# Innovative Bioplastic from Coffee Grounds Waste and Cassava Starch: A Circular Economy-Based Coffee Packaging Solution

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**Abstract.** The rapidly growing coffee industry in Indonesia, especially in Bali, produces large amounts of coffee grounds waste, most of which has not been optimally utilized. On the other hand, the use of conventional plastics that are difficult to decompose causes serious environmental problems. This study aims to develop cassava starch-based bioplastics with the addition of coffee grounds as fillers to improve their mechanical properties and biodegradability. Bioplastics were made with three variations of coffee grounds concentrations, namely 10%, 20%, and 30% of the total solids. Characterization tests included tensile strength, elongation, and resistance to water and humidity. In addition, biodegradation tests were carried out in soil and water media for 7 days. The results showed that bioplastics with 10% coffee grounds had the highest tensile strength and elongation, while increasing the concentration of coffee grounds tended to decrease mechanical properties but increase the rate of degradation. This study provides an alternative use of coffee grounds waste in the development of sustainable, environmentally friendly materials.

**Keywords:** Bioplastics, Coffee Grounds Waste, Green Materials

## 1 Introduction

Indonesia is currently facing a significant plastic pollution crisis, with an estimated 30% increase in plastic waste flow projected between 2017 and 2025 (Flury & Narayan, 2021). One of the most promising strategies to mitigate this issue is the development of biodegradable plastics, which offer an environmentally friendly alternative to conventional petroleum-based plastics. These bioplastics can be derived from various natural sources such as starch, cellulose, or other biopolymers, and are capable of decomposing under natural environmental conditions. However, despite their environmental advantages, bioplastics often exhibit limitations in terms of mechanical strength and water resistance (Darni & Utami, 2009).

Among the natural materials used for bioplastic production, starch stands out due to its abundance, renewability, and ease of processing. It is composed primarily of two


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polysaccharides, amylose and amylopectin, which can form film-like structures when heated with water and plasticizers. The amylose-to-amylopectin ratio heavily influences the mechanical and solubility properties of starch-based bioplastics; higher amylose content generally results in stronger and more rigid films (Abe et al., 2021). Cassava starch, in particular, is widely used in Indonesia due to its low cost, availability, and favorable film-forming characteristics. Nevertheless, starch-based bioplastics are inherently brittle and tend to absorb moisture, which limits their application in packaging and other industrial uses (Jayarathna et al., 2022).

To overcome these challenges, various fillers and reinforcing agents have been explored to enhance the performance of starch-based bioplastics. One such potential filler is spent coffee grounds, an organic waste material that households, coffee shops, and the coffee processing industry abundantly generate. Indonesia, especially Bali, has seen rapid growth in coffee consumption, both in traditional settings through ceremonial use and in modern urban lifestyles. As coffee consumption increases, so does the volume of coffee waste, most of which is discarded as unutilized organic waste (Asiah et al., 2022). The utilization of organic waste as a functional raw material has also been explored in other studies. This approach demonstrates the significant potential of organic waste to be developed into value-added materials while supporting the circular economy concept (Widantha et al., 2024).

Spent coffee grounds contain valuable bioactive compounds, including cellulose, lignin, and polyphenols. These components make coffee grounds a promising filler to enhance the mechanical properties of bioplastics. Incorporating them into a starch matrix can improve tensile strength, increase elasticity, and reduce water absorption, depending on the particle dispersion and concentration. Furthermore, coffee grounds may contribute additional benefits such as UV resistance, antimicrobial properties, and natural coloration, reducing the need for synthetic additives (Dewi, 2023). From a sustainability perspective, utilizing coffee waste aligns with the principles of the circular economy, turning waste into value-added products while promoting environmentally responsible manufacturing (Zhang et al., 2023). Surface modification of lignocellulosic materials is essential for improving compatibility and adhesion between the filler and the matrix, thereby enhancing mechanical performance (Yogi Asana et al., 2025). Previous studies have shown that natural fiber-reinforced composites can be significantly improved by optimizing parameters such as fiber content, surface treatment, and filler addition, particularly when using materials like coconut fiber and alumina (Widantha, 2023). These findings emphasize the potential of organic waste-based reinforcements to enhance the functional properties of environmentally friendly materials.

This study aims to evaluate the effects of varying concentrations of spent coffee grounds on the characteristics of cassava starch-based bioplastics. The key properties assessed include tensile strength, elongation, and environmental resistance, such as biodegradability and water solubility. The results are expected to provide insights into the development of more durable, sustainable bioplastics that are suitable for use in eco-friendly packaging, particularly in the coffee industry. Ultimately, this research supports the dual goals of improving material performance and enhancing waste valorization in response to environmental concerns.

# 2 Methodology

## 2.1 Bioplastic Preparation

This research utilized cassava starch as the primary biopolymer and spent coffee grounds as the filler material. Cassava starch was extracted manually through a wet sedimentation method and then dried. Spent coffee grounds were collected from local coffee shops, oven-dried at 60°C for 24 hours, and then sieved using a 60-mesh screen (250 µm) to achieve a more uniform particle size. Glycerol was used as a plasticizer to improve the flexibility of the bioplastics.

The coffee grounds were added in three different concentrations: 10%, 20%, and 30% by weight of starch, namely B1, B2, and B3, with B0 as the control sample. The bioplastic fabrication process was carried out using the solution casting method. The starch, glycerol, water, and coffee grounds were mixed and heated at a temperature of 70–80°C under constant stirring until gelatinization occurred. The mixture was then poured into flat molds and allowed to dry at room temperature for 48 hours to form bioplastic films. The dried films were then conditioned before testing.

## 2.2 Mechanical and Biodegradability Testing

All tests were conducted at the Materials Testing Laboratory, Department of Mechanical Engineering, Politeknik Negeri Bali. Mechanical testing was performed using a Plastic Tensile Testing Machine (RAMT brand) to measure tensile strength and elongation at break. The test specimens were cut into strips with a width of 2 cm and a gauge length of 5 cm. The tensile test was conducted at a speed of 10 mm/min, and each formulation was tested three times to ensure data consistency. The results were recorded in terms of maximum tensile strength (MPa) and elongation (%), which indicate the material's ability to withstand tension and its flexibility. The biodegradability test was conducted by burying the bioplastic specimens in moist garden soil for 7 days. Each specimen had dimensions of 5 × 5 cm and was buried at a depth of approximately 5 cm. The soil was maintained at room temperature and kept consistently moist to simulate natural degradation conditions. The initial mass of each sample was recorded before burial. After the test period, the samples were retrieved, cleaned, air-dried, and reweighed to calculate the percentage of mass loss.

# 3 Result and Discussion

## 3.1 Result

**Visual Appearance of Bioplastics.** The bioplastic films produced with different concentrations of spent coffee grounds showed clear variations in appearance, as presented in Figure 1. From left to right, the samples represent formulations with 10%, 20%, and 30% coffee grounds, respectively. At 10% filler content, the film appears relatively transparent with fine and evenly distributed coffee particles. The surface remains smooth and homogeneous, indicating good dispersion at this concentration. The 20% sample shows increased opacity and darker coloration, with some visible irregularities and localized aggregation of filler. In the 30% sample, the film becomes significantly more opaque and heterogeneous, with denser clusters of coffee particles, indicating potential challenges in achieving uniform dispersion at higher filler levels. These observations suggest that increasing the filler content affects not only the color and opacity of the bioplastic. It may also alter the internal structure and uniformity of the matrix, which can influence its mechanical properties and degradation behavior.

**Figure 1.** Bioplastic Films with 10%, 20%, and 30% Spent Coffee Grounds Content (Left to Right).

**Tensile Strength and Elongation.** The tensile strength of the bioplastic samples varied depending on the concentration of spent coffee grounds. The control sample (B0), which contained no filler, showed a tensile strength of 2.21 MPa. A slight improvement was observed in sample B1 (10% filler), which reached the highest tensile strength at 2.37 MPa. However, increasing the filler content further to 20% (B2) and 30% (B3) resulted in a significant decline in tensile strength to 1.56 MPa and 1.18 MPa, respectively. These results indicate that moderate amounts of coffee grounds can reinforce the bioplastic structure, but excessive filler weakens it.

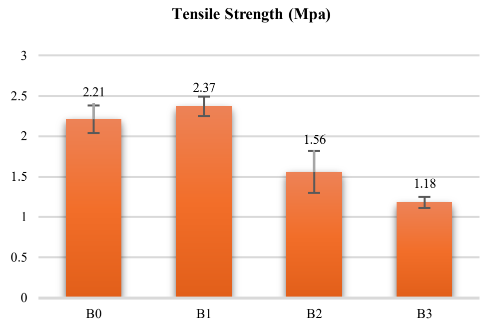


**Figure 2.** Tensile Strength of Bioplastics with Different Spent Coffee Ground Concentrations

A similar trend was observed in elongation at break. Sample B0 showed 31% elongation, while B1 increased slightly to 32%, indicating improved flexibility. In contrast, B2 and B3 experienced sharp reductions in elongation, dropping to 20% and 14%, respectively. This suggests that higher filler content restricts the mobility of polymer chains, reducing the material's ductility.

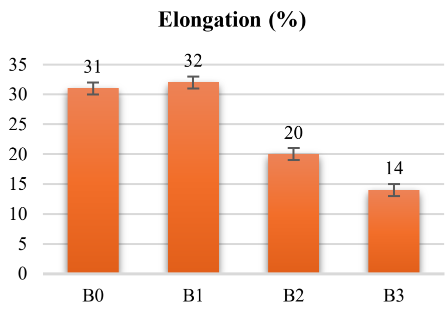


**Figure 3.** Elongation at Break of Bioplastics with Different Filler Concentrations

**Biodegradability in Soil and Water.** Biodegradability tests were conducted in both soil and water for 7 days. In soil, the control sample (B0) degraded by 16%, while B1, B2, and B3 showed progressively higher degradation at 18%, 21%, and 22%, respectively. This trend suggests that coffee grounds enhance microbial breakdown, likely due to their organic and porous nature.

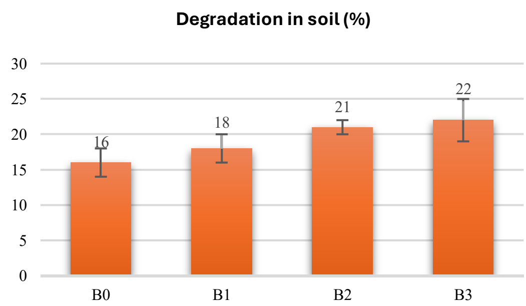


**Figure 4.** Soil Biodegradation (%) After 7 Days of Burial for Each Bioplastic Sample

In water, B0 had a lower degradation rate of 9%. As the filler content increased, the degradation improved, with B1 reaching 14%, and both B2 and B3 achieving 16%. Although degradation in water was generally slower than in soil, the presence of coffee grounds still facilitated the breakdown of the bioplastic structure in aquatic environments.

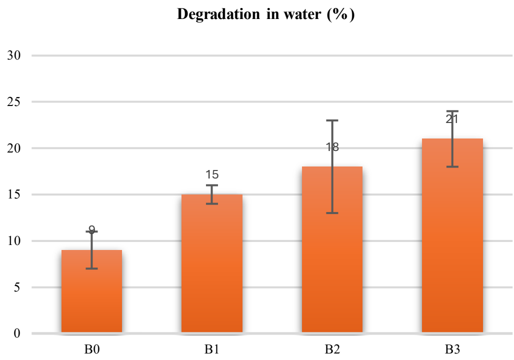


**Figure 5.** Water Biodegradation (%) After 7 Days of Immersion for Each Bioplastic Sample

### 3.2 Discussion

The addition of spent coffee grounds as a filler significantly influenced the mechanical and biodegradation characteristics of cassava starch-based bioplastics. The results indicate a clear trade-off between tensile performance and biodegradability as the filler concentration increased.

**Mechanical Characteristics.** The tensile test results showed that the bioplastic without filler (B0) had moderate strength and flexibility, which slightly improved with the addition of 10% coffee grounds (B1). This suggests that a small amount of coffee filler can enhance the polymer network. The improvement is likely due to better interfacial interactions between the hydrophilic starch matrix and the lignocellulosic structure of the coffee grounds. The fibrous content of coffee grounds may also act as reinforcement, helping to distribute the applied load more evenly throughout the bioplastic.

However, when the filler content increased to 20% (B2) and 30% (B3), both tensile strength and elongation decreased sharply. This decline can be attributed to several factors. First, excessive filler may not disperse uniformly, leading to agglomeration and internal defects that weaken the matrix. Poor filler dispersion creates stress concentration points within the composite, which can cause cracks to initiate and propagate under tensile load, reducing the load-bearing capacity of the material. These failure mechanisms align with common observations in natural-fiber-filled bioplastics. The structure and final mechanical properties of composite materials depend on the reinforcement and polymer matrix interaction. Factors such as filler type, aspect ratio, filler loading, and orientation are critical and must be optimized to achieve the best balance of strength and stiffness (Boey et al., 2022).

Other research has shown that the tensile strength of bioplastics with the addition of carboxymethyl chitosan ranged from 1.04 MPa to 1.61 MPa, indicating that the addition of materials like carboxymethyl chitosan can enhance the tensile strength of bioplastics (Marsa et al., 2023). Furthermore, studies have indicated that bioplastics made from various starch types and treatments show a wide range of tensile strength values. The tensile strength and elongation values of bioplastics from various treatments showed a relatively large range of results, depending on the types of additives and treatments applied (Gabriel et al., 2021).

**Biodegradability Characteristic.** Biodegradability testing in both soil and water revealed an opposite trend: the higher the filler content, the greater the degradation rate. Sample B3 showed the highest degradation in both media, while the control sample B0 degraded the least. This outcome demonstrates that coffee grounds, being organic and biodegradable themselves, promote microbial activity and accelerate the disintegration of the bioplastic. The porous structure of the coffee particles likely increases surface area and water absorption, allowing for more efficient microbial colonization.

Degradation was more pronounced in soil than in water across all samples. This is expected due to the richer microbial population and better aeration in soil environments, which enhances enzymatic breakdown of both starch and lignocellulosic materials. Water environments, by contrast, tend to have slower degradation rates due to limited oxygen availability and reduced microbial diversity. Nevertheless, the improvement observed in water degradation also confirms the positive role of spent coffee grounds in facilitating biodegradation under various environmental conditions.

Other research has found that bioplastics do not degrade on day 0, but by day 3, approximately 30–50% of the bioplastic had degraded. By day 6, degradation reached between 60–90%. This indicates that biodegradability can occur relatively quickly, depending on the conditions, and highlights the potential of using natural additives to enhance biodegradation (Dewi et al., 2020).

Additionally, research showed that bioplastics with coconut shell powder had varying rates of weight loss, ranging from 23% to 34%. The presence of cellulose in the bioplastic enhances biodegradability, as its hydrophilic groups promote water absorption, allowing microbes to break down the plastic more efficiently (Rusdianto et al., 2021). In line with this, other studies have observed that the biodegradation rate of chitosan-based bioplastics ranges from 12% to 35%, further confirming that bioplastics containing natural materials with higher cellulose content tend to degrade faster due to their ability to interact with environmental moisture and microbes (Solekah & Sasria, 2021).

## 4 Conclusion

The addition of spent coffee grounds influenced both the strength and biodegradability of cassava starch-based bioplastics. A 10% filler content (B1) gave the best balance, slightly improving mechanical properties while enhancing degradation. Higher filler levels increased biodegradability but reduced strength and flexibility. These results show that coffee grounds can serve as a sustainable filler, supporting biodegradable packaging applications while utilizing organic waste effectively.

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