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Research Article

Investigating the Durability and Life Cycle of Bioplastic Bags Made from Mixed Banana and Cucumber Peel Waste

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Abstract: Plastic pollution is a serious environmental problem because traditional petroleum-based plastic bags cause air, water, and soil pollution and take many years to decompose. This study focused on using banana and cucumber peel waste to produce a more sustainable bioplastic as an alternative to traditional plastic bags. The objectives of this study are: (1) to develop a method for creating bioplastic bags from mixed banana and cucumber peel waste by determining the necessary steps involved in the process, (2) to determine the durability of bioplastic bags made from mixed banana and cucumber peel waste in terms of tensile strength, water resistance and biodegradability, and (3) to evaluate the life cycle of bioplastic bags made from mixed banana and cucumber peel waste in terms of estimated lifespan, biodegradation process, and recommended disposal methods. The researchers used a quasi-experimental research design through an experimental procedure by collecting, cleaning, and shredding the peels into small pieces. The materials were then mixed with agar-agar, glycerin, and borax, heated and stirred to form a mixture, poured into molds, and dried to produce bioplastic sheets. The results showed that the bioplastic could carry around 1.25 kg before tearing and had limited water resistance, as it became soft after about 2 hours in water. However, it demonstrated high biodegradability, fully decomposing within 9 days. The study concludes that bioplastic made from banana and cucumber peel waste is a promising, eco-friendly alternative to traditional plastic, although improvements are recommended to enhance its strength and durability.

Keywords: ***Bioplastic, Banana Peel, Cucumber Peel, Quasi-Experimental Research, Biodegradability, Sustainable Material***

INTRODUCTION

Plastic pollution poses a significant environmental crisis, underscoring the urgent need for alternatives to traditional petroleum-based plastics. Plastic bags pollute the air through their life cycle, from raw material extraction and the manufacturing process to disposal. Especially the plastic products that people always use, like plastic grocery bags, which can cause a variety of environmental problems. The raw materials to produce plastic bags are mainly crude oil and natural gas, and the extraction process of those raw materials can cause the emission of a considerable amount of air pollutants into the atmosphere. In addition, plastic products like plastic bags contribute to water and soil pollution.

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Plastic pollution has become a major environmental challenge, with millions of plastic pieces contaminating ecosystems and adversely affecting humans, animals, and the environment. According to the United Nations Environment Programme (UNEP), plastic pollution is a global issue, with 19-23 million tons of plastic waste entering aquatic ecosystems each year, disrupting habitats and natural processes. The Center for Biological Diversity notes that traditional petroleum-based plastic bags can take anywhere from 10 to 1,000 years to decompose in landfills.

A variety of alternative options are being created and promoted to replace plastic grocery bags, including paper bags, jute bags, and other biodegradable materials (Bowen Li et al., 2022). Researchers and industrialists have developed different approaches to reduce non-biodegradable plastic waste, noting that reusability is easier to achieve than degradability, while identifying bioplastics as the ultimate solution to the plastic waste problem (Mangal et al., 2023)

The sustainability of bioplastics is evaluated by examining their environmental impact from production through to end-of-life stages

Numerous studies have showcased the environmental advantages of bioplastics, particularly in reducing global warming potential and fossil fuel usage; however, comprehensive reviews on the holistic environmental impacts of bioplastics throughout their life cycle are scarce. They find that the environmental impact of bioplastics is influenced by feedstock choices, processing methods, and disposal practices. (Islam et al., 2024).

The long decomposition period of petroleum-based plastics, combined with the growing demand for plastic in daily life, exacerbates the global plastic pollution crisis. Bioplastics, derived from renewable resources, offer a promising solution. This study seeks to explore the potential of bioplastics made from agricultural waste, particularly banana and cucumber peel waste. These peels, often discarded, represent a substantial and underutilized resource. Bioplastics are expected to contribute to the “Sustainable Development Goal (SDG) Number 12: Responsible Consumption and Production,” a proposal from the United Nations (UN), in the future, which includes consumption of less-toxic reagents during production, development of new recycling and degradation pathways, and a shift away from fossil fuels, especially if integrated into circular economies (Karan et al., 2019, Zhu et al., 2016).

The report of The Food and Agriculture Organization of the United Nations (FAO), published in 2021, “Assessment of agricultural plastics and their sustainability - A call for action,” recommends the replacement of non-biodegradable, conventional polymers with biodegradable, bio-based polymers. This supports the delivery of SDG12- responsible consumption and production. Additionally, bioplastics can contribute to SDG 12 by offering a sustainable alternative to plastic bags that are made up of cucumber and banana peel waste, which can minimize plastic waste.

Several studies have explored the use of agricultural waste, such as banana peel, in bioplastic production, focusing on various aspects such as material properties, biodegradability, and life cycle assessment. According to the study of Azieyanti et al. (2020), to develop a bioplastic from food waste, banana peel as a new alternative to produce plastic. The study used additives such as corn starch, potato starch, and sage together with banana peels as natural-based materials. The chemical-based materials that the researchers used consist of hydrochloric acid, sodium hydroxide, and glycerol. They found out that the banana peel bioplastic with chemical-based products showed a high tensile strength and elongation at break compared to natural based. However, the modulus of elasticity of bioplastics with natural components retrieved the highest results based on the tensile properties results.

Plastics have become an essential and fundamental part of our world today, as this is an ideal and necessary material that can be utilized in diverse

applications. Despite its advantages, plastics are harmful and are a major problem in our environment. Their durability and resistance make it challenging to combat environmental degradation and pose a threat to our ecosystem. Bridging the gap between the need and sustainability, this study explores the potential of bioplastics made from agricultural waste, particularly banana and cucumber peels, as a sustainable alternative to petroleum-based plastics. These peels, often discarded, are rich in starch and cellulose, making them suitable candidates for bioplastic production.

METHOD

This research study utilized a quasi-experimental research design combining both a qualitative approach to determine and investigate the durability and life cycle of bioplastics that were derived from agricultural residue. Specifically, the independent variables of the study were the types and quantities of peel waste used, particularly Lacatan banana peels and slicing cucumber peels, while the dependent variables were the durability and biodegradability of the produced bags. For each plastic sheet produced, approximately 200 grams of Lacatan banana peels and 150 grams of slicing cucumber peels were used, resulting in one (1) biodegradable plastic sheet with an approximate size of 20 cm × 20 cm and uniform thickness. These measurements ensured consistency in the production process and allowed for reliable assessment of durability and biodegradability across samples.

The research process begins with the collection and preparation of all the materials needed to conduct the study. The peel samples were specifically collected from a local public market in Pili, Camarines Sur, where fresh Lacatan banana and slicing cucumber were sourced from vendors. The banana and cucumber peels were gathered immediately after consumption or food preparation to ensure freshness, then washed thoroughly to remove dirt and impurities.

The cucumber and banana peel waste was then combined and processed to extract the biopolymers with the desired texture. The mixture was subsequently boiled and thickened, molded into the desired shape, and dried to form biodegradable plastic sheets.

Figure 1. Lacatan Banana

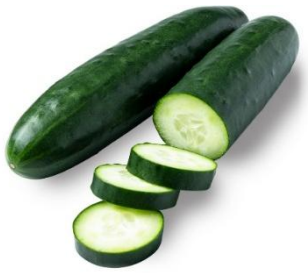

Figure 2. Cucumber

Subsequently, the samples underwent manual checking to test its durability and strength, including assessing the environmental factors and conditions that contribute to the product outcome. The output of this process was tested to evaluate its durability and to measure and gather data regarding its life cycle. The collected and gathered data throughout the process helped to determine and investigate the feasibility and sustainability of producing bioplastics using agricultural residue.

A quasi-experimental design was utilized in this study because it involves the manipulation of the independent variable (the bioplastic product process)

without random assignment of participants. Using a quasi-experimental design allowed the researcher to observe how changes in the production process affect the durability and life cycle of the bioplastic while also considering environmental conditions. This approach was practical when full control over all variables was not possible, making the study more realistic and applicable to real-world situations.

This research on the durability and life cycle of bioplastic bags made from waste Lacatan banana and slicing cucumber peels uses both quantitative and qualitative methods to provide a more complete evaluation. The quantitative aspect involves measuring the bioplastics' weight, thickness, tensile strength, and rate of degradation, including the number of days or weeks required for decomposition. This provides measurable data on their performance and sustainability compared to conventional plastics. Meanwhile, the qualitative aspect focuses on observing and describing the bags' appearance, texture, flexibility, and physical changes over time.

The materials used in the production, durability testing, and life cycle assessment of the bioplastic bags include banana and cucumber peels as the primary raw materials, along with rice starch, water, agar, glycerin, and borax as binding, plasticizing, and stabilizing agents. These materials were essential in forming the bioplastic sheets and in evaluating their strength, flexibility, and biodegradability under controlled conditions.

By combining these approaches, the study not only produces reliable scientific evidence but also considers real-world usability and perception. This balance of numbers and descriptive insights ensures a comprehensive assessment of whether bioplastic bags are truly a viable alternative to conventional plastic.

RESULTS AND DISCUSSION

The Necessary Steps in Order to Create a Bioplastic Bag Made from Mixed Banana and Cucumber Peel Waste

First, fresh "lacatan" bananasand cucumbers were collected and washed with clean water to remove dirt. After washing, the peels were dried using a clean towel or tissue paper. The bananas and cucumbers were then peeled, and only the skins were kept while the edible parts were removed. The string-like fibers attached to the banana peel were also removed so that only the clean peel remained. Afterward, the banana and cucumber peels were chopped into small pieces to make blending easier. The chopped banana peels were blended with 600 ml of water until smooth, and the same process was done with the cucumber peels using another 600 ml of water. The blended mixtures were filtered using a clean cloth and a sifter to separate the liquid from the solid particles, and the cloth was squeezed to extract as much liquid as possible. The filtered banana and cucumber liquids were collected separately, each measuring about 600 ml, then combined in one container to obtain 600 ml of mixed liquid.

Next, a bioplastic binding solution was prepared in a separate container using 1½ tablespoons of agar-agar, 1½ tablespoons of glycerin, and ½ tablespoon of borax. The borax was first dissolved in one tablespoon of hot water. The combined banana and cucumber liquid was poured into a cooking pot and heated until it slightly boiled. The agar-agar was added first and stirred until dissolved, followed by glycerin, and lastly the dissolved borax. The mixture was stirred continuously in a slow and consistent motion for about 15 minutes. After cooking, the mixture was poured into a clean flat tray, spread evenly, and left to cool and dry at room temperature for about four days to one week, or it could be oven-dried to speed up the process.

Once the bioplastic dried, an agar-agar glue was prepared by dissolving one teaspoon of agar-agar powder in three tablespoons of water and heating it over low

heat until it became clear. The dried bioplastic was carefully removed from the tray and cut into desired shapes. Warm water was brushed along the edges, and the agar-agar glue was applied to seal the parts together. Finally, the glued sections were allowed to dry completely to form the bioplastic bag.

According to Sable et al. (2024), agar-agar powder was an effective natural polymer for producing biodegradable plastic materials. Their study demonstrates that agar-agar powder was an effective base material for producing strong biodegradable bioplastics, while glycerin acts as a plasticizer that improves flexibility. This study is related to our research because we also use agar-agar powder as the main base material in producing bioplastic made from a mix of banana and cucumber peels. Similar to the findings of Sable et al. (2024), the agar-agar used in our study helps form a stronger structure, while the addition of glycerin helps our product be flexible and stretchable. Therefore, this related literature supports our research by providing scientific evidence that agar-agar and glycerin were effective components in developing strong, flexible, and biodegradable bioplastics.

Figure 3. Bioplastic Product

The Durability of Bioplastic Bags Made from Mixed Banana and Cucumber Peel Waste

With growing concern over plastic pollution, researchers have explored alternative and eco-friendly materials derived from agricultural waste. Banana and cucumber peels were biodegradable materials that can be utilized in the production of sustainable bioplastics. This study focuses on evaluating the durability of bioplastic bags made from mixed banana and cucumber peel waste to determine their potential as an environmentally friendly substitute for conventional plastic bags. Durability was assessed in terms of tensile strength, water resistance, and biodegradability. Tensile strength measures the ability of the bioplastic bag to carry weight without tearing. Water resistance determines how well the material maintains its structure when exposed to moisture. Biodegradability evaluates how effectively the bioplastic decomposes under natural environmental conditions, ensuring its sustainability and reduced environmental impact.

The study of Gurunathan et al. (2025) is related to our research because it also studied the durability of bioplastic materials, including their tensile strength. The current study similarly studies these properties to assess the durability of bioplastic bags made from banana and cucumber peel waste. Both studies aim to determine whether biodegradable materials can serve as environmentally friendly alternatives to traditional plastic bags. In addition, both studies contribute to the growing body of research promoting sustainable materials to help reduce plastic pollution and environmental damage.

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Durability of Bioplastic Bags made from Mixed Banana and Cucumber Peel Waste in terms of Tensile Strength

The tensile strength of the bioplastic bags was evaluated by the researchers by conducting an actual strength test using measured amounts of rice in grams. The test was done gradually, initially starting with lighter weights of rice and increasing the weight to observe how much load the bioplastic bag could carry before any noticeable changes in the bioplastic material. The bag was first filled with 250 grams of rice, and no visible stretching or tearing was observed. When the weight was increased to 500 grams and then to 750 grams, the bioplastic bag remained intact, and just a slight stretching began to appear as the load became heavier. And when the load increased to 1 kilogram, the bioplastic bag was still able to hold the weight of rice, but there was noticeable strain and stretch on the material. To further test its limit, the researchers placed 1 kilogram and 250 grams (1.25 kg) of rice inside the bag. At this maximum limit, the bioplastic material was still intact, but it showed stretching in the bag, which indicated that it was near its tensile capacity load. Based on the observations, the bioplastic bag was able to withstand up to 1.25 kilograms before reaching its tensile limit. These results show that the bioplastic bag has reliable strength and can carry light to moderately heavy loads under controlled conditions. However, no additional weight of rice can be added because the bioplastic bag has already reached its maximum capacity.

According to Laras Devikaduri and Vitri Aprilla Handayani, banana peel waste can be used to produce environmentally friendly bioplastics with measurable mechanical properties such as tensile strength. This study explains that the composition of banana peel and natural adhesives can affect the strength and durability of the bioplastic material. This also supports the present study because it examines the tensile strength of bioplastic bags made from banana and cucumber peel waste. Therefore, their findings provide supporting evidence that banana peel–based bioplastics can produce durable biodegradable materials.

Durability of Bioplastic Bags made from Mixed Banana and Cucumber Peel Waste in terms of Water Resistance

Table 1 presents the water resistance test that was done to determine and observe how the bioplastic bag reacts when it stays in water for a long time. The bioplastic sample was dipped in normal water for about four to five hours, and was monitored by a timer; it was checked every thirty minutes to observe any changes.

Table 1. Water Resistance Test Results of Bioplastic Bags Over Time

TIME	OBSERVATION
30 minutes	The bioplastic bag became slippery in texture, but it was still strong and has kept its structure.
1 hour	The bioplastic bag remained intact and showed no significant changes.
1 hour and 30 minutes	The bioplastic still had a slippery and gelatin-like texture, but it slowly started to tear apart.
2 hours	The bioplastic became very soft, very slippery, and hard to lift from the water.

In the first 30 minutes, the bioplastic bag became slippery in texture, but it was still strong and kept its structure. This shows that water started touching and softening the surface of the material, but the inside part was still intact. At this stage, the material could still handle the moisture of water for a short time without getting damaged. The bioplastic bag remained intact and showed no significant changes, with observations recorded at 30-minute intervals following the first hour. After 1 hour and 30 minutes, the bioplastic was still slippery and had a gelatin-like texture, but it slowly started to tear apart. This means the water had already entered the insides of the material and weakened it. Since many bioplastics are made from natural ingredients that absorb water, they tend to soften when soaked. The water loosened its bond that holds the material together, resulting in a loss of strength, and it began to tear apart. In the last 30 minutes of the test, reaching the 2-hour mark, the bioplastic became very soft, very slippery, and hard to lift from the water. The results show that the bioplastic bag can handle moisture for only a short period of time, and its strength can decrease when exposed to water for a longer duration of time.

In this study, the water resistance test showed that the bioplastic initially maintained its shape and strength but gradually became slippery and softened after prolonged exposure to water moisture. As time increased, water penetrated the material, weakened the bonds holding the polymer matrix together, and eventually caused the sample to lose its structural integrity and tear apart. These findings align with the related literature, which explains that water absorption directly affects the structural strength and durability of starch-based bioplastics. In general, the results demonstrate that while the developed bioplastic can temporarily withstand moisture, its strength decreases significantly with extended water exposure (AH Dawam Abdullah et al., 2020).

Durability of Bioplastic Bags made from Mixed Banana and Cucumber Peel Waste in terms of Biodegradability

The biodegradability of the bioplastic was tested by burying it in soil and observing what happened over time. The bioplastic samples were buried about 3–4 inches deep in the soil. The soil was slightly wet, which helped the breakdown process because moisture supports the growth and activity of microorganisms. After 3 days, it was observed that the soil started sticking to the surface of the bioplastic. This may have happened because the material began to soften, making it easier for soil particles to attach to it. This was an early sign that the decomposition process had started.

As the days passed, the bioplastic continued to soften and lose its original shape. Small cracks appeared, and the material slowly broke apart. These changes showed that the microorganisms in the soil were actively breaking down the bioplastic. After 1 week and 2 days (9 days), the bioplastic completely decomposed. No visible solid pieces were found in the soil. This means the material fully broke down under the given conditions.

This article focuses on a few critical issues that must be addressed for bioplastic production to become commercially viable. The growing use of plastic products has led to significant environmental issues, including plastic particles in our food chain, posing health risks to humans, animals, and the environment. Biodegradable plastics, or bioplastics, are being explored as a more sustainable alternative to address this problem, with global production seeing significant growth in recent years. (Gong, L., et al., 2024)

The Life Cycle of Bioplastic Bags made from Mixed Banana and Cucumber Peel Waste in terms of Estimated Lifespan, Biodegradation Process, and Recommended Disposal Methods

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The results revealed that the bioplastic bag made from a mixture of banana and cucumber peel waste completely decomposed within one (1) week and two (2) days when buried in moist soil. This short decomposition period indicates that the developed bioplastic material has high biodegradability.

Compared to conventional plastic bags, which can take several years to break down, the produced bioplastic demonstrates a significantly shorter lifespan in natural soil conditions.

The biodegradation of the bioplastic bag was monitored through a soil burial observation. The material was buried approximately 3-4 inches below the soil surface. The following changes were observed during the decomposition process.

Table 2: Life Cycle Assessment of Bioplastic Bags in Terms of Estimated Lifespan and Biodegradation Process

TIME SPAN	OBSERVATION
After 3 days	The bioplastic bag showed visible signs of structural weakening and began tearing into large pieces.
After 6 days	The material further degraded into smaller fragments, indicating continuous microbial and moisture activity in the soil.
After 9 days	The bioplastic was no longer visible in its original form. It fully decomposed and integrated into the soil, leaving no noticeable debris or residual fragments.

These observations confirm that the bioplastic bag progressively deteriorated over time until complete decomposition was achieved. Based on the results of the study, the disposal method used in this study for the bioplastic bag, soil burial, was proven effective. The findings suggest that deeper burial promotes faster decomposition due to increased soil moisture and microbial activity. It was also observed that environmental conditions affect the degradation rate. During rainy conditions, higher moisture levels accelerate decomposition. In contrast, during dry or sunny periods, the breakdown process may occur at a slower rate due to reduced moisture content in the soil. The results support the conclusion that the developed bioplastic bag is environmentally friendly and suitable for natural soil disposal.

According to Cheng Fang et al. 2024, in their study “Characterizing fragmentation of compostable bioplastic: releasing microplastics or small bioplastic debris” published in Environmental Sciences Europe, compostable bioplastic bags undergo degradation and fragmentation when exposed to organic waste and environmental conditions such as moisture, microorganisms, and heat. The study found that a compostable bioplastic bag used for collecting food waste began to break down within about one week, releasing small fragments as part of the biodegradation process. Furthermore, the findings help explain the estimated lifespan of bioplastic bags, since the study observed how long the material remained stable and when it started to fragment under real-life waste conditions. This information was relevant for determining how long a biodegradable bag made from banana and cucumber peel waste lasted before degrading.

CONCLUSIONS

The study identified a systematic process for producing bioplastic bags made from mixed banana and cucumber peel waste. The procedure included collecting and cleaning the peels, drying, and mixing them with water and other ingredients to form a mixture. After a series of trials, the bioplastic bag was successfully formed through an optimized ratio of the ingredients. The mixture was then heated while being stirred to achieve a consistent texture before being poured into the tray and left to dry in the oven. After drying, the material forms bioplastic sheets that were shaped into bags by gluing it with agar-agar paste. However, the procedures should be carefully monitored, especially during the drying period, to ensure the quality of the formed bioplastic material.

The results showed that bioplastic bags made from banana and cucumber peel waste have moderate durability. In terms of its tensile strength, the bags were able to carry light loads of rice with slight tearing as the loads were increased up to 1 1/4 kilograms of rice, showing its use for light to moderate weight. However, the material showed limited water resistance for 1 hour, as it absorbs moisture and becomes softer when exposed to water for a long period of time. Despite its limitations, the bioplastic demonstrated good biodegradability due to its organic composition.

The study found that bioplastic bags made from banana and cucumber peel waste have a shorter lifespan compared to conventional plastic bags, which supports environmental sustainability. The bags remained usable for a limited period, but it gradually degraded when exposed to moisture, heat, and microorganisms. During the biodegradation process, microorganisms such as bacteria break down the organic material until it is fully decomposed in a span of 9 days. The bioplastic proved its aim to be sustainable. The study successfully investigated the purpose of doing so. This suggests that this material was beneficial and sustainable to the environment, supporting the proposed solution to the research gap.

DECLARATIONS

This section should include as follow: "*The authors declare that there is no conflict of interest*"

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References

[1] THE ABDULLAH, H. D., FIKRIYYAH, A.K. & FURGHONIYYAH, U. (2020). Effect of chitin addition on water resistance properties of starch-based bioplastic properties https://iopscience.iop.org/article/10.1088/1755-1315/483/1/012002/meta

[2] ALI, S., ABDELKARIM, E., ELSAMAHY, T., AL-TOHAMY, R., LI, F., KORNAROS, M., ZUORRO, A., ZHU, D., & SUN, J. (2023). Bioplastic production in terms of life cycle assessment: A state-of-the-art review. Environmental Science and Ecotechnology, 15, 100254. https://doi.org/10.1016/j.ese.2023.100254

[3] AZIEYANTI, N. A., AMIRUL, A., OTHMAN, S. Z., & MISRAN, H. (2020). Mechanical and morphology studies of bioplastic-based banana peels. Journal of Physics: Conference Series, 1529(3), 032091. https://doi.org/10.1088/1742-6596/1529/3/032091

[4] DEVIKADURI, L., & HANDAYANI, V. A. (2025). Environmentally Friendly Bioplastic Derived from Banana Peel (Musa paradisiaca) Waste and Agar-Agar Adhesive: An Experimental Study Employing a Completely Randomized Design (CRD)

https://journal.iteba.ac.id/index.php/jurnalsintak/article/view/712?utm_source=chatgpt.com

[5] FANG, C., ZHANG, X., ZHANG, Z., & NAIDU, R. (2024). Characterizing fragmentation of compostable bioplastic: releasing microplastics or small bioplastic debris https://link.springer.com/article/10.1186/s12302-024-00946-1

[6] GONG, L., PASSARI, A.K., YIN, C., THAKUR, V.K., NEWBOLD, J., CLARK, W., JIANG, Y., KUMAR, S., & GUPTA, V.K. (2024). Sustainable utilization of fruit and vegetable waste bioresources for bioplastics production. https://scholar.google.com/scholar?hl=en&as_sdt=0%2C5&q=biodegradability+plastic+fruit+and+vegetable+wastes&btnG

[7] GURUNATHAN, M. K., & NAVASINGH, R. J. H. (2025). Development and characterization of starch bioplastics as a sustainable alternative for packaging https://www.nature.com/articles/s41598-025-00221-0

[8] ISLAM, M. S., XAYACHAK, T., HAQUE, N., LAU, D., BHUIYAN, M., & PRAMANIK, B.K. (2024). Impact of bioplastics on the environment from production to end-of-life. Journal of Cleaner Production. https://www.sciencedirect.com/science/article/pii/S0957582024006359

[9] KARAN, H., FUNK, C., GRABERT, M., OEY. M., & HANKAMER, B. (2019). Green Bioplastics as Part of a Circular Bioeconomy https://pubmed.ncbi.nlm.nih.gov/30612789/

[10] LI, B., LIU, J., YU, B., & ZHENG, X. (2022). The environmental impact of plastic grocery bags and their alternatives. IOP Conference Series: Earth and Environmental Science, 1011(1), 012050.https://doi.org/10.1088/1755-1315/1011/1/012050

[11] MANGAL, M., RAO, C. V., & BANERJEE, T. (2023). Bioplastic: an eco-friendly alternative to non-biodegradable plastic. Polymer International, 72(10), 984–996. https://doi.org/10.1002/pi.6555

[12] Marjadi, D., & Dharaiya, N. (2010). Applications of nanotechnology in animal disease diagnosis, treatment, and prevention. Everyman's Science, 45(2), 106–110. https://www.researchgate.net/profile/Raja-S/publication/266676379_Applications_of_Nanotechnology_in_Animal_Disease_Diagnosis_Treatment_and_Prevention/links/5a85ac8d0f7e9b1a95482123/Applications-of-Nanotechnology-in-Animal-Disease-Diagnosis-Treatment-and-Prevention.pdf

[13] RAMADHAN, M. O., & HANDAYANI M.N. (2020). The potential of food waste as bioplastic material to promote environmental sustainability: A review. IOP Conference Series: Materials Science and Engineering, 980(1), 012082. https://doi.org/10.1088/1757-899X/980/1/012082

[14] SABLE, S., VAIRAL, A., BHOSALE, V., SURVE, S., RAZA, U., & THENGRE, M. (2024). Bioplastic from agar powder: Preparation and its characterization https://scholar.google.com/scholar?scilib=1&scioq=agar+agar+bioplastic&hl=en&as_sdt=0,5#d=gs_qabs&t=1772697438197&u=%23p%3Dak0dMKhXXqUJ

[15] TOTALENERGIES CORBION. (2022, February 22). Bioplastics: A sustainable alternative recommended by the United Nations. https://totalenergiescorbion.com/bioplastics-a-sustainable-alternative-recommended-by-the-united-nations/

[16] UNITED NATIONS ENVIRONMENT PROGRAMME. (n.d.). Plastic pollution. Retrieved December 1, 2025, from https://www.unep.org/plasticpollution

[17] ZHU, Y., ROMAIN, C., & WILLIAMS, C. K. (2016). Sustainable polymers from renewable resources. https://doi.org/10.1038/nature2100