

A Versatile Bioplastic Film Fabricated From Cocos Nucifera (Coconut Coir) In Guyana

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Abstract – The coconut plant is an abundant crop stretching across all regions of Guyana in South America. The coconut coir is a cellulose-rich component of the coconut that can be converted into a versatile, biodegradable plastic film with thermomechanical properties comparable to single-use plastics on the world market. The hemicellulose and lignin content of the coconut coir was reduced by 56.5% and 71.7% respectively. An alkali/bleaching treatment of 8% sodium hydroxide (NaOH) and 8% sodium chlorite (NaClO₂) solutions was found to be best. The pretreated coir produced uniform bioplastic films within 6-9 days after dissolution in trifluoroacetic acid (TFA). A 100% conversion of raw coir fibers into plastic film was achieved, with an ultimate tensile strength of 9.12 MPa. This bioplastic film is also thermally stable, starting to degrade at around 250 °C, similar to the degradation temperature of 97% cellulose-rich filter paper.

Index Terms – Bioplastics, coconut coir, tensile strength

I. INTRODUCTION

Global plastic production reached 390.7 million tonnes in 2021 and is projected to reach 445 million tonnes by 2025 and a further 589 million tonnes by 2050. Bioplastics currently represent roughly 0.5 percent of the over 400 million tonnes of plastic produced annually [1]. Global plastic production increased again in 2023 due to the rising demand and new applications. Furthermore, reference [1] shows that it is projected that bioplastic production will increase from 2.18 million tonnes in 2023 to 7.43 million tonnes by 2028. There is a search for platforms that will enable the production of bioplastics from existing bio resources. Various research has been conducted on producing renewable plastics from starch, high-purity cellulose sources, and engineered strains of organisms capable of secreting and producing bioplastics [2], [3], [4], [5]. But, just as interesting is the idea of producing plastics from the by-products or waste from established industries, such as the pulp and paper industry or the agricultural sector.

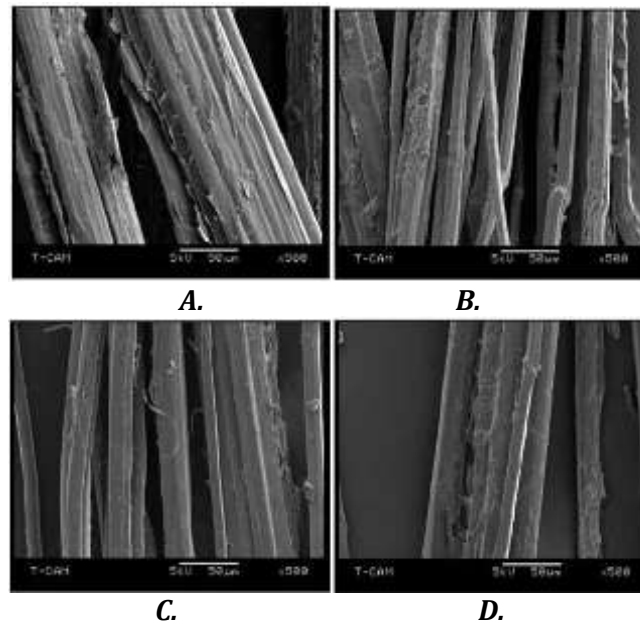
For instance, the agro-food industry generates a large tonnage of waste materials that, in most cases, is used for biomethane production or simply re-applied to the fields as a manure source. But what if the by-products/waste materials can be used to produce plastics or other high-value commodities? For example, a one-step chemical biomass conversion process for the production of bioplastics using agricultural wastes native to Italy [6]. Reference [6] focused on digesting cellulose-rich agro waste (cocoa pod husk, rice husk, parsley stem, and spinach stem) using trifluoroacetic acid (TFA) to produce plastics with varying strengths and properties.

In this study, coconut coir (CC) will be pre-treated to remove the hemicellulose and lignin fractions before acidic digestion using TFA. The pre-treatment will be done primarily to reduce the lignin and hemicellulose fractions, which are known to contribute to kinks and failure of plastic films. Plastic films will be fabricated and characterized to establish their thermo-mechanical properties. The need for environmentally friendly materials is growing rapidly, especially in Guyana. Despite the burden on the Government of Guyana to clean up the environment, there is still a waste disposal issue caused mainly by non-biodegradable materials, of which single-use plastic is a major one.

II. LITERATURE REVIEW

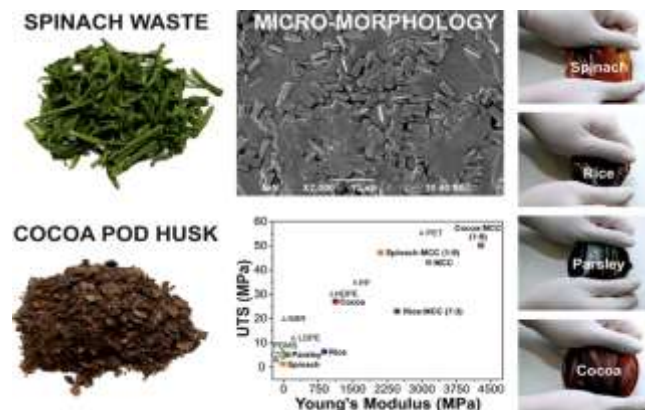
Studies confirm that alkali treatment causes bonding between fibers to be destroyed. It is believed that due to the deterioration and removal of lignin, fibers are separated, thereby exposing reactive sites on the surface of fibers [7]. Reference [7] found that increasing surface roughness from the removal of cementing matrices that bonded individual fibers together is known as fiber fibrillation. Fig. 1 shows that as the concentration of the alkali solution increased, fiber separation seemed to improve.

Fig. 1. (A) Untreated fibers and fibres treated with (B) 2.5%, (C) 5%, and (D) 7% NaOH solution. It was concluded that alkali concentrations of 2.5 wt.% and 5 wt.% provide better fiber separation with less cellulose degradation.



Reference [6] investigated the direct transformation of edible vegetable wastes into bioplastics using TFA. The results produced films from the wastes of cocoa pod husk, rice hulls, parsley, and spinach stems, with varying mechanical properties. It was observed that the color and transparency of the plastic films were indicative of the raw material used, as shown in Fig. 2.

Fig. 2. Plastic films fabricated from spinach, rice, parsley, and cocoa.



Filter paper was used as the reference material in this study, as it has about 97% cellulose. After 3 days of aging, cellulose plastics were cast. Dried films were trifluoroacetylated immediately after their formation and evaporation of TFA. However, this esterification was found to be temporary as it was spontaneously reversed in the presence of water or a humid atmosphere after 1-2 days.

III. MATERIALS AND METHODOLOGY

Whatman #1 filter paper (97% cellulose), 80% sodium chlorite flakes (Mol. wt. 90.44 g/mol), potassium bromide, sodium hydroxide pellets (Mol. wt. 40.01 g/mol, > 98 %), and acetic acid (Mol. wt. 60.05 g/mol, > 99.7 %) were all sourced from amazon; trifluoroacetic Acid (TFA) (Mol. wt. 114.02 g/mol, > 99 %) was purchased from Sigma Aldrich USA, and coconut coir fibers peeled from coconuts picked from random trees in East Canje Berbice Guyana.

Pre-treatment of Coconut Coir

Briefly, approximately four (4) grams of the raw material was heated via reflux at around 85 °C for 4 hours with 4%, 8% and 16% (w/v) sodium hydroxide solution (200 mL). The fibers were continuously washed with distilled water. The alkali treated material was then bleached via heating in reflux for 2-4 hours at around 130 °C in 200 mL (1:1 v/v) of 2%, 4% and 8% solution of sodium chlorite and acetate buffer (27 g of sodium hydroxide and 75 mL acetic acid diluted to 1 L). The reaction was left to cool to room temperature, then washed with excess distilled water. Three samples of CC were treated with 4% sodium hydroxide, after which each was then bleached using 2%, 4% and 8% sodium chlorite. This was repeated for the samples treated with 8% and 16% NaOH. Hence, there were a total of nine (9) samples. The design of alkali and subsequent bleaching treatments, along with material yield, are summarized in Table 1.

Table 1. Pre-treatment Matrix

Raw Material	Alkali Treatment (% NaOH)	Bleaching Treatment (% NaClO ₂)	Final Weight (g)
CC1	4	2	1.98
CC2		4	1.78
CC3		8	1.75
CC4	8	2	1.70
CC5		4	1.69
CC6		8	1.68
CC7	16	2	1.77
CC8		4	1.68
CC9		8	1.66

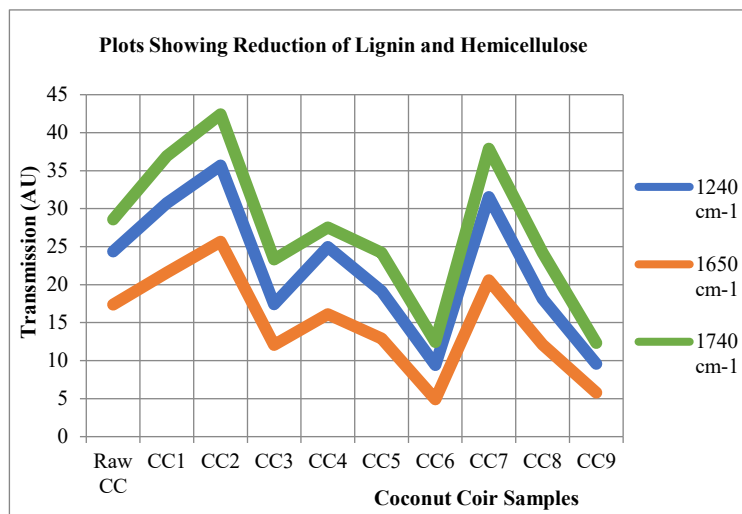
Sample CC6 resulted in the highest decrease in lignin and hemicellulose content, which corresponds to the pre-treatment conditions of 8% NaOH and 8% NaClO₂.

IV. RESULTS/DISCUSSION

The alkali treatment of the fibres involves the removal of surface impurities, the swelling of the crystalline region, and the alkalization of the peripheral hydroxyl groups. The common trend in the observations is that there is a gradual decrease in hemicellulose and

lignin from the raw materials. Further, bleaching with sodium chlorite causes an oxidative fragmentation of the lignin, and some part of the lignin dissolves out as lignin chloride [8]. Reference [8] focused primarily on fibres originating from coconut coir. The peaks at three particular wavelengths of 1240 cm^{-1} , 1650 cm^{-1} , and 1740 cm^{-1} are characteristic of lignin and hemicellulose content.

Fig. 3. A summary of the peak intensities for all CC samples

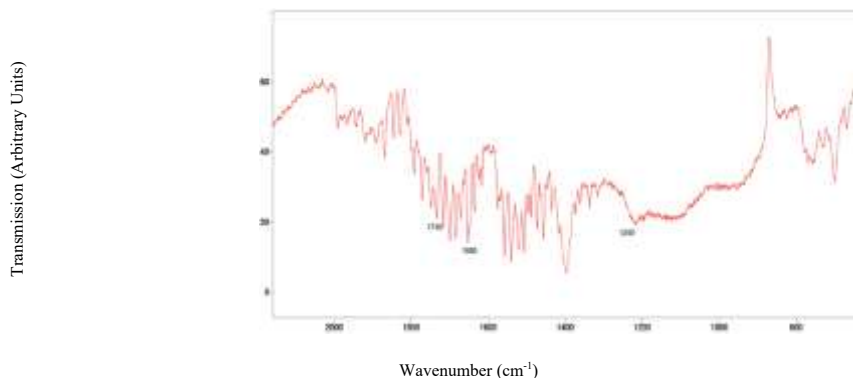
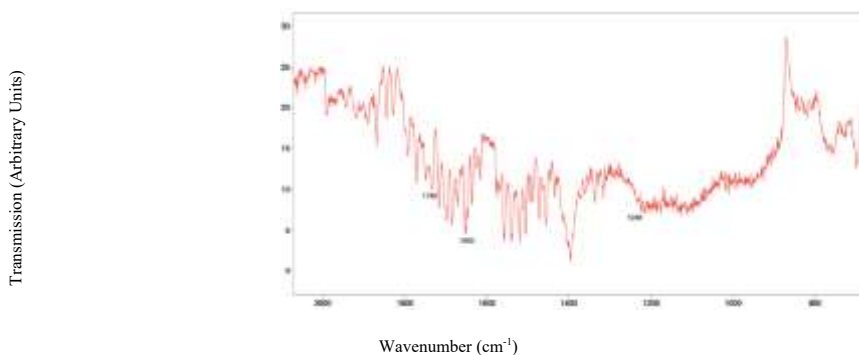


Reference can be made to Table 2 to observe the extent of cleaning as a result of the various combinations of alkali/bleaching pre-treatment conditions used for the CC samples.

Table 2. Reduction of Hemicellulose and Lignin from CC

Coconut Coir	Transmission (AU) at Peaks of Interest		
	@ 1240 cm^{-1}	@ 1650 cm^{-1}	@ 1740 cm^{-1}
Raw CC	24.36	17.38	28.58
CC1	30.75	21.58	36.91
CC2	35.68	25.65	42.42
CC3	17.40	12.05	23.32
CC4	24.94	16.11	27.55
CC5	19.14	12.89	24.22
CC6	9.42	4.91	12.43
CC7	31.54	20.59	37.91
CC8	18.15	12.12	24.19
CC9	9.57	5.81	12.33

Recent work also found that plastic films from coconut coir have an increased tensile strength of 22.8 MPa after a 29% and 12% decrease in lignin and hemicellulose content, respectively [9].

Fig. 4. IR spectrum of raw coconut coir**Fig. 5. IR spectrum of CC6**

The coconut coir fibers have three major components: cellulose, hemicellulose, and lignin. These three components are composed mainly of esters, aromatic ketones, and alcohols with different oxygen-containing functional groups. Lignin present in the coir fiber gives characteristic peaks at 1240 cm^{-1} , 1650 cm^{-1} , and 1740 cm^{-1} corresponding to the aromatic skeletal vibration and carbonyl groups. It can be observed that the intensities (AU) of these peaks in Fig. 4 were significantly reduced, as shown in Fig. 5. The values for raw CC and CC6 in Table 2 support these spectra.

The peak at 1650 cm^{-1} corresponds to the presence of $\text{C}=\text{O}$ linkage, which is a characteristic group of lignin, and at 1740 cm^{-1} is due to hemicellulose. Another possibility is that carboxyl or aldehyde absorption could be arising from the opened terminal glycopyranose rings or oxidation of the $\text{C}-\text{OH}$ groups, as in reference [8]. From IR analysis, it is observed that alkali and bleaching treatment of the raw CC resulted in a reduction of lignin and hemicellulose fractions, i.e., a 71.7% and 56.5% decrease in lignin and hemicellulose content, respectively.

Fig. 6. Raw CC fiber converted into bioplastic film

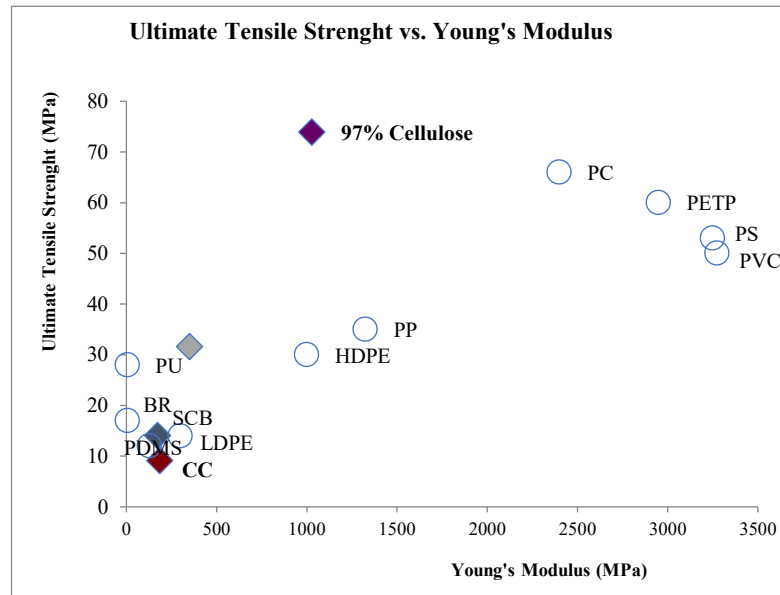
The tensile strength and modulus of the filter paper-based plastic are superior compared to that of CC because of the high purity of cellulosic content (97%) that enables better dispersion during casting and homogenous mixing as evident in Table 3.

Table 3. The Ultimate Tensile Strength of CC Film

Bioplastic Films	Ultimate Tensile Strength (MPa)	Tensile Modulus (MPa)	Elongation (%)
Filter Paper	73.92	1029.16	8.21
Coconut Coir	9.12	185.64	8.63

The ultimate tensile strength of pure cellulose is about 84 MPa compared to 73.92 MPa for 97% cellulose filter paper [10]. Another report found that cellulose (along the fiber length) has a tensile strength ranging from 720 MPa to 1080 MPa [11]. This is an indication that the method used was reasonable. The environmentally unfriendly phthalates that are present in engineered polymers are responsible for ductility, but are absent in the CC plastic film in this study. Nonetheless, the plastic film shows similar characteristics to the low-density polyethylene (LDPE) based plastic products like the squeezable bottles (e.g., honey and mustard), polyurethane (PU), soft rubbers and elastomers (BR), and silicones (PDMS) as shown in Fig. 7.

Fig. 7. The CC bioplastics are among engineered polymers



V. CONCLUSION

A. This study can be used as an important stepping stone in Guyana towards advocating that the potential is there to contribute to reducing the use of single-use plastic. It creates a new line in the value chain for one of the waste components of the abundant coconut

crop in Guyana. Although there are many sectors for the application of these films, such as automotive, medical, and agricultural, a good start would be to target the popular utensils line, like forks, spoons, cups, plates, and food boxes. Also, it would be interesting to investigate the incorporation of various plasticizers into these films and tune them according to necessary potential applications. Biodegradable studies should also be conducted to assess the time of degradation of these particular films.

VI. REFERENCES

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