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ABSTRACT

This research work is for synthesis and characterisation of bioplastic from dried sugarcane leaves using cellulose mediated method. This is a substitute for petrochemical plastic which can persist in soil and water for years leaching harmful elements. FTIR research confirmed the presence of certain cellulose and ester functional groups required for films fabrication. The bioplastic obtained has an elongation break point of 44% and a tensile strength of 5.6 MPa. This means that the bioplastic is a mechanically stable polymer. Water solubility and water absorption tests revealed 65% solubility within 24 h. Soil biodegradability was 61.7% within 7 days, which indicates a high degree of environmental compatibility.

Post-dissolution water analysis represents normal water parameters such as pH: 7.9, TDS: 418 mg/L, BOD: 7.7 mg/L, COD: 14 mg/L, Na: 9.2 mg/L confirming non-toxicity and biocompatibility. Compared to petrochemical plastics, the sugarcane leaf-based bioplastic demonstrated much higher biodegradability, sustainability, and waste valorisation, making it a feasible solution for environmental applications.

Keywords: Biodegradable, Bioplastic, Petrochemical Plastic, Sugarcane dried leave

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CHAPTER 1
INTRODUCTION

Plastics have evolved a necessary part of living due to their adaptability, versatility, and cost-effectiveness. However, this convenience is raising severe environmental effects day by day. Most conventional plastics are obtained from non-renewable petrochemical sources such as petroleum, and they offer great resistance to degradation. Globally, plastic production has been over 400 million tonnes annually and it is estimated that approximately 79% of plastic after use ends up in landfills and only a small fraction, about 9% is majorly recycled, while the rest either remains for centuries or releases harmful compounds when incinerated[1].

17 ommon single-use plastics such as low-density polyethylene (LDPE) as well as high-density polyethylene (HDPE) are majorly problematic as they can persist in nature for up to 250 years under landfill or water bodies [2][3] plastics leads to soil infertility, groundwater contamination, and the formation of microplastics, are mostly detected in water bodies, food sources, and also in human tissues now a days[4].

In view of this increasing crisis, bioplastics have emerged as a favorable alternative as they are derived from the known sustainable resources such as starch, cellulose, chitin, and plant oils. They are designed to clone the properties of 9 trochemical plastics while being biodegradable under natural conditions such as polylactic acid (PLA) and polyhydroxyalkanoates (PHA) produced from edible crops like corn, cassava, or sugarcane juice [5]. These bio alternatives help reduce fossil fuel dependence, but their large-scale production highly competes with food supplies and raises huge concerns regarding land use and food security in dominance.

To overcome this issue, researchers are focusing on non-edible, waste biomass as agricultural residues such as wheat straw, rice husk, banana peels and sugarcane bagasse are renewable, inexpensive, and abundant in huge amount [6]. Utilizing these waste residues not only prevents waste accumulation but also uplift the concept of a circular bioeconomy, representing a sustainable solution where agricultural by-products are converted into high-value products instead of being burned in fields causing alarming air pollution [7]

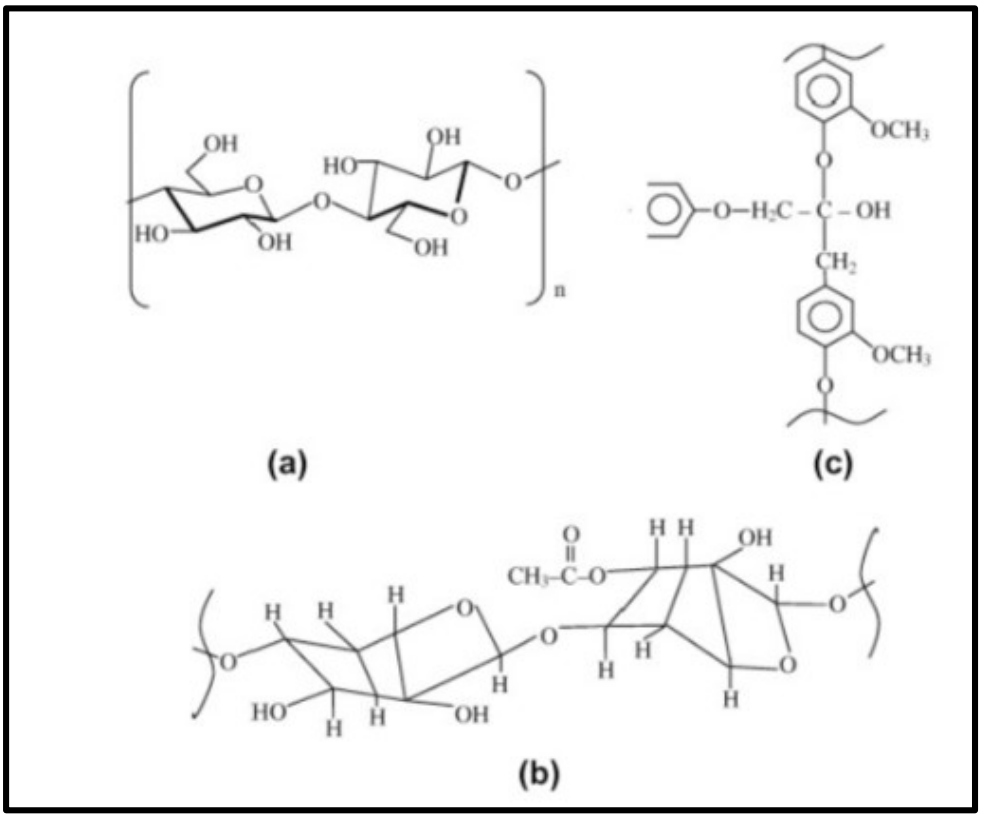
Among these residues, sugarcane dry leaves present an abundant and underutilized feedstock. India, the world's second-largest producer of sugarcane, generates 65 million of tonnes of dry leaves each year during harvest [8]. These leaves are majorly burned in open fields, causing air pollution, smog formation, as well as greenhouse gas emissions.

Sugarcane leaves are rich in lignocellulosic composition, that are the key structural constituents of biomass [9]. Cellulose being the most abundant natural polymer on planet, offers a strong prospect for bioplastic evolution due to

its renewability, film-making ability, and biodegradability. Despite the growing research in bioplastics, there remains a gap in the utilization of sugarcane dry leaves as a direct source of raw material for plastic synthesis.

The present research, therefore, focuses on the assessment of the physical and environmental characteristics of the obtained bioplastic from sugarcane dried leaves (SCLBP) and assess its capability as a sustainable alternate for petrochemical plastics. This work provide to the global effort toward achieving principles of the United Nations Sustainable Development Goals representing SDG 12: Responsible Consumption and Production and SDG 13: Climate Action thereby, promoting waste valorization and decreasing environmental hazards[10].

This study presents a sustainable approach to obtain and distinguish bioplastics from sugarcane dry leaves through a cellulose-extraction pathway, offering an environment responsible solution to conventional petrochemical plastics. By using abundant agricultural residue like sugarcane dried leaves, this research not only contributes to plastic waste mitigation approach but also provides a viable path for converting biomass into biodegradable material that offers non-toxic soil and water degradation characteristics.



1.1 Global Plastic Pollution Crisis

Plastic pollution is one of the biggest environmental problems of the twenty-first century. Since the advent of commercial plastic manufacture in the 1950s, over 9 billion tonnes of plastic have been made worldwide. Plastics are now essential materials in the packaging, agricultural, health care, electronics, and transportation industries because they are strong, light, and inexpensive to produce. However, the rampant use of single-use plastics and the poor disposal habits have led to the accumulation of massive amounts of plastic debris in terrestrial and marine ecosystems. Every year, millions of tonnes of plastic waste are predicted to be dumped into the ocean, threatening marine biodiversity and drastically changing ecosystems. Plastic waste can remain for decades or perhaps centuries before it slowly breaks down into microplastics and nanoplastics.

1.2 Environmental Impact of Petrochemical Plastics

Conventional polymers are derived from non-renewable fossil fuels such as petroleum and natural gas. Polyethylene (PE), polypropylene (PP), polystyrene (PS) and polyethylene terephthalate (PET) are mechanically and chemically resistant and therefore very durable. But its resistance to biological degradation in nature is also a major environmental disadvantage. Landfill disposal takes up land resources, whereas incineration produces pollutants and greenhouse gases. Furthermore, petrochemical plastics develop secondary microplastics upon degradation that can persist in the environment for an extended duration. The increasing demand for plastics from fossil fuels also results in higher carbon emissions and the consumption of scarce natural resources. Therefore, the creation of sustainable and biodegradable alternatives.

1.3 Bioplastic as a sustainable Future

Bioplastics have received a lot of attention as eco-friendly alternatives to petroleum-based plastics. These goods are wholly or partly based on renewable biological resources such as starch, cellulose, proteins, vegetable oils and microbial metabolites. Bioplastics may have biodegradability, compostability or bio-based qualities depending on their composition and structure. Like polylactic acid (PLA), polyhydroxyalkanoates (PHA), thermoplastic starch and cellulose based polymers. Unlike conventional plastics, biodegradable bioplastics can be degraded to carbon dioxide, water, and biomass by microorganisms under favourable environmental conditions. In addition, their production can reduce greenhouse gas emissions and dependence on fossil fuels. However, the utilisation of food crops as feedstocks for the manufacture has prompted concerns regarding food security, land use and economic sustainability .

1.4 Agricultural Waste as a Resource for Bioplastic Production

Agricultural activities generate huge quantities of biomass residues every year. Materials such as rice straw, wheat straw, corn stalks, banana peels, sugarcane bagasse, coconut husk and sugarcane dry leaves are often disposed of, burnt or left to rot in the open. Burning agricultural leftovers in the open air dramatically increases greenhouse gas emissions, air pollution and depletion of vital biomass resources. The cellulose, hemicellulose and lignin of these wastes can be used as renewable raw material for production of biodegradable items. One of efficient techniques for waste management and also for supporting the ideas of circular economy is the conversion of agricultural waste into value-added goods such as biofuels, biocomposites and bioplastics. Such measures promote efficient use of resources, minimise environmental degradation and provide greater economic opportunities to rural communities.

1.5 Sugarcane Dry Leaves as a Promising Feedstock

Sugarcane is one of the most cultivated crops in the world and is a particularly important crop in countries such as India, Brazil, China and Thailand. Agricultural wastes including huge quantities of straw and dry leaves are created during harvesting operations. Typically these residues are either burnt in the field or dumped as litter, causing pollution and the production of greenhouse gases. Sugarcane dry leaves are a useful feedstock for cellulose extraction and development of biodegradable goods because of the high content of cellulose, hemicellulose and lignin. Its high cellulose content provides excellent film forming ability, biodegradability, renewability and mechanical strength. Sugarcane dry leaves are still under-utilized when compared to sugarcane bagasse despite their availability. Therefore, the application in the production of bioplastics is a way to safeguard the environment and valorise the biomass in an eco-friendly way.

1.6 Research Gap

Biodegradable plastics have made great strides, although most of the research has been on starch-based bioplastics, polylactic acid (PLA), polyhydroxyalkanoates (PHA) and cellulose from agricultural wastes such as sugarcane bagasse, rice straw and banana fibres. Sugarcane dry leaves are one of the least investigated lignocellulosic residues for the creation of bioplastic biofilms, although they are produced in large quantities during harvesting operations. The current research focuses on the utilisation of sugarcane bagasse, while the potential of sugarcane dry leaves as a direct source of cellulose for biodegradable biofilms has received less attention. Besides, some research articles published thus far have mostly focused on the assessment of biodegradability with little

information on the physico-chemical behaviour, water interaction features, environmental compatibility and structural characterisation of the obtained films. However, the comparative analysis of mechanical performance, transparency, thickness and effect on water quality after deterioration of sugarcane leaf-based biofilms is still absent. There also aren't enough studies on whether the breakdown products from bioplastics made from sugarcane leaves are safe for the environment. Therefore, a detailed examination of cellulose extraction, biofilm development, physicochemical characterisation, biodegradability, mechanical properties and environmental friendliness is still required. The current study intends to address these gaps by developing a cellulose-based bioplastic biofilm from dried sugarcane leaves and evaluating its structural, mechanical, biodegradation, and environmental properties.

1.7 Novelty of the Work

The novelty of the present work is the use of sugarcane dried leaves as the major feedstock for the preparation of biodegradable cellulose-based bioplastic biofilms, an underutilised agricultural waste. The present work explores the direct conversion of sugarcane dried leaves into value-added biofilm materials by means of cellulose extraction and film production approaches, in contrast with much of the published work that focuses on sugarcane bagasse or starch-rich biomass.

The present study also presents the novelty of evaluating mechanical, physicochemical, biodegradation, and environmental performance in a single experimental framework. Besides the evaluation of tensile strength, elongation, transparency, water solubility and biodegradation behaviour, the water quality after film dissolving in terms of pH, BOD, COD, TDS and salt concentration is also studied. Such an integrated environmental assessment is infrequently reported in sugarcane leaf-based bioplastics studies.

This research also furthers waste valorisation and the notions of the circular bioeconomy by transforming agricultural waste, which is generally burnt in fields, into an environmentally beneficial biodegradable product. The results support the development of ecologically friendly packaging alternatives and advocate the use of sustainable resource management approaches.

1.8 Objectives of the Study

1.8.1 Main Objective

To develop and describe a biodegradable bioplastic biofilm using cellulose extraction from sugarcane dry leaves and to evaluate its feasibility as an environmentally sustainable material.

1.8.2 Specific Objective

1. To collect and process dry leaves from sugarcane as a source of lignocellulosic biomass for cellulose extraction.
2. To remove cellulose from dried sugarcane leaves by bleaching and alkali treatments.
3. To produce biodegradable bioplastic biofilms using appropriate plasticising agents and extracted cellulose.

4. To evaluate the physical features of the biofilm such as thickness and transparency.
5. To find out the water solubility and water absorption characteristics of the created bioplastic biofilm.
6. To evaluate the biodegradation behaviour of the formed biofilm in soil in natural environment.
7. To study the mechanical properties of the bioplastic biofilm such as elongation at break, Young's modulus and tensile strength.
8. To describe the structural make up and functional groups of the generated biofilm by FTIR analysis.
9. To analyse the environmental compatibility of the degraded biofilm by applying physicochemical analysis of water quality measures.
10. To assess the potential of bioplastic biofilms obtained from dried sugarcane leaves as eco-friendly and sustainable materials for packaging.

1.9 Scope of the Study

The major objective of the present work is to synthesise and characterise biodegradable bioplastic biofilms obtained from dried leaves of sugarcane by cellulose extraction methodologies. The study includes the use of environmental friendly materials for cellulose isolation, chemical pretreatment, biomass gathering and biofilm production. This work also evaluates important mechanical, physical and environmental parameters of the created biofilm such as thickness, transparency, water solubility, water absorption, tensile strength, elongation at break, Young's modulus and biodegradability. Structural characterisation is conducted by Fourier transform infrared spectroscopy (FTIR) to discover the principal functional groups responsible for biofilm formation. By examining changes in water quality indices during biofilm disintegration, the study extends beyond environmental assessment and provides insight into its ecological safety. Advanced industrial scale processing, commercial product

development, thermal characterisation, barrier property evaluation, nanocellulose reinforcing and long-term durability investigation are outside the scope of this study, but may be considered for future research.

1.10 Significance of the Study

The increasing amounts of conventional plastic waste are a major environmental problem since it persists for long periods in terrestrial and aquatic environments and is not biodegradable. Therefore, sustainable alternatives from renewable resources have to be developed to minimise the environmental damage and to reduce the dependence on fossil fuel-based plastics. Here, the present work is quite significant since it uses dried leaves of sugarcane, an abundant agricultural waste, as a raw material for the development of biodegradable bioplastic biofilms. The present work contributes in sustainable waste management by providing a biodegradable product with added value from agricultural waste. The production of bioplastics from sugarcane dry leaves can also contribute to the reduction of waste generation, greenhouse gas emissions and air pollution, as these are often thrown away or burnt in open spaces. The research also advances the idea of a circular bioeconomy by promoting the effective utilisation of renewable biomass resources.
Moreover, the study delivers scientific knowledge on the mechanical, structural, physical and environmental aspects of sugarcane-leaf-based bioplastic biofilms. The data could assist authorities, corporations and researchers in finding environmentally benign replacements for standard plastics. When environmental sustainability is of prime importance, the resulting biofilm appears to be a promising candidate for biodegradable packaging materials.

Also, the research is consistent with the UN Sustainable Development Goals (SDGs), particularly SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action) and SDG 15 (Life on Land) through encouraging sustainable use of resources and minimising environmental damage. Thus, the present investigation promotes the development of sustainable biomaterials for future applications from a scientific and environmental point of view.

CHAPTER 2

LITERATURE REVIEW

Scientists are seeking to develop renewable and biodegradable materials from agricultural waste in response to growing environmental concerns stemming from the world's dependence on traditional plastics. Sugarcane dry leaves, a copious lignocellulosic residue created after harvesting, is an underutilised biomass with great potential for the development of bioplastics. The dry leaves are made of cellulose, hemicellulose and a tiny amount of lignin, which are important structural components for film formation, mechanical strength and biodegradability, similar to sugarcane bagasse. Due to its high cellulose content, easy regeneration, and wide availability in sugar-producing countries, sugarcane bagasse has emerged as a suitable sustainable feedstock in research.
Due to their similar composition to that of dry sugarcane leaves, they are a possible alternative raw material for cellulose-based bioplastics. Studies on agricultural residues have shown that lignocellulosic biomass can be easily converted into biodegradable polymers by chemical, enzymatic or thermal treatments [5]. Bagasse fibres have been studied for their potential as reinforcement in polymer composites and the effects of alkaline, silane or acid treatment on fibre and fibre matrix adhesion and mechanical behaviour have been studied.
These pretreatments remove lignin and waxy surfaces and expose hydroxyl groups, which increase bonding during film manufacturing. These results confirm the methodological approach for sugarcane dry leaves where cellulose rich slurry suitable for bioplastic synthesis is generated by chemical pulping and bleaching steps.

The simultaneous production of cellulose-glycerol and lignocellulosic bioplastics gives additional mechanistic insight into cellulose films derived from sugarcane leaves. FTIR examination shows characteristic O-H, C-H and C-O functional groups that influence hydrogen bonding and structural stability of bioplastic films. In cellulose–glycerol systems, plasticisers such as glycerol intercalate in between cellulose chains reducing the intermolecular contact and increasing flexibility . This effect has been thoroughly documented.
The impact of these molecular interactions on the mechanical behaviour and microstructure of sugarcane dry leaf bioplastics is also expected.Other agro-wastes such as rice straw, mango waste cellulose and cocoyam starch have also been used for the production of bioplastics providing more evidence that agricultural leftovers can be used to generate durable, biodegradable films. Rice straw cellulose films have good tensile properties and a significantly lower carbon footprint than petroleum based polymers.
The inherent microbial biodegradability of polysaccharide-based materials is illustrated by the rapid biodegradation of cocoyam starch bioplastics, which lose around 70% weight in 7 days.
The results indicate that sugarcane dry leaves can be used in the manufacture of bioplastics due to their similar biochemical composition. Many assessments claim that the valorisation of agricultural waste is congruent with the

notions of circular economy through pollution reduction, rural income increase and the substitution of renewable and biodegradable plastics for those based on fossil fuels. India grows a huge amount of sugarcane and the dry leaves are often discarded or burnt. Using them has two advantages, the first is to reduce the environmental hazards and the second is to create environmentally friendly packing materials. The research also reveals that lignocellulosic residues may be transformed into mechanically stable, biodegradable and sustainable polymer films, giving a solid foundation for the development of bioplastics based on sugarcane dry leaf. This makes dry sugarcane leaves a practical and scalable feedstock for developing novel green materials.

Chapter 3
Methodology

3.1 Raw Material Collection and Preparation

Sugarcane dry leaves were the major employed lignocellulosic biomass to produce the biodegradable bioplastic biofilm. Leaves were collected from the agricultural fields of Meerut, Uttar Pradesh, India after the harvesting season. The leaves of the sugarcane were picked for their high cellulose content, availability, low-cost and renewability. Open-field burning of agricultural waste such as sugarcane leaves is a typical method of disposal, resulting in increased greenhouse gas emissions and air pollution. Thus, their use for bioplastics production is an environmentally benign way to valorise biomass.

The leaves, following collection, were washed thoroughly under running water to remove dust, grime and other surface contaminants. The washed leaves were then rinsed with distilled water to remove any final impurities. The cleansed leaves were sun dried for 24 to 48 hours to reduce the moisture content and to prevent microbial growth during storage. The dried leaves were then cut into little pieces of 1-2 cm length for uniform grinding and chemical treatment. The prepared biomass was maintained in sealed containers prior to further processing.

3.2 Chemical Pretreatment of Sugarcane Dried Leaves

The major purpose of pretreatment was to remove lignin, hemicellulose, waxes and other non-cellulosic components of the sugarcane leaf biomass to provide cellulose-rich material for bioplastic synthesis. The powder dried sugarcane leaves were treated with 30% (w/v) sodium hydroxide (NaOH) solution as alkali treatment. The alkali solution was mixed with approximately 10 g of powdered biomass and heated to 80 °C for 1 h with continuous stirring. Alkali treatment leads to breaking of the lignin-carbohydrate complex and hence facilitates the removal of hemicellulose, lignin, pectin, waxes and extractives.

Then, the slurry was washed by distilled water until the pH was periodically neutralised after treatment. The washing operation ensured that all the dissolved pollutants and residual alkali were removed. The treated biomass was oven-dried for 24 hr at 60°C before proceeding to bleaching step.

3.3 Bleaching and Cellulose Purification

The alkali-treated biomass was further bleached with hydrogen peroxide (H_2) to increase the purity of cellulose. The alkali treated fibres were then mixed with 30 % (w/v) solution of hydrogen peroxide and heated at 70°C for one

hour. The bleaching process removes chromophoric compounds and residual lignin which are responsible for the dark colour of biomass. Lignin content reduces, cellulose fibres have greater purity and lighter hue. The material was then bleached and washed several times with distilled water until a neutral pH was attained. The pure cellulose fibres were dried at 60°C in a hot air oven and ground into a fine powder to be used in the manufacturing of bioplastics

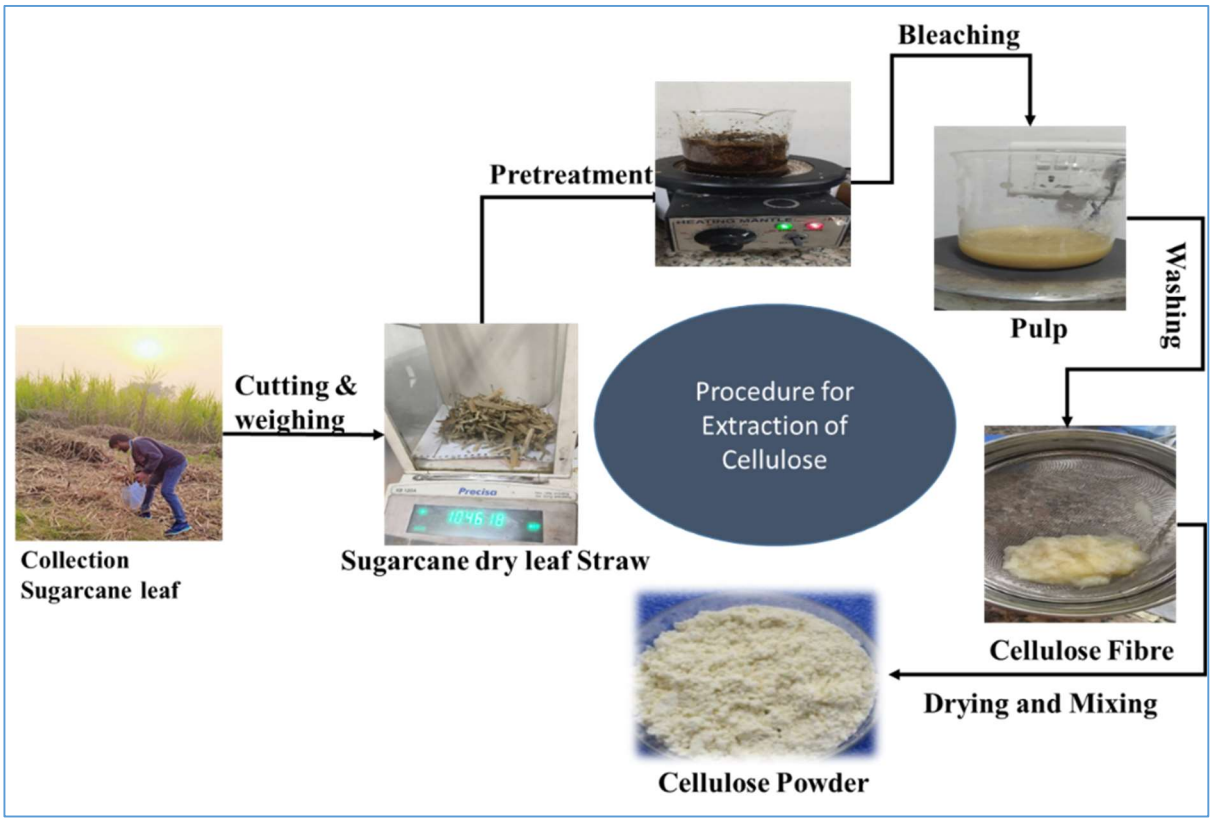


Fig. 1 Experimental procedure for making cellulose powder

3.4 Preparation of Cellulose-Based Bioplastic Biofilm

The major structural component for bioplastics manufacture was a cellulose-rich powder derived from the dried sugarcane leaves. predetermined ratios of various substances such as cellulose powder, starch, glycerol, vinegar (acetic acid) and distilled water were mixed together. Glycerol was employed as a plasticiser to boost flexibility, cellulose as a reinforcing agent, starch as the film forming matrix and acetic acid to facilitate homogeneous mixing and polymer interaction. The mixture was made in a 500 mL beaker with 100 mL distilled water. The contents were heated to 70 °C using a magnetic stirrer at 800 RPM for around 15 minutes. Constant swirling prevented agglomeration and gave uniform dispersion of the cellulose particles.

As the heating process went on the mixture gradually converted into a homogeneous viscous paste suitable for film casting.

Table 1 Compositions of bioplastic film

Sample	Cellulose (gm)	Starch (gm)	Acetic acid (ml)	Glycerol (ml)	Distilled Water (ml)
SCLBP	5	3	2	1	100

3.5 Film Casting and Drying Process

The resulting slurry was carefully deposited on sterile glass petri dishes to form thin, homogenous coatings. The slurry was uniformly spread on the surface of the Petri dish to obtain a uniform thickness of the film. Air bubbles in the mixture were removed to prevent defects in the resulting biofilm. The cast films were dried in a typical laboratory environment until all the water had evaporated. Hydrogen bonding interactions between cellulose, starch and glycerol molecules during drying resulted in the formation of a continuous bioplastic biofilm.

The films were carefully removed from the Petri dishes once drying was complete and stored in tight plastic bags before to characterisation.

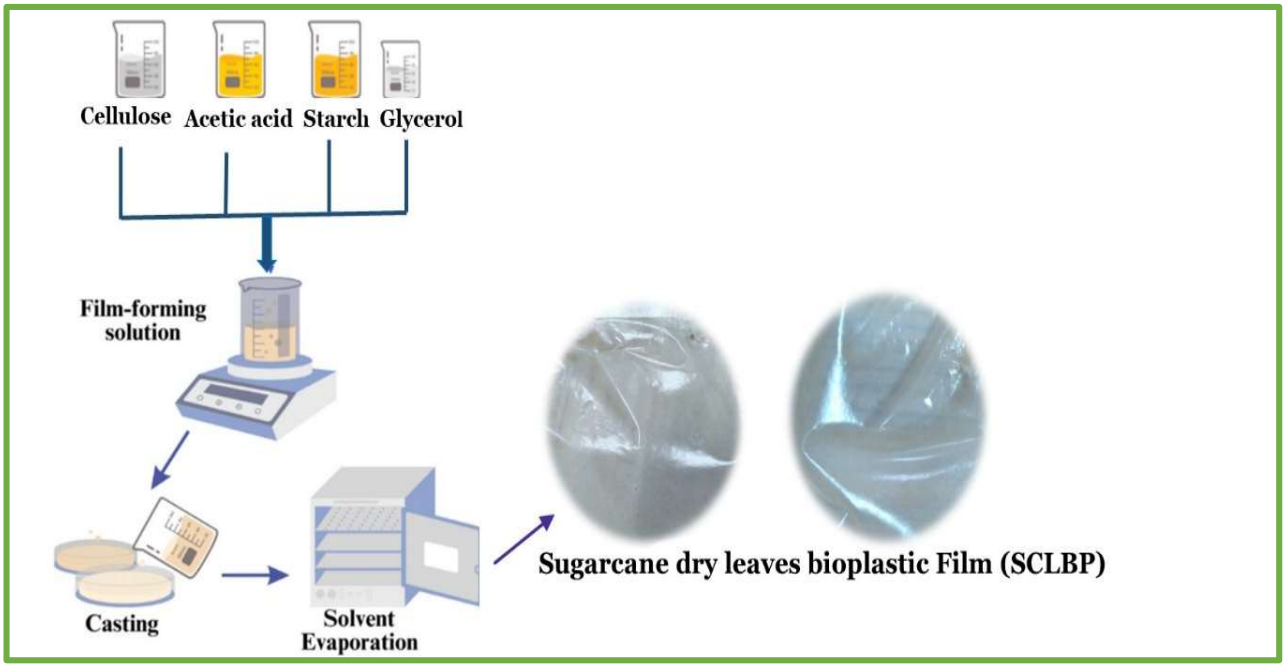


Fig.2 Preparation of Bioplastic Film

3. Characterization

3.1. Thickness and Transparency of Bioplastic Films

The obtained bioplastic film thickness was calculated for analysing the mechanical and optical properties of bioplastics using a micrometre screw gauge [20]. For each sample, measurements were taken at three different points with respect to the surface to ensure uniformity and the obtained average point was noted as the final thickness of SCLBP film [20].

The transparency of the SCLBP film was measured following the protocol by Oblitas R, Quispe-Sanchez [22] . Bioplastic film fragments of measurement 10mm × 35 mm (length × width) were cut and placed in quartz cuvettes, and finally the value of absorbance was recorded at a wavelength of 600 nm using Eppendorf UV spectrometer[22]. The transparency of the samples was evaluated using the following equation 1.

$$\text{Transparency\%} = \left(\frac{A_{600}}{D}\right) \quad (1)$$

Where A600 shows the values of absorbance of sample at 600 nm and D denotes the thickness of the film in millimeters (mm)[22].

3.2. Absorption and Solubility characteristics of SCLBP Film

The solubility as well as absorption capability of the film in water was evaluated using the technique referenced by El-Sheekh et al [20], [23]. The SCLBP initially is dried in oven for approximately 24 h was chopped into small sizes of 3 cm^2 [20]. The film then was submerged in 80 ml of deionised water for approximately 24 h. The water was separated using Whatman paper after after 24 h and the remaining SCLBP was dried again in the oven at 80 ◦C temperature for 24 h time. Water solubility, generally demonstrated as percentage rate was estimated using the Equation 2.[20], [22]

$$\text{Solubility (S\%)} = \frac{Initial\ dry\ wieght - Final\ \ dry\ wieght}{Initial\ wieght} \times 100 \quad (2)$$

The water absorption of SCLBP film was estimated using proposed methodology [24]. To calculate absorption rate of SCLBP film, it was reduced to smaller sizes of 2cm^2 and then dried in oven at temperature of 85◦C for about 24 h. Initially, the weight of the dried bioplastic film was noted. The SCLBP film then was submerged in deionised water for about 50 ml volume for almost 24 h. Then, after the filtration of water, the final SCLBP film weight was observed [20]. The uptake water absorption rate was evaluated in percent using the Equation 3[20].

$$\text{Water absorbance (\%)} = \frac{Final\ wiegh\ \ - Initial\ wieght}{Initial\ wiegh} \times 100 \quad (3)$$

3.3. Soil Biodegradability of Bioplastic Films

The bioplastic film biodegradability efficiency in soil was evaluated using the methodology proposed [20]. This test analyse the biodegradation rate of the SCLBP film. The film was cut into smaller square measuring 2 cm^2, and the initial weight of the SCLBP film was recorded. The smaller film was covered beneath a layer of moist soil within a depth of 3 cm. After a period of 7 days, the film was taken out from soil and washed with deionised water and ultimately dried in oven at 85ºC temperature for about 24 h period and final weight was analysed. Equation 4 was used to calculate the biodegradation rate [20]

$$\text{Biodegradability}(\%) = \frac{Initial\ wiegh\ \ - Final\ wieght}{Initial\ wieg} \times 100 \quad (4)$$

3.4. Water Parameter Analysis

After performing the water solubility assessment of the prepared SCLBP film, the quality of the test water was determined to observe physicochemical properties of water [25]. The HACH multi parameter electrodes and probes was used to measure water quality parameters, comprising pH, total dissolved solids (TDS), biological oxygen demand (BOD), chemical oxygen demand (COD) sodium concentrations[26]. The pH was measured using a HACH HQ40d Multi-Parameter Meter, while TDS values were directly obtained from the same probe. BOD was analysed after 5 days of incubation (BOD_5 method) using a HACH HQ440D electrode [27]. The COD was measured using HACH DRB200 electrode. All the results were compared with standard permissible limits for water quality to determine whether any leaching or contamination occurred due to bioplastic degradation during solubility testing.

3.5. Mechanical Properties of SCLBP

The mechanical strength of the sugarcane dried leaf–based bioplastic film was calculated using a Universal Testing Machine (UTM) in compliance with ASTM D882 standard [28], [29]. Obtained Bioplastic Film sample were cut into uniform strips measuring 120 mm X 20mm. During testing, the tensile strength, obtained stress-strain curve were used to evaluate parameters such as Young's modulus, yield strength, strain at break, and toughness. These parameters were used to evaluate the support-bearing capacity, rigidity, and flexibility of the developed Bioplastic film.

3.6. FTIR

The chemical functional groups in the SCLBP film analysis were determined using the PerkinElmer Spectrum II FTIR. Approximately 2 mg of obtained bioplastic film was weighed and analysed under FTIR, with range of 400-650 cm^{-1} at resolution unit of 4 cm^{-1}[20]. The obtained spectra were analysed using origin pro software where baseline correction and spectral smoothing were also done. This system was opted for its speed, non-destructive nature, and reliability in interpreting the cellulose-based compositional analysis in bioplastic film [30].

Chapter 4

Result and Discussion

4.1. Thickness and Transparency of bioplastic film

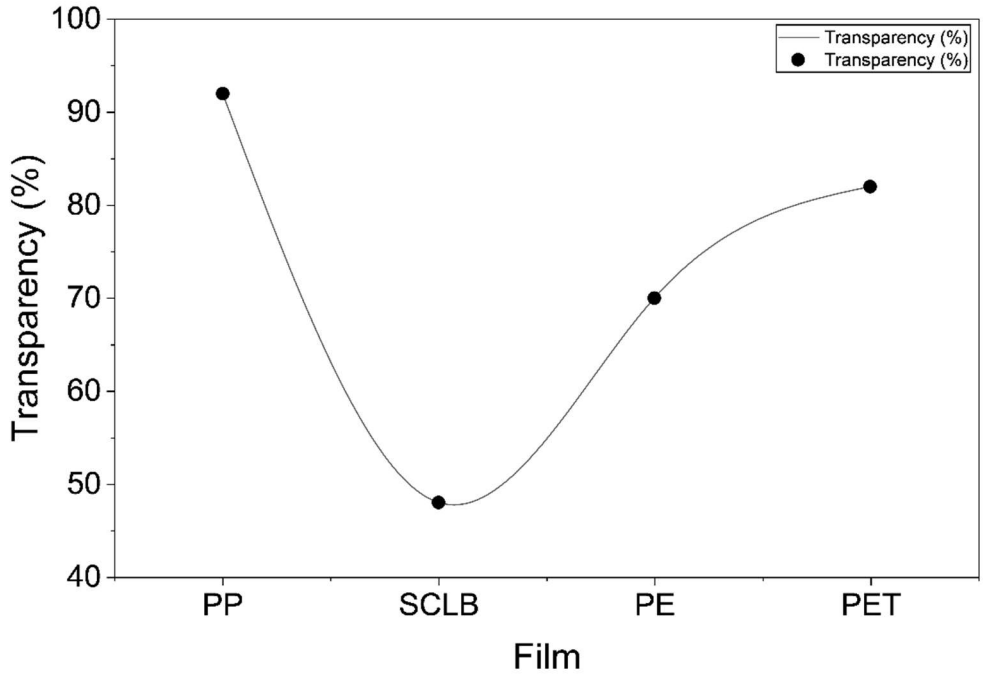
The bioplastic film developed from sugarcane dried leaves exhibited transparency of 48%, representing a semi-transparent appearance and moderate clarity [21][22][23]. This reduced transparency of the SCLBP film is due to the availability of lignocellulosic fibers and surface roughness present within the polymer matrix[24][25]. The conventional plastics such as LDPE, PP, PET, and GPPS generally exhibit transparency levels between 85–90% as compared in Fig. 3 [26][27][28]. The absorbance value of the bioplastic was found to be 0.320, recommending a moderate visible light absorption. This optical behaviour contrasts with petrochemical plastics that show minimal absorbance due to the presence of smooth and non-porous structure. Furthermore, the bioplastic film thickness measured 0.408 mm, which is higher in comparison to synthetic plastic films as compared in Table 2.

These finding represent the sugarcane-leaf-derived bioplastic lower transparency, and slightly higher thickness can be advantageous in eco-friendly packaging application.

The thickness and transparency of biodegradable films are important parameters affecting their potential applications in the packaging field. The low transparency of the SCLBP film shows that the optical clarity was reduced due to light scattering in the polymer matrix by cellulose fibres extracted from dry leaves of sugarcane. Comparable results have been obtained with cellulose-based bioplastics produced from agricultural waste, where the presence of higher levels of fibres improves structural integrity, but reduces transparency. The considerably higher thickness of the film produced may be due to the incorporation of cellulose particles and the formation of a dense polymeric network during film casting and drying, in addition. In general, the thicker the material, the better the resistance to physical damage during handling and transport and the greater the mechanical stability. The

transparency of developed biofilm was lower than petrochemical plastics, but results are suitable for applications such as biodegradable carry bags, agricultural mulch films, disposable packaging materials and protective wrapping applications in which total product visibility is not required. Hence, the developed sugarcane dried leaf based bioplastic biofilm showed a good balance of structural and optical properties, indicating its potential use as an environment friendly packaging material.

Material	Typical Thickness Range	Literature Reference (Citable)
HDPE Film	0.02– 0.20 mm	[29][30]
LDPE Film	0.015–0.10 mm	[31][32]
PP Film	0.02–0.10 mm	[33]
PET Film	0.1 - 1mm	[34]
SCLBP	0.408 mm	Present Study


Transparency (%)
Transparency (%)
100
90
80
70
60
50
40
Transparency (%)
PP
SCLB
PE
PET
Film

4.2. Solubility and Absorption of SCLBP

Water solubility and absorption are necessary parameters that analyzed the hydrophilic and hydrophobic nature of bioplastic film, particularly used for packaging material applications. The sugarcane dried leaf-based bioplastic film showed a water solubility of 65% and water absorption of 55% after 24 hours, depicting a high affinity toward moisture thus proving its biodegradable nature. The polar functional groups present in cellulose and hemicellulose in sugarcane dried leaves easily form hydrogen bonds with water molecules. In contrast, conventional polyethylene and polypropylene are almost insoluble in water, less than 1% and have very low water absorption capacity nearly 0.5% due to their non-polar and hydrophobic nature as compared in Table 3 [35] Therefore, the ability of greater water uptake of the bioplastic film reflects the hydrophilic characteristics due to its lignocellulose components and shows potential biodegradability and eco-friendliness.

The resulting SCLBP film is very water soluble with significant absorption behaviour because of the presence of multiple hydroxyl (–OH) groups in cellulose, starch and glycerol molecules. The functional groups enhance the intermolecular interactions with the water, causing the swelling of the biofilm and the further absorption of moisture. These features are often seen in biodegradable materials made of cellulose and are regarded to be beneficial for the environmental degradation of disposed materials. The higher affinity to water improves biodegradation in the natural environment by boosting microbial colonisation and enzymatic activity. The developed film can be useful for short term packaging, agricultural mulch films, disposable products and compostable materials where rapid environmental degradation is desired. The increased water absorption may limit the use of this film in long term moisture sensitive packaging applications. The described solubility and absorption properties indicate that sugarcane dried leaf-based bioplastic biofilm holds considerable potential as an eco-friendly and biodegradable replacement for conventional petroleum-based plastics.

Material / Polymer	Water Solubility (%)	Water Absorbance (%)	References
SCLBP	65%	55%	Present study
PP	Insoluble	0.01–0.03%	[36]
LDPE	Insoluble	0.02%	[37]
HDPE	Insoluble	0.01–0.02%	[38]

4.3 Soil biodegradability of bioplastic films

Biodegradability in soil determines the environmentally friendly characteristics of bioplastic films thus offers an alternative to non-degradable synthetic plastics. The soil biodegradability test result showed that the sugarcane dried leaf-based bioplastic film exhibited a degradation rate of 61.7% within 7 days under natural soil conditions. Due to the lignocellulosic composition, this biopolymer film is highly susceptible to microbial attack and environmental decomposition thus exhibit a much faster degradation rate.

In contrast, conventional plastics like polyethylene and polypropylene show an insignificant degradation rate, less than 2% even after 200 years in soil, due to their non-polar hydrocarbon backbone that resists microbial enzymatic activity. Rate of degradation of different bioplastic films with respect to the time period is mentioned in Table 4. Thus, the high biodegradability observed in the sugarcane-leaf-based film can be impute towards its natural polymer composition and porous surface morphology, which easily facilitate moisture absorption and effect of microbial colonization in soil.

The prepared SCLBP film has great biodegradable performance due to its natural lignocellulosic content and biodegradable polymer matrix. The breakdown of the polymer structure is caused by the usage of the cellulose and starch parts as a source of carbon and energy by microorganisms in the soil, such as bacteria, fungi and actinomycetes. The presence of hydrophilic functional groups favours the entry of moisture into the film and favours microbial proliferation and enzymatic degradation. Under normal settings the polymer chains degrade into simpler molecules such as carbon dioxide, water and biomass. The substantially higher rate of biodegradation of the SCLBP film over conventional plastics highlights its sustainability with respect to the environment and less potential for long-term accumulation in the ecosystems. Thus, the developed bioplastic biofilm from sugarcane dry leaf has significant potential for applications requiring fast environmental degradation and a smaller ecological footprint, especially in the disposable packaging and agricultural industries.

Table 4. Soil biodegradation analysis of bioplastic film

Material	Rate of biodegradation	Time period of degradation	References
Sugarcane dried leaf bioplastic	61.7%	7 days	Present study
LDPE (Low-density polyethylene)	0.2 – 5%	1-2years	[39][40]
HDPE (High-density polyethylene)	0 –1%	1-2years	[41][42]
PP (Polypropylene)	1%	1-2years	[42]

4.4 Physicochemical properties of water

After undergoing the solubility test of SCLBP bioplastic film in water**,** the physicochemical quality of the test water was analysed to evaluate any changes in its composition. The pH value analysed was 7.9, depicting a slightly alkaline nature of water**,** determining the dissolution of distinct organic components from the bioplastic. The biochemical oxygen demand was measured after 5-day incubation period and recorded as 7.7 mg/L, representing moderate microbial activity due to the presence of biodegradable organic matter in bioplastic film. The chemical oxygen demand was found to be 14 mg/L, confirming the presence of partial oxidation of organic components. The total dissolved solids level was found to be 418 mg/L, giving a slight increment as compared to freshwater data, majorly due soluble organic and inorganic residues present in the bioplastic matrix. Additionally, the sodium (Na^+) concentration was recorded at 9.2 mg/L, referring to negligible leaching of alkali ions in due of the solubility process. In contrast to bioplastic, petrochemical plastics such as polypropylene, remarkable increase in COD, BOD, pH, TDS and Na after degradation of so many years, due to extreme leaching of organic and inorganic compounds thus disturbing the water quality at a high level as mentioned in Table 5 [43]. Therefore, the overall, findings suggest that while the dissolution process of the sugarcane dried leaves based bioplastic film instigated some organic as well as inorganic matter into the water, but

the results remained within the permissible environmental limits, thus, representing that the material does not exert influential adverse effects on the water quality after complete dissolution.

Table 5. Water Quality parameter assessment of bioplastic film

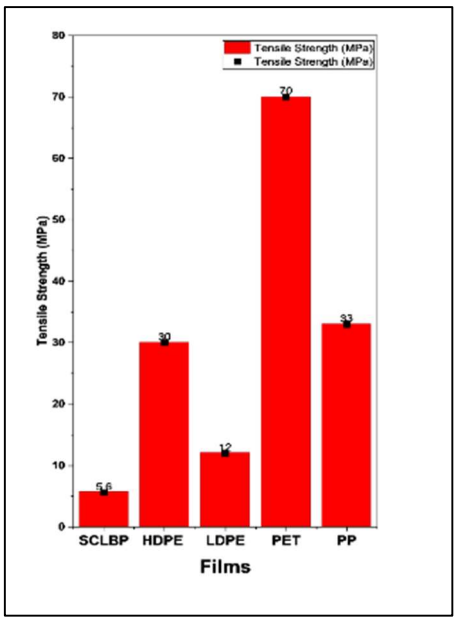
Parameter	Present Study	Petrochemical Plastics (PP / PE / PET)
pH	7.9 (slightly alkaline)	Plastic leachates often cause pH alteration (commonly increase) due to release of additives, stabilizers, and degradation products [44].
BOD (mg/L)	7.7 mg/L	Leachates from PP/PE/PET increase BOD through release of organic oligomers and additives; value varies with aging/weathering.[45]
COD (mg/L)	14 mg/L	Elevated COD widely reported in plastic leachates due to oxidisable organic matter formed during polymer degradation [43].
TDS (mg/L)	418 mg/L	Petrochemical plastic leachates show significant increase in TDS contributed by soluble additives, pigments, stabilizers, heavy-metal traces [46].
Na^+ (mg/L)	9.2 mg/L	Ionic leaching occurs in PE/PP leachates, although sodium is generally minimal; depends on stabilizer/processing additives.

The physicochemical examination of water after dissolution of the SCLBP film is an important evidence of the environmental compatibility of the bioplastic material. The observed values of pH, BOD, COD, TDS and sodium concentration were below the permitted environmental limits indicating that the breakdown products of biofilm did not significantly deteriorate the water quality. This behaviour is a consequence of the natural origin of the components of the film such cellulose, starch and glycerol, which are usually non-toxic and quickly biodegradable. The SCLBP film produced had no adverse influence on the aquatic environment, unlike conventional petrochemical plastics which

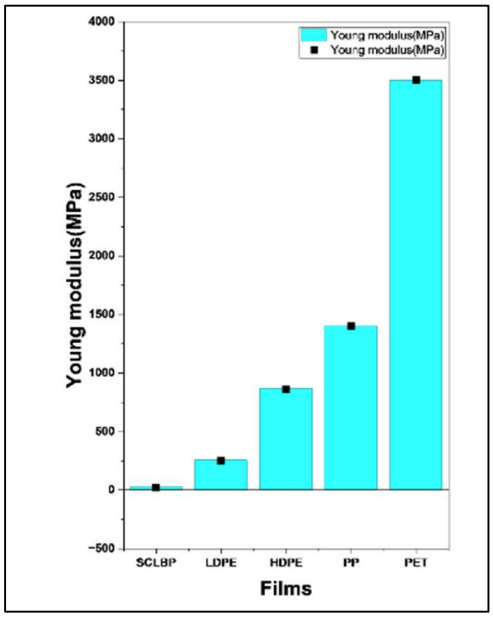
may release harmful additives, stabilisers, plasticisers and microplastic particles during decomposition. These results show that the bioplastic biofilm produced from sugarcane dried leaves has very good environmental safety and may assist to mitigate water pollution caused by synthetic plastic waste. Thus, the proposed material can be considered as a sustainable and eco-friendly option for applications where environmental exposure and end-of-life degradation are expected.

4.5. Mechanical Properties of SCLBP film

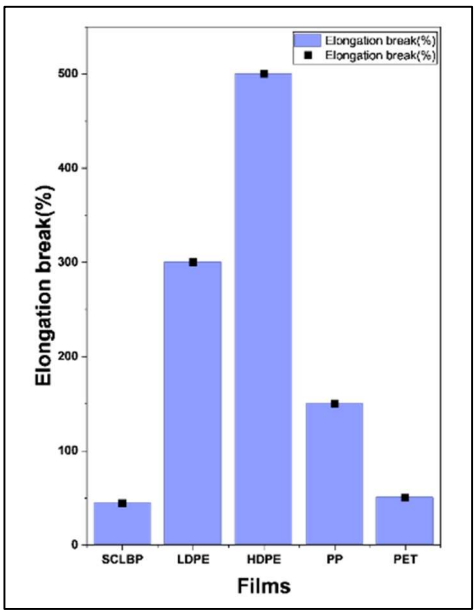
The mechanical strength of SCLBP film represents the characteristics of a biodegradable polymer. The tensile strength of 5.6 MPa and Young's modulus 60 MPa obtained from the SCLBP film reflecting the lower stiffness as compared to known common petrochemical plastics such as LDPE, HDPE and PP as shown in Fig.4 (a)(b)(c)[47][48][49], [50], [51] However, the elongation at break point of 44% indicates that the film offers flexibility and ductility. These findings confirm the medium mechanically stable while retaining flexibility of the SCLBP film fit for applications such as packaging, disposable bags, or biodegradable wraps where high degradability are desired.



(a)



(b)



(c)

Fig.4 (a)(b)(c) Representation of Mechanical properties of plastic film: Tensile strength, Young modulus and Elongation break respectively

The interaction of the cellulose fibres, starch matrix and glycerol plasticiser greatly affected the mechanical behaviour of the generated SCLBP film. Glycerol decreases the intermolecular tensions between the polymer chains increasing its flexibility . Cellulose acts as a reinforcing element to promote the structural integrity of the biofilm. The tensile strength and elongation at break obtained for the manufactured film provide a balanced combination of strength and flexibility for application in biodegradable packaging. This phenomenon is often observed in biodegradable films based on cellulose, due to the nature of their polymeric structure, despite their mechanical properties being poor in comparison to well developed petrochemical plastics. Moreover, the cellulose separated from sugarcane dry leaves produced a continuous polymer network which improved film cohesiveness and avoided excessive brittleness. The obtained results reveal that the fabricated SCLBP film possesses enough mechanical stability for short-term packaging, throwaway goods, agricultural uses and other environmentally friendly applications where the high mechanical performance is not so important as biodegradability and environmental sustainability.

4.6. FTIR

The Fourier Transform Infrared (FTIR) spectrum of the bioplastic produced from sugarcane dried leaves Fig.5 exhibits different absorption peaks that indicates the presence of characteristic functional groups acquired from lignocellulosic biomass constituents such as cellulose, hemicellulose, and lignin. A wide absorption band noticed around 3330 cm^{-1} corresponds to O–H group stretching vibrations [52] , representing its presence from polysaccharides, comprised with the hydrogen-bond in cellulose and hemicellulose. The significant peaks near 2910 cm^{-1} are represented to C–H stretching vibrations of aliphatic –CH and $–CH_2$ group, therefore confirming the organic polymeric backbone structure. The distinct band detected at 1732 cm^{-1} represents C=O stretching vibrations of ester and carbonyl groups [53], which are initially associated with hemicellulose and lignin fractions. Furthermore, the band around 1620 cm^{-1} is assigned to C=C stretching [54], characteristic of the lignin aromatic skeleton. The absorption bands in the region of 1000–1200 cm^{-1} confine to stretching vibrations due to C–O–C and C–O[55], typical of glycosidic linkages and ether bonds in cellulose and hemicellulose. The presence of these associated functional groups confirms that the structural

involvement of the sugarcane dried leaves largely retained during bioplastic formation. Hence, the FTIR analysis acknowledge that the developed bioplastic originates from sugarcane leaf, affirming its biogenic and sustainable polymeric constitution

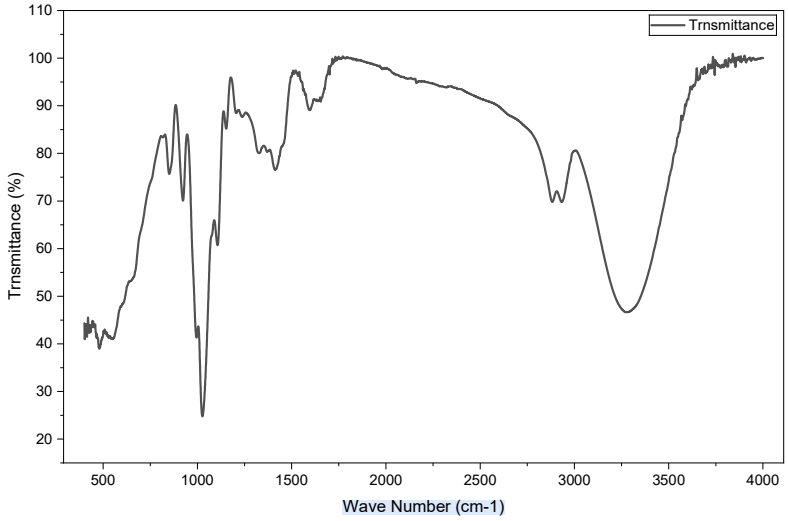


Fig. 5 FTIR Analysis of SCLBP film

The FTIR data further indicate the good incorporation of cellulose-rich components of sugarcane dry leaves into the generated bioplastic biofilm. The presence of particular hydroxyl, carbonyl and ether functional groups indicates the formation of intermolecular bonds between the cellulose, starch and glycerol molecules in the polymer matrix. These functional groups play an important role on the physical, mechanical and biodegradation properties of the biofilm. The broad O–H stretching band suggests the presence of significant hydrogen bonding contributing to the structural stability and film cohesiveness . The detection of C-O and C-O-C vibrations also confirms that the manufactured substance is based on polysaccharides. No strange or harmful chemical signatures are present, indicating that the biofilm consists primarily of naturally occurring biodegradable material. Therefore, FTIR analysis confirms the successful synthesis of bio-based polymeric film from dried sugarcane leaves and further supports the potential of the film as a bio-degradable packaging material as an eco-friendly alternative.

Chapter 5
Conclusion and future scope

CONCLUSION

The present research successfully signifies an environment friendly and sustainable approach towards developing bioplastic from sugarcane dried leaves. This biomass holds an abundant agricultural residual waste, served as a potent source of cellulose, exhibiting that it can be adequately converted into biodegradable materials. The selection of sugarcane leaves as the raw material provides an effective method of waste utilization but also promotes sustainable alternative to the petrochemical-derived plastics [56].

The comparative analysis between the proposed bioplastic film and conventional petrochemical plastic like polyethylene, reveals important environmental advantages of the SCLBP. The developed biofilm showed 65% water solubility in 24 h and 61.7% soil degradation rate in 7 days at much faster under natural circumstances. Also, the mechanical strength of SCLBP film showed the tensile strength of 5.6 MPa and Young's modulus 60 MPa having elongation break point of 44% demonstrating it's potential as mechanically stable polymer. The thickness of the film was slightly higher, while the transparency index was relatively low as compared to petrochemical plastics that depicts the structural characteristics of cellulose. Despite these distinct variations, the bioplastic maintained desirable film coalition suitable for packaging applications.

Also, the assessment of water quality parameters such as pH: 7.9, TDS: 418 mg/L, BOD: 7.7 mg/L, COD: 14 mg/L, Na: 9.2 mg/L after submersion of the bioplastic film confirmed that the water remained within safer and normal limits, depicting that the film material don't liberate any harmful chemicals or change the aquatic environment during dissolution. This finding highlights the non-toxic, sustainable and eco-compatible nature of the developed bioplastic.

Overall, the study finds that bioplastic made from dried sugarcane leaves offers a viable sustainable substitute for traditional petrochemical plastics. Additionally, it encourages environmental preservation, the circular economy, and waste valorisation [57].]. Therefore, this study proposes a realistic method to convert agricultural waste such as dried leaves of sugarcane, an unused raw material, into an eco-friendly plastic which can assist to minimise pollution and is safe to the environment.

The study demonstrates the potential of dried leaves of sugarcane as a raw material for cellulose-based biodegradable bioplastics. However, there are a lot of opportunities to bring this study closer to practical use and the manufacture of high-performance biopolymers. One major trend for the future is the manufacturing of PLA (polylactic acid) granules

from sugarcane leaves, which can significantly increase the bioplastic's mechanical properties, thermal resistance, and economic viability. Sugarcane leaves contain fermentable carbohydrates and they can be fermented by microorganisms to produce lactic acid which can then be polymerised to PLA. This would enable the production of fully compostable, bio-based PLA pellets which can be moulded or extruded into consumer-grade plastic articles, packaging sheets and films.

Another important topic is the integration of cellulose-PLA hybrid composites, which combine the durability and processability of PLA with the strength of cellulose fibres. These composites can be better solutions than bioplastics based on starch or glycerol in industrial packaging, agricultural films, and biomedical applications. The use of nanocellulose obtained from sugarcane bagasse enhances tensile strength, barrier properties and thermal stability.

Further studies on characterisation of material using advanced techniques such as SEM, XRD, DSC and TGA can provide more thorough information on microstructure, crystallinity and thermal behaviour. These assessments will improve the production process and improve the uniformity of the output. Future research also may be directed to soil microbial interaction, enzyme-mediated biodegradation and long-term degradation kinetics to get a better knowledge of environmental performance.

References