Bioplastic formulation from organic waste and its characterization

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Abstract:
A substitute for plastic is bioplastic, derived from renewable resources such as maize starch, straw, wood chips, sawdust, and recycled food waste. They provide environmental benefits such as reduced fossil fuel dependency and lower carbon footprint but face challenges like high production costs and limited biodegradability under certain conditions. Applications include packaging, agriculture, automobiles, and medical fields. Future advancements in production technologies and waste management, fuelled by increasing consumer consciousness and regulatory assistance, will strengthen the feasibility and acceptance of bioplastic, contributing significantly to sustainable material solutions. This research paper aims to formulate bioplastic from vegetable and fruit waste which could replace conventional plastic.

KEYWORDS: Bioplastic, Biodegradability, Bio-based, Petroleum-based and Sustainability

1. Introduction

Plastics made of petrochemicals are not environmentally friendly, because they have a significant amount of carbon footprint. The overuse of plastics has severely impacted the ecosystem, and humans are estimated to produce 34 million tons of plastic annually. Approximately 7% of that is recycled, with the remaining 93% being disposed of in landfills, seas, and oceans. Carbon dioxide and methane, two greenhouse gases released during the burning or incineration of plastic, impact the global climate. Numerous issues, including trash buildup on land and in natural ecosystems like the sea and oceans, are brought on by products based on petrochemical derivatives. Humans also suffer from thyroid hormone imbalance due to plastic pollution (Shah et al., 2021; Fredi et al. 2021). Bioplastics are a revolutionary class of biobased and biodegradable materials that are derived from biomass and waste materials like jackfruit, waste banana peel, organic waste, agriculture waste, newspaper waste, oil palm empty fruit bunch, sugar cane, corn starch, potato starch, rice straw, rapeseed oil, vegetable oil, cellulose from plants, starch, cotton, bacteria, and at times from multiple nanoparticles such as carbohydrates (polysaccharides) (Abe et al. 2021;Bhuyan et al. 2022). Bacteria, algae, and fungi are examples of natural microorganisms that can degrade bioplastic (Sidek et al., 2019; White et al.2020; Atiwesh et al. 2021). Bioplastics have the potential to significantly influence the future of plastics and build a more sustainable society through sustained research, investment, and cross-sector collaboration. So, the present study aims to formulate bioplastic from vegetable and fruit waste which could replace conventional plastic.

2. **Materials and methodology**

2.1. Collection of organic waste and drying

1. The organic waste such as fruits and vegetable peel was collected from home and fruit vendors of Kalinga University.
2. The gathered waste was properly cleaned of dirt and contaminants using tap water.
3. To remove moisture, the waste was next allowed to air dry in the sun for a few days.

2.2. Organic waste powdering

1. To start, the dried waste's particle size was decreased by crushing it in a mortar and pestle.
2. Next, the waste was ground into a fine powder in a mixer jar.

2.3. Formation of Bioplastic (Samer 2019, Shrestha et al., 2023)

The different concentrations (10%, 20%, and 25%) of bioplastic were formed using cornstarch, vinegar, glycerol, waste powder, PVA (Polyvinyl Alcohol), and distilled water. The amount of cornstarch, glycerol, vinegar, and distilled water is 5 grams, 5 ml, 5 ml, and 50 ml respectively. The quantity of these materials is kept constant while preparing different concentrations of bioplastic. There is only variation in the amount of waste powder and PVA, as shown in Table 4.4. The prepared solutions of bioplastic film are evenly spread over a flat surface and kept overnight at room temperature.

2.4. Characterization of bioplastic

a. Density assay (Dhivya et al., 2021).

By cutting a film of 1.2 × 1.2 cm in size and measuring the mass of the film with an analytical balance, the density of the newly produced bioplastic was investigated. In summary, the following formula is typically applied to denote and determine the mass divided by the volume of density.

$$Density\ (\%) = \frac{Mass\ (gram)}{volume\ (cm3)}$$

b. Swelling assay (Dhivya et al., 2021).

A piece of bioplastic film with an approximately 1.2 x 1.2 cm diameter was first weighed. The weighted film piece was then added to a container with distilled water and left undisturbed for 24 hours at room temperature. After incubation, the bioplastic film was weighed once more to record the percentage of swelling ratio, which was calculated using the following equation:

$$Swelling\ ratio\ (\%) = \frac{wet\ weight - dry\ weight}{wet\ weight} \times 100$$

Where,

Dry weight = original weight of bioplastic

Wet weight =swelling weight of bioplastic (peeled film), respectively.

c. Solubility assay (Dhivya et al., 2021).

The solubility assay was used to investigate the sustainability and retention of the obtained compounds. Pre-weighed bioplastic film of various concentrations was immersed overnight in several solvents, including ammonia, methanol, sulphuric acid, ethanol, acetic acid, and acetone.

2.5. Biodegradability potential

The biodegradability test is done to assess the biodegradation rate of bioplastic in comparison with conventional plastic. In this approach, the isolated plastic-degrading bacteria is inoculated in nutrient broth with the help of an inoculating loop in a sterile ambience. Now, with the help of forceps small pieces of bioplastic film measuring 1.2*1.2 cm of different concentrations and a piece of normal plastic are immersed in nutrient broth. Then, the flasks are kept in an orbital shaker incubator for different durations to determine the biodegradation rate of bioplastic films concerning normal plastic.

3. Results and discussion

3.1. Initial observation of bioplastic films

Table 1: Physical appearance and transparency of bioplastic films

Sample name	Waste powder (in grams)	PVA (in grams)	Physical appearance	Transparency
A	0.5	-	Light brown with a smooth texture.	Opaque
B	0.5	0.5	Light brown with a smooth texture.	Opaque

C	1	-	Brown with a rough texture	Opaque
D	1.25	-	Dark brown with a tough texture	Opaque

The above table shows the physical appearance of the bioplastic film is influenced by changes in the concentration of waste powder. By increasing the concentration of waste powder in the different samples of the bioplastic film, they became darker in color and tougher in texture. Adding PVA does not significantly impact the physical appearance compared to the samples without PVA. All the samples remain opaque regardless of their composition.

3.2 Density assay

Table 2: Density of bioplastic films

Sample name	Waste powder (in grams)	PVA (in grams)	Mass (in grams)	Volume (in cm3)	Density (mass/volume)
A	0.5	-	0.034	1.728	0.0196
B	0.5	0.5	0.035	1.728	0.0202
C	1	-	0.049	1.728	0.0283
D	1.25	-	0.051	1.728	0.0295

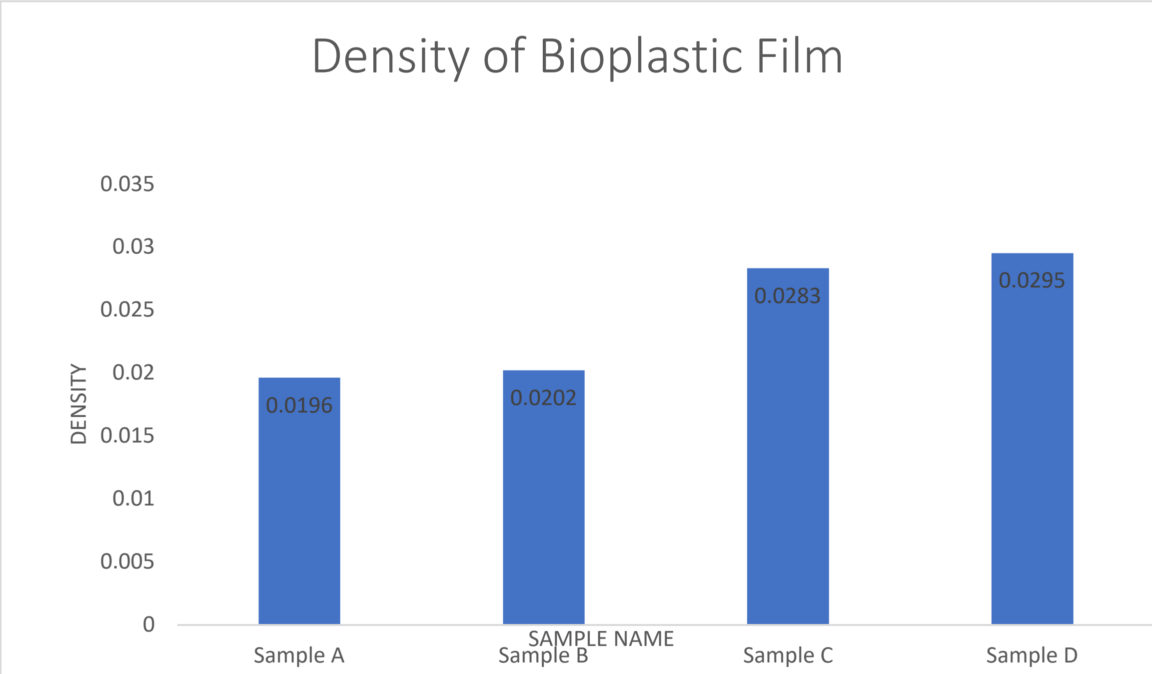

Fig. 1: Density of bioplastic samples

The density of the bioplastic film of different samples increases with the increase in the amount of waste powder. And there is a slight increase in the density of the sample with PVA. Therefore, the concentration of the waste powder and the inclusion of PVA are significant factors affecting the density of bioplastic film

3.3 Swelling ratio

Table 3: Swelling ratio of bioplastic films

Sample name	Waste powder (in grams)	PVA (in grams)	Dry weight (in grams)	Wet weight (in grams)	Swelling ratio (%)
A	0.5	-	0.034	0.1	66%
B	0.5	0.5	0.035	0.09	61.1%
C	1	-	0.049	0.07	30%
D	1.25	-	0.051	0.06	15%

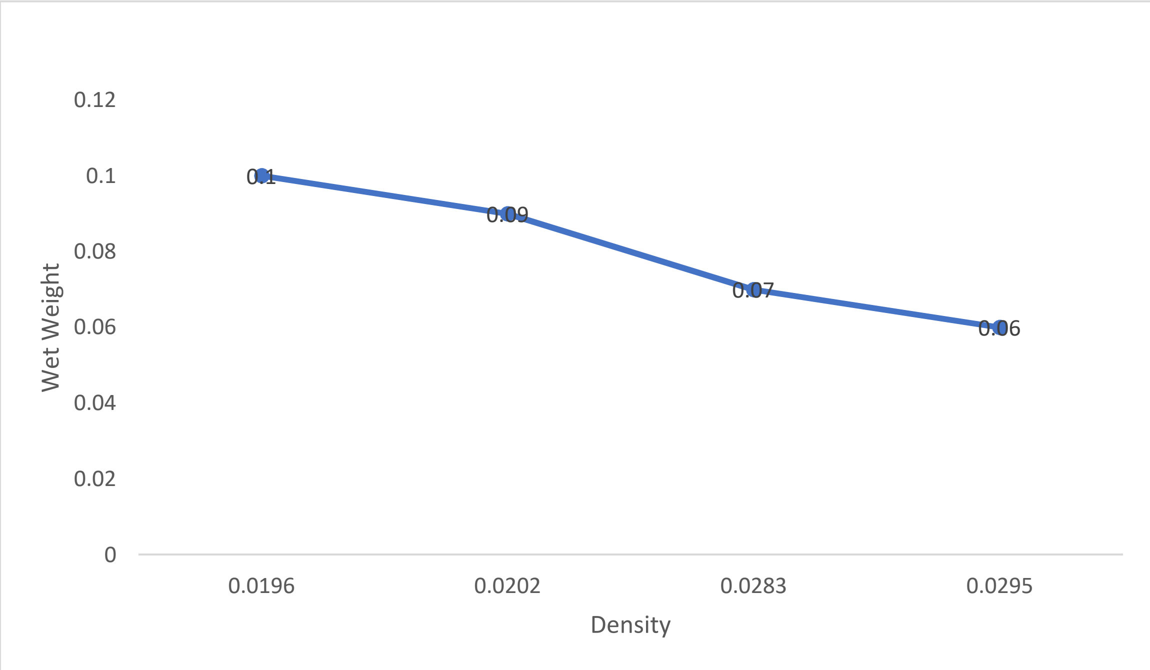

Fig 2: Water absorption efficiency of bioplastic with varying density

The increase in the amount of waste powder in samples leads to higher dry and wet weight but a lower swelling ratio. Adding PVA (as in sample B) also leads to higher wet and dry weight but a lower swelling ratio similar to other samples without PVA. It means the swelling ratio is inversely proportional to the density of the sample (as the density increases swelling ratio of the sample decreases)

3.4. Solubility assay

Table 4: Solubility test of bioplastic films

Solvents	Sample A	Sample B	Sample C	Sample D
Ammonia	Insoluble	Insoluble	Insoluble	Insoluble
Acetone	Insoluble	Insoluble	Insoluble	Insoluble
Acetic acid	Insoluble	Insoluble	Insoluble	Insoluble
Chloroform	Insoluble	Insoluble	Insoluble	Insoluble
Ethanol	Insoluble	Insoluble	Insoluble	Insoluble
Methanol	Insoluble	Insoluble	Insoluble	Insoluble
Sulphuric acid	Soluble	Soluble	Soluble	Soluble
Water	Insoluble	Insoluble	Insoluble	Insoluble

The above-tabulated data shows that all the samples of bioplastic films are only soluble in sulphuric acid (in a highly acidic environment). The addition of PVA and variation in the concentration of waste powder do not affect the solubility of bioplastic film in the tested solvents, except in sulphuric acid, where all the samples dissolve.

3.4. Biodegradability potential

Table 6: Degradation rate of bioplastic sample of 7 days

Sample name	No. of days	Initial weight (in grams)	Final weight (in gram)	Percentage of degradation
Sample A	7	0.5	0.26	48%
Sample B	7	0.5	0.30	40%
Sample C	7	0.5	0.37	26%
Sample D	7	0.5	0.39	22%
Normal plastic	7	0.5	0.49	2%

Table 7: Degradation rate of bioplastic sample of 7 days

Sample name	No. of days	Initial weight (in grams)	Final weight (in gram)	Percentage of degradation
Sample A	14	0.5	0.17	66%
Sample B	14	0.5	0.19	62%
Sample C	14	0.5	0.26	48%
Sample D	14	0.5	0.28	44%
Normal plastic	14	0.5	0.46	8%

Table 8: Degradation rate of bioplastic sample of 21 days

Sample name	No. of days	Initial weight (in grams)	Final weight (in gram)	Percentage of degradation
Sample A	21	0.5	0.09	82%
Sample B	21	0.5	0.11	78%
Sample C	21	0.5	0.18	64%
Sample D	21	0.5	0.2	60%
Normal plastic	21	0.5	0.43	14%

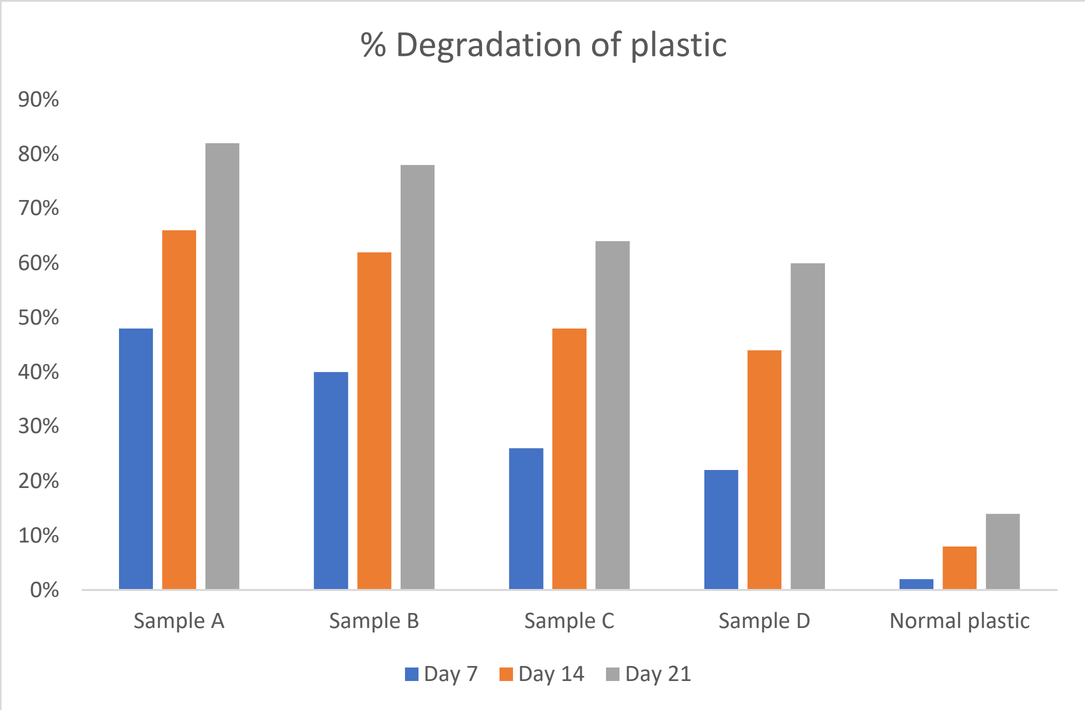

Fig 3: The degradation percentage of bioplastic and normal plastic

All samples have shown partial degradation within a week after incubation with plastic-degrading bacteria. As the number of days increased the percentage of biodegradation of the samples also increased. The degradation rate of normal plastic was slower than the samples of bioplastic

The change in concentration of waste powder affects the physical appearance, density, and swelling ratio of different samples of bioplastic film. However, the addition of PVA does not have strong impact on the physical appearance of bioplastic film, but it has a slight effect on the density and swelling ratio of the samples. The samples become darker and tougher with increasing concentration of waste powder. The density also increases with an increase in the concentration of waste powder. However, the swelling ratio decreases with the increase in the density and amount of the waste powder. The addition of PVA (in sample B) reduces the swelling ratio, indicating that PVA also contributes to less water absorption. A slight increase in the density was also observed in Sample B because of the addition of PVA along with the waste powder.

All the samples of bioplastic films were only soluble in sulphuric acid, irrespective of the concentration of waste powder and PVA used in the formation of bioplastic film. This suggests that bioplastic film is resistant to a wide range of solvents that are less acidic than sulphuric acid but susceptible to highly acidic environments. The rate of degradation of different samples of bioplastic films is faster than the conventional plastic material. This is because the percentage of degradation of bioplastic samples increases with the increase in the duration of days. The biodegradation of bioplastic could also be enhanced under the influence of a strong acidic environment. The entire result concludes that samples of bioplastic degrade at a faster rate and, therefore can be used as an eco-friendly alternative to petroleum-based plastic to minimize its usage and reduce the adverse effects on the environment caused by it. The results obtained are primary reports only, further extensive research and evaluation is required before its commercial production.

4. Conclusion and future prospectus

Bioplastic is emerging as a promising alternative to conventional plastic. With ongoing research, bioplastics have the potential to replace conventional petroleum-based plastics in a variety of industries, including packaging, agriculture, and the medical field, due to their increasing efficiency, cost-effectiveness, and adaptability. It has several advantages such as low carbon footprints, biodegradability, agricultural waste disposal, nontoxicity, and reduced reliance on limited fossil fuels. As an alternative to depleting petroleum reserves, they can be produced from renewable resources including sugarcane, corn starch, and algae, encouraging sustainable agriculture practices. However, bioplastic has some disadvantages which include its hydrophilic nature, low material performance, poor mechanical properties, high production costs, and a lack of awareness among customers regarding its label, identification, and recycling. In addition, not all bioplastics can be decomposed naturally, others need industrial composting facilities, which are not easily accessible. It is essential to balance these benefits and drawbacks to develop and use bioplastics in the future.

For effective end-of-life management, developments in the infrastructure for composting and recycling bioplastics are essential. The switch from conventional plastics to bioplastics will be fuelled by cooperative efforts by corporations, governments, and academic institutions to develop favorable policies, invest in research, and educate consumers. By working together, bioplastics have the potential to significantly reduce their adverse impact on the environment, promote a circular economy, and lay opportunities for a more sustainable future.

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