Exploring The Potentials of *Curcuma caesia* Starch in Fabricating Bioplastics from Fruit Peels

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Abstract- Bioplastics derived from renewable plant resources have gained immense attention as sustainable alternatives to petroleum-based plastics. This study explores the use of starch extracted from Curcuma caesia rhizomes combined with fruit peels (red banana, Nenthiran banana, Poovan banana, and Kamala orange) as feedstock for bioplastic fabrication. The starch exhibited excellent binding properties, enabling the formation of uniform, flexible, and biodegradable sheets. Optimization of starch concentration, acid catalysis, and glycerol plasticization led to bioplastic films with an average thickness of 330 ± 20 µm, comparable to commercial polyethylene sheets. Degradation studies in red soil demonstrated complete biodegradation within 60 days. This study highlights the potential of Curcuma caesia starch as a novel binder in bioplastic fabrication, supporting the circular economy through fruit peel valorization and offering a promising alternative for packaging applications.

Indexed Terms- Bioplastics, Curcuma caesia, starch, fruit peels, biodegradability, sustainable packaging, green materials.

I. INTRODUCTION

The excessive use of petroleum-derived plastics has led to significant environmental pollution, particularly due to their resistance to natural degradation. Consequently, the development of bioplastics—biodegradable polymers derived from renewable resources—has emerged as a sustainable alternative to conventional plastics, particularly for applications in packaging, agriculture, and the biomedical field (Agarwal *et al.,* 2020; Avérous, 2004). The sue of too many plastics results in more harmful effects and takes a long time to degrade which results in toxic decomposition (JaiKishan Chandrana and Sai Chandra 2021). Starch, being biodegradable, renewable, and economically feasible, is the most commonly used biopolymer for bioplastic production. Traditionally, starch derived from sources such as maize, potato, and cassava has been employed for this purpose (Godbole *et al.,* 2003). However, the global demand for food-grade starches in bioplastic production raises sustainability concerns and encourages the search for alternative sources. Medicinal plants offer an underutilized yet promising starch source. *C. caesia* Roxb., commonly known as black turmeric, is a rhizomatous medicinal plant rich in secondary metabolites and polysaccharides. Recent studies have shown that the rhizomes of *C. caesia* contain approximately 47.24% starch, with unique physicochemical properties, such as low solubility (0.47%), which can influence film-forming capabilities and binding efficiency (Borah *et al.,* 2019). Utilizing starch from *Curcuma caesia* could offer a dual benefit: value addition to medicinal plants and development of biodegradable packaging material. Additionally, fruit peels such as those from bananas and citrus fruits are abundantly available agricultural wastes rich in lignocellulosic fibers and pectin, making them suitable for reinforcement in bioplastic matrices (Bano & Negi, 2017; Sharma *et al.,* 2021). Integrating these waste materials into bioplastic production not only contributes to waste valorization and circular economy goals but also improves the mechanical and biodegradability characteristics of the resulting films.

In this study, we explore the feasibility of using *C. caesia* starch in combination with banana and orange peels to fabricate bioplastics. The objective is to optimize the starch concentration, plasticizer content, and processing conditions to develop flexible, biodegradable bioplastic sheets, and assess their degradation under soil conditions. The work contributes to sustainable materials research by promoting the use of plant-based, non-food, and agro-waste resources for bioplastic production.

II. MATERIALS AND METHODS

1. Collection and Preparation of Raw Materials

Fresh rhizomes of *Curcuma caesia* Roxb. were sourced from local farms in Kannur, Kerala, India. The rhizomes were washed thoroughly under running tap water to remove soil and other particulate matter. The outer skin was carefully peeled using a sterile stainless-steel knife, and the cleaned rhizomes were grated and used for starch extraction.

Three varieties of banana peels—Red banana (Musa acuminata), Nenthiran banana (Musa paradisiaca), and Poovan banana (Musa spp.)—and Kamala orange (Citrus reticulata) peels were collected from fruit vendors. The peels were washed under tap water followed by distilled water to remove adhering dirt and pesticide residues. The cleaned peels were manually chopped into uniform small pieces (~1–2 cm).

2. Pre-treatment of Fruit Peels

The chopped banana peels were soaked in 0.2 M sodium metabisulfite solution for 45 minutes at room temperature to inhibit enzymatic browning and microbial growth. After soaking, the peels were rinsed with distilled water and boiled in fresh distilled water for 30 minutes at 100°C to soften the cellulosic material and improve plasticity.

Kamala orange peels were similarly washed, chopped, and boiled directly in distilled water for 30 minutes without prior soaking. Post-boiling, all peels were drained and placed on sterile filter paper for surface drying (~30 minutes). Once partially dried, the peels were transferred to a sterile mortar and pestle and ground into a fine, smooth, homogeneous paste.

3. Extraction of *Curcuma caesia* Starch

The grated rhizomes of *Curcuma caesia* were homogenized in distilled water (1:3 w/v) and filtered through muslin cloth to remove fibers. The filtrate was left undisturbed at room temperature for 4 hours to allow starch sedimentation. The supernatant was carefully decanted, and the starch pellet was washed twice with distilled water and oven-dried at 40°C for 24 hours. The dried starch was powdered and stored in airtight containers for further use.

4. Bioplastic Film Preparation

To prepare bioplastics, 50 g of fruit peel paste was transferred into a 250 ml borosilicate glass beaker. Depending on the peel type, *Curcuma caesia* starch was added in which Banana peels: 0.5 g starch per 50 g paste and Orange peels: 1.0 g starch per 50 g paste. To the starch-peel mixture, 8 ml of 0.5 N hydrochloric acid (HCl) was added as a catalyst to initiate starch gelatinization and hydrolysis reactions. The mixture was stirred thoroughly using a sterile glass rod to ensure uniform dispersion. Then, 6 ml of glycerol was added as a plasticizer to improve film flexibility and reduce brittleness. The mixture was again stirred until a viscous, uniform gel-like consistency was achieved. The pH of the mixture was measured using a digital pH meter and adjusted to the optimal range of 5.5–6.0 using 0.5 N sodium hydroxide (NaOH) dropwise, as required.

5. Casting and Drying of Bioplastic Films

The prepared mixture was poured and uniformly spread onto a clean ceramic tile using a sterile glass rod or spatula to ensure even coating. The tile was placed in a pre-heated oven and baked at 150°C for 12 minutes. This thermal treatment ensured partial evaporation of water, activation of the starch matrix, and solidification of the film. After baking, the tile was removed and allowed to cool to ambient temperature (25 ± 2°C). The bioplastic film was carefully detached from the tile surface using a metal spatula and stored in a desiccator to prevent moisture absorption until further testing.

6. Biodegradation Study

To evaluate biodegradability, each film sample was cut into equal-sized strips (5 cm × 5 cm) and buried approximately 5 cm deep in 500 g of wet red soil placed in plastic containers. The containers were maintained under ambient outdoor conditions for 60 days. Moisture content in the soil was maintained by periodic watering. Visual observations of degradation were made every 15 days, and changes such as discoloration, tearing, and structural integrity were documented. Complete degradation was defined as >90% mass loss or visual disappearance of the film.

7. Film Thickness Measurement

The thickness of the prepared bioplastic sheets was measured using an air wedge apparatus (accuracy ±10 µm) at the Department of Physics, Government College of Technology, Coimbatore. Three readings were taken at different points of each sheet, and the average was reported.

III. RESULTS AND DISCUSSION

1. Visual and Physical Characteristics of the Bioplastic Films

The bioplastic films produced using *Curcuma caesia* starch in combination with fruit peels (banana and orange) were uniform, flexible, and non-sticky. The optimal starch concentration was found to be 0.5 g per 50 g of banana peel paste and 1.0 g per 50 g of orange peel paste. Lower concentrations of starch led to poor binding and film fragility, while higher concentrations resulted in brittleness and uneven spreading—likely due to the excess amylose content disrupting uniform gelatinization (Avérous, 2004; Mishra *et al.,* 2008). The average thickness of the bioplastic films was 330 ± 20 µm, which is comparable to commercial polyethylene bags used in the food and packaging industries (Sharma *et al.,* 2021). The visual appearance and surface morphology of bioplastic films varied with peel source, as shown in Figure 1. Films made with Poovan peel showed greater roughness and brittleness, whereas Red banana-based films were more uniform and flexible.

Figure-1 The visual appearance and surface morphology of bioplastic films varied with peel source

Fig 1. *Bioplastic sheets fabricated using individual and blended banana peel types—Poovan, Nenthiran, and Red banana—exhibited distinct surface textures and coloration. Variations are attributed to differences in fiber content, pigment composition, and starch-binding efficiency. Notably, the Red banana + Nenthiran blend showed more uniform texture and less shrinkage post-baking.*

2. Role of *Curcuma caesia* Starch in Film Formation

The addition of *Curcuma caesia* starch improved the film-forming ability of the fruit peel paste. Starch gelatinization, aided by acid hydrolysis (using 0.5 N HCl), allowed better integration of glycerol and peel matrix during baking. The low solubility and moderate amylose content of *Curcuma caesia* starch (Borah *et al.,* 2019) contributed to enhanced film integrity and reduced water sensitivity compared to typical starches. The starch acted as a bio-binder, maintaining cohesion between the pectic and fibrous components of the peel paste. Similar starch-based film enhancements have been documented in studies utilizing medicinal plant starches (Bangar *et al.,* 2021), validating the present findings that *Curcuma* *caesia* can serve as an eco-friendly and functional alternative to conventional sources.

3. Optimization of Processing Parameters

The optimum baking temperature and time were determined to be 150°C for 12 minutes. At lower temperatures (<130°C) or shorter durations, the films remained soft and incomplete, while higher temperatures (>160°C) or prolonged heating caused charring and film brittleness. Interestingly, a previous study by JaiKishan Chandrana and Sai Chandra (2021) reported an optimum baking temperature of 120°C. These results align with thermal transition behaviours reported in starch-glycerol matrices, where gelatinization and plasticization must reach a critical balance for stable film formation (Krochta & De Mulder-Johnston, 1997). The addition of 6 ml glycerol per 50 g of peel paste provided sufficient plasticity, making the films flexible and easy to peel. Glycerol, a commonly used plasticizer, reduces intermolecular hydrogen bonding among starch chains, thereby enhancing mobility and flexibility (Sanyang *et al.,* 2016). However, excess glycerol was avoided to prevent film stickiness and tackiness.

4. Soil Biodegradability Analysis

The soil degradation test revealed that all bioplastic films began to show visible degradation by the 30th day and fully degraded by the 60th day. Degradation included discoloration, tearing, fungal colonization, and physical breakdown. The presence of fruit peel fiber, cellulose, and pectin facilitated microbial degradation under soil conditions. Figure 2 illustrates the visual stages of degradation at 15-day intervals, confirming progressive breakdown and microbial activity. The rapid biodegradability observed is consistent with previous studies using banana peel and starch-based composites (Ghazali *et al.,* 2020; Bano & Negi, 2017). These findings reinforce the suitability of these bioplastics for short-term applications such as mulch films, nursery grow bags, capsule coating, and eco-friendly packaging, where degradation after use is advantageous.

Figure-2 Biodegradation Sequence of Bio Plastic Film Over 60 Days in Red Soil.

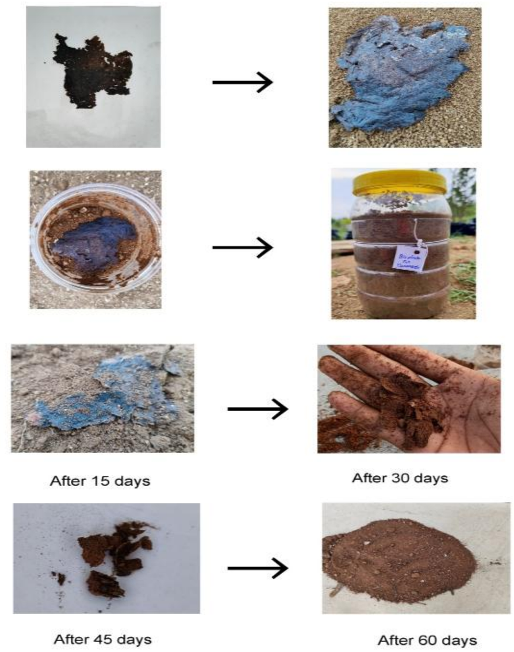

Fig 2.The bioplastic sheet was buried in moist red soil and observed at 15-day intervals. Initial fragmentation began at day 15, followed by partial microbial decomposition at day 30. Significant degradation was visible by day 45, and complete disintegration occurred by day 60, indicating the sheet's efficient biodegradability under natural soil conditions.

5. Comparative Advantage and Sustainability

Compared to cornstarch and potato starch-based films, *Curcuma caesia*-based bioplastics offer several benefits such as Utilization of a medicinal plant starch not competing with food-grade starch sources,Integration of fruit peel waste, promoting circular economy principles and Achieving commercially viable film thickness and biodegradability with minimal processing. Moreover, the use of agro-waste reduces the carbon footprint and cost of raw materials, aligning with the goals of green chemistry and zero-waste production (Nandakumar *et al.,* 2022).

CONCLUSION

The present study demonstrates the successful fabrication of biodegradable bioplastic films using Curcuma caesia starch in combination with banana and orange peel waste. The optimized formulation, comprising 0.5–1.0 g of medicinal plant starch with fruit peel paste and plasticizer, produced films with desirable mechanical integrity and flexibility. The films exhibited a consistent thickness of approximately 330 ± 20 µm and degraded completely within 60 days under natural soil conditions, confirming their environmental compatibility. The incorporation of Curcuma caesia starch enhanced the binding and film-forming properties, while the use of agro-waste materials like banana and citrus peels contributed to cost-effectiveness, waste valorization, and alignment with circular economy principles. Among the peel types, red banana and blended peel formulations exhibited superior texture and degradation profile. Overall, this green bioplastic formulation offers a promising alternative to petroleum-derived packaging materials for short-term applications such as nursery grow bags, capsule coatings, and food wrappers. Future studies should focus on scaling the process, assessing mechanical strength and water resistance of Curcuma caesia-based bioplastics to broaden their applicability in healthcare and food industries.

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