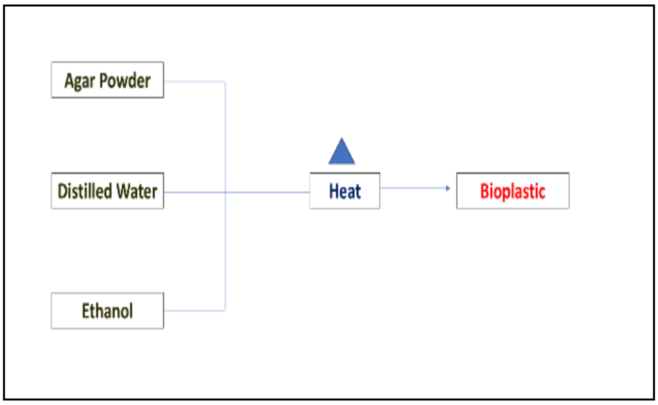

Figure 1: A flowchart of Preparation Process

Figure 2: Our Agar- Based Bioplastics

3.1.2 Preparation Process of Agar-Based Bioplastic

The preparation of agar-based bioplastic involves multiple steps. The process is carefully controlled to ensure consistency in the final product.

Step 1: Weighing and Mixing of Ingredients
A gentle amount of agar powder (typically 2-4% by weight of the total solution) is weighed using an analytical balance.

A measured volume of distilled water is taken, typically in the range of 100-200 ml, depending on the required concentration.

The agar powder is gradually mixed with the water, while continuously stirring to prevent clumping.

Step 2: Heating and Gelation
The mixture is heated in a hot plate or water bath at a temperature between 80-100°C.

Continuous stirring is maintained.

As the temperature increases, the agar undergoes gelatinization, forming a uniform viscous solution.

Step 3: Addition of Ethanol as Plasticizer
Ethanol is added to the heated agar solution in a controlled manner.

The concentration of ethanol typically ranges between 1-5% by volume.

The solution is stirred continuously to ensure proper mixing and uniform plasticization.

Step 4: Casting the Bioplastic Solution
Once the solution reaches its homogenous consistency, it is poured onto a flat glass.

The thickness is controlled by adjusting the volume of solution.

The film is then spread, using a glass rod to achieve a smooth surface.

Step 5: Drying and Curing
The cast bioplastic film is left to dry at room temperature (25-30°C) or in an oven at 40-50°C.

The drying process may take 24-48 hours, depending on humidity and thickness.

Once dried, the bioplastic film is carefully peeled off the mold and stored in a controlled environment for testing.

3.1.3 Considerations for Optimizing Bioplastic Properties
Plasticizer Concentration: The amount of ethanol impacts flexibility. Excess ethanol may weaken the film, while too little may not reduce rigidity.

Drying Conditions: Slow drying at room temperature results in more uniform films, but high-temperature drying may cause cracks.

Film Thickness: It affects mechanical properties; thinner films tend to be more flexible but may lack durability.
The prepared agar-based bioplastic films are now ready for further mechanical and biodegradability testing.

3.2 Testing of Bioplastic Properties
Once the agar-based bioplastic films are prepared, they undergo mechanical and biodegradability testing to evaluate their practical applicability. The key tests performed in this study include tensile strength, elongation at break, and biodegradability analysis.

3.2.1 Tensile Strength Testing
Objective: To determine the maximum force the bioplastic can withstand before breaking.

Methodology:
The bioplastic films are cut into standard rectangular strips (e.g., 50 mm × 10 mm).
The film is clamped at both ends, and a constant force is applied until the film breaks.

Expected Outcomes:
Higher ethanol concentration should increase flexibility but reduce tensile strength.
Compared to traditional plastics, agar-based bioplastics may show lower tensile strength.

3.2.2 Elongation at Break Testing
Objective: To assess how much the bioplastic can stretch before breaking, indicating its flexibility.

Methodology:
The same film samples used.
The film is subjected to a stretching force until it breaks, and the elongation is measured.

Expected Outcomes:
Ethanol as a plasticizer should increase elongation and making the bioplastic more flexible.
Compared to traditional regular plastics, agar-based films may show lower elongation.

3.2.3 Biodegradability Testing
Objective: To evaluate how quickly and effectively the bioplastic decomposes in natural conditions.
Methodology:

3.2.3.1 Soil Burial Test:
Bioplastic samples are buried 5 cm deep in soil and regularly monitored.
The weight loss of the samples is measured weekly.

3.2.3.2 Water Degradation Test:
The bioplastic is immersed in natural water sources to observe degradation rates.

3.2.3.3 Microbial Degradation Test:
Samples are exposed to microbial-rich environments to decomposed.

Changes in texture and weight are documented.

Expected Outcomes:
Agar-based bioplastics should degrade within a few weeks to months.
Unlike petroleum plastics, which take hundreds of years to decompose, agar-based plastics should weight loss within 20-30 days.

3.2.4 Interpretation of Results
Tensile Strength and Elongation: The strength and flexibility must be balanced for practical applications.
Water Absorption: Since agar is hydrophilic, water resistance tests will indicate the potential use of this bioplastic in industries.

Biodegradability: The rapid degradation of agar-based bioplastic confirms its potential as a sustainable alternative.

4. Results and Discussion

4.1 Physical Properties
The physical properties of agar-based biodegradable plastic were assessed to define its eligibility for various applications. The bioplastic films showed a smooth and semi-transparent appearance, making them visually addressing for packaging and food-related purposes. The thickness of the films varied depending on the concentration of agar. The flexibility, elasticity and other properties improved with ethanol as a plasticizer, preventing rigidity and cracking.

Density measurements showed that the agar-based bioplastic had a lower density compared to traditional plastics, making it lightweight and easy to handle. The film's color remained stable over time, with no apparent degradation under normal conditions. Additionally, surface smoothness analysis showed that ethanol reduced surface roughness, and ensuring better mechanical stability.

Again, thermal analysis indicated that agar-based bioplastic had moderate heat resistance, resisting temperatures up to 70°C before significant conformational changes. This suggests that the bioplastic is suitable for room-temperature and its related applications. The films also illustrated good adherence properties, making them consistent with lamination and coating processes.

4.2 Effect of Ethanol on Mechanical Properties
Ethanol played a key role in improving the mechanical or physical properties of agar-based bioplastic. The addition of ethanol reduced rigidity of agar and enhanced flexibility, making the films easier to handle and less bent to cracking. The results of tensile strength test showed that bioplastic films with ethanol increased better elasticity and stretchability.

The elongation at break test showed that increasing ethanol concentration improved the material's ability to stretch, without breaking. However, excessive ethanol led to a decrease in tensile strength, suggesting that an optimum balance is needed. At 3% concentration of ethanol, the plastic films displayed maximum strength and flexibility, making them proper for various applications.

Overall, ethanol effectively enhanced the flexibility of agar-based bioplastics, making it an ideal alternative to rigid petroleum-based plastics for short-term packaging and any disposable products.

4.3 Water and Moisture Absorption Characteristics
Water absorption is another property of bioplastics. Agar-based bioplastics showed high water conformity, which is expected due to hydrophilic nature of agar. So, in controlled humidity environments, the films absorbed moisture gradually, reaching equilibrium conditions within 48 hours.
The water absorption test showed that thinner films absorbed more moisture compared to thicker films. When the films are submerged in water, the films composed but maintained structural integrity for up to 24 hours, after which they began to degrade. This suggests that agar-based bioplastics may require hydrophobic coatings for prolonged water applications.

The moisture holding capacity of the films was influenced by ethanol concentration. Higher concentration of ethanol led to lower water absorption capacity, as ethanol reduced the intermolecular forces within the agar matrix. This suggests that ethanol also improves moisture resistance, and making it beneficial for usability in humid conditions.

Overall, while agar-based bioplastics absorb moisture, their performance can be improved through coating techniques or blending with hydrophobic additives, and then it is possible to be used in a wider range of applications.

4.4 Biodegradability and Environmental Impact Assessment
Biodegradability test confirmed that agar-based bioplastic decomposes faster than conventional plastics. In soil burial test, the films showed degradation within 15 days, and losing nearly 50% of their weight in 30 days. By the 60th day, complete breakdown occurred, and leaving no residue.

The water degradation test showed that agar-based bioplastics partially dissolved within two weeks, suggesting their suitability for natural degradation. And microbial analysis revealed that naturally occurring soil bacteria and fungi accelerated the decomposition, further highlighting their environmental sustainability.

Unlike petroleum-based traditional plastics, agar-based bioplastics integrate into the natural carbon cycle. Their ability to degrade without releasing harmful microplastics makes them a sustainable alternative for reducing plastic pollution.

In conclusion, the high biodegradability of agar-based bioplastics makes them a practicable candidate for replacing the single-use plastics.

5. Conclusion and Future Scope

5.1 Key Findings and Implications
This study highlights the potential of agar-based bioplastics as an eco-friendly alternative to petroleum-derived plastics. The research indicated that using ethanol as a plasticizer significantly improved the flexibility and mechanical properties of the bioplastic. The optimal ethanol concentration was found to be 3%, which provided a balance between both tensile strength and elasticity.

One of the most important findings was the biodegradability of the agar-based bioplastic. The soil burial test showed that the material decomposed by 50% within 30 days and fully by 60 days. The water degradation test further confirmed its rapid breakdown in natural conditions.

However, the study also identified limitations for broader commercial applications. The bioplastic has high water absorption capacity, which may impact its usability in humid environments. While ethanol improved moisture resistance, further modifications such as hydrophobic coatings or polymer blends are necessary for broader applications.

Overall, this study provides valuable insights into the formation, mechanical behavior, and environmental impact of them. The findings suggest that with improvements, this bioplastic has the potential to replace traditional plastics in various applications, particularly in food packaging, disposable purposes, and biodegradable films.

5.2 Future Research and Potential Applications
While this study establishes a strong foundation for agar-based bioplastics, further research is needed to enhance their properties. One key area of focus is improving their mechanical strength. Cross-linking techniques could also be explored to improve film strength and water resistance.

Another crucial research is water resistance enhancement. Since agar is highly hydrophilic, the bioplastic's moisture absorption properties must be higher. Future studies could explore natural hydrophobic coatings or biodegradable synthetic coatings to improve water resistance while maintaining eco-friendliness.

Additionally, large-scale production must be assessed. This includes cost analysis, scalability, and industrial processing techniques.

The potential applications of agar-based bioplastics wide over food packaging. Given its biodegradable and non-toxicity, it could be used in medical applications. In agriculture, it could serve as biodegradable mulch films, and reducing plastic waste in farming. Furthermore, the natural transparency and flexibility of the product make it ideal for eco-friendly wrapping films disposable cutlery.

Future studies should also measure the long-term environmental impact of agar-based bioplastics through life cycle analysis (LCA). This would provide a deep insight into its carbon footprint, decomposition, resource consumption, and disposal pathways, ensuring its sustainability.

In conclusion, agar-based bioplastics hold great promises as a sustainable alternative to petroleum-based plastics. While current research has demonstrated their possibilities, further advancements will be crucial for widespread adoption. With continued innovation, these bioplastics could play a significant role in reducing plastic pollution and supporting the global sustainability efforts.

Data Availability
none
Conflict of Interest
The author declares no conflict of interest.

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Authors' Contributions
The author solely contributed to all aspects of the research, including conceptualization, experimental design, material preparation, data collection, analysis, and manuscript writing. The author also conducted all testing procedures, interpreted the results, and finalized the conclusions, ensuring the study's originality and scientific rigor.

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AUTHOR PROFILE

Akash Jyoti Boruah, doing B.Sc in Botany from Jorhat Kendriya Mahavidyalaya under Dibrugarh university, Assam, India. Auhtor recently published a research paper titled "Integrative Study of Traditional Medicinal Flora in Jorhat West" in International Journal of Scientific Research in Biological Sciences **(IJSRBS)**.

