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Development of an Environmentally Friendly Bioplastic Film Derived from Water Hyacinth

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Abstract

The water hyacinth, an invasive aquatic plant negatively impacting ecosystems, serves as a promising source for raw materials in the production of carboxymethylcellulose (CMC)-based bioplastics due to its high cellulose concentration. This initiative not only mitigates water hyacinth pollution in natural water resources but also contributes to the reduction of plastic waste through the creation of biodegradable CMC bioplastic films. The cellulose extraction from water hyacinth precedes the synthesis of CMC, followed by the production of bioplastic films. The characterization of the materials includes the use of FTIR analysis, utilizing a wavelength range of 400–4000 cm-1 to obtain the FTIR spectrum. The urgent need for increased inventions and research in this field is emphasized to overcome existing challenges and establish effective methods for producing bio-based plastics. This eco-friendly approach aims to decrease dependence on traditional polymers derived from fossil fuels, paving the way for a more sustainable future. Plastic pollution, a severe environmental issue impacting wildlife and the human food chain, particularly in areas like land, oceans, and large bodies of water, underscores the importance of transitioning towards eco-friendly alternatives.

Keyword: Invasive species, water hyacinth, CMC-based bioplastic, FTIR analysis, sustainable plastic

INTRODUCTION

Today, plastic has become an indispensable material in our daily lives, finding applications in various fields such as coating, construction, containers, packaging, and textiles [1]. Unfortunately, marine animals ingest plastic debris unintentionally, leading to altered digestive physiology [2]. Plastics, due to their exceptional qualities like durability, lightweight, and good thermal and electrical insulation, have become a global commodity with wide-ranging applications at low costs [3]. The manufacturing of personal protective equipment (PPE) amid the COVID-19 pandemic underscores the widespread reliance on plastics. Despite their widespread use, plastic waste has become a significant environmental concern, with a large portion ending up in landfills or natural ecosystems [4].

The Federal Union of India, comprising 28 states and 8 union territories, is experiencing rapid economic growth, particularly in urbanization and infrastructure development. The petrochemical sector, a substantial contributor to India's GDP, has witnessed significant growth, aligning with economic, geographic, and demographic expansions [5,6].

The introduction of bioplastics, derived from plant sugars like maize, sugar beets, potatoes, wheat, or sugarcane, presents a more environmentally friendly and renewable alternative to traditional plastics. Two common types of bioplastics are polylactide acid (PLA) and polyhydroxy kanoate (PHA). Despite claims that the production of bioplastics consumes less fossil fuels, some studies indicate comparable energy usage to conventional plastics [7].

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A specific initiative aimed at creating a biodegradable material for sustainable packaging involves utilizing carboxymethyl cellulose (CMC) from agricultural waste. The study focuses on converting CMC into a biodegradable polymer for packaging, with physiochemical characterization using scanning electron microscopy (SEM), atomic absorption spectroscopy (AAS), and Fourier transform infrared (FTIR) spectroscopy [8].

Bioplastics, derived from renewable biomass sources, offer advantages such as transparency, flexibility, strength, barrier properties, and heat resistance. Three categories of bioplastics include starch-based, cellulose-based, and protein-based bioplastics [9]. These materials find applications in disposable items, structural materials, and even electroactive bioplastics for electric current transportation. Biopolymers can also coat paper as an alternative to petrochemical coatings, with low energy requirements for production [10].

While the ap peal of bioplastics lies in their degradability and use of renewable feedstocks, their success depends on proper disposal methods or "end-of-life options." These options include composting, recycling, energy from waste solutions (landfill, anaerobic digestion, and incineration), with landfill being the least favorable both economically and environmentally [11]. Despite these advantages, there are obstacles hindering the widespread adoption of bioplastics, including facility costs, production expenses, higher resin costs, compatibility issues with processing equipment, packaging regulations, and industry resistance [11].

MATERIALS AND METHODS

Materials and Instrumentations

Sodium hydroxide (Univar), sodium chlorite (Alfa Aesar), acetic acid (RCI Labscan), monochloroacetic acid (Sigma-Aldrich), polyethylene glycol (Mw = 400 g/mol) (Sigma-Aldrich), Ethanol (Merck) and Methanol (Merck) are analytical grade. The instruments used to characterize the CMC films are FTIR spectrometer (PerkinElmer), SDTA 851e, 34SC-2 universal testing machine (Instron), JEMARM200F transmission electron microscope (JOEL), JSM-7610F scanning electron microscope (JOEL) and SML-21 environmental chamber (ESPEC).

Collection of Water Hyacinth

The stems of water hyacinth were collected and cleaned with tap water, as shown in above (Figures 1–3) and water hyacinth powder was obtained (Figure 4).

Figure 1. Collection of water Hyacinth from Kali Nadi near to Medical, Meerut

Figure 2. Water hyacinth

Figure 3. Sample washing.

Figure 4. Dry water hyacinth powder.

Figure 5. Powder mixed with NaOH.

Figure 6. Powder mixed with NaCl.

The seventy grams of dried powder was mixed with 700 ml of 10%(w/v) NaOH (as shown in Figure 5) and stirred continuously at 80°C for 2 hours to remove hemicellulose. Subsequently, the product underwent filtration and rinsing with distilled water, followed by drying in an oven at 80°C for a duration of 12 hours.

The 25 g of as-received powder was mixed with 750 ml of 1%(w/v) $NaClO_2$ and adjusted the pH to 4 with acetic acid and stirred continuously at 80°C for 2 hours to remove lignin. Following this, the product underwent filtration and washing with distilled water prior to being dried at 80°C for a period of 12 hours.

The obtained powder already had abundant cellulose (in Figures 6 and 7). The twelve grams of the obtained cellulose was mixed with 15 ml of 55%(w/v) NaOH and 240 ml of 95% (v/v) ethanol, stirred at room temperature for 30 mins before adding 12 g of monochloroacetic acid. Subsequently, the mixture was stirred at 60°C for 6 hours. Following this, the product underwent neutralization with acetic acid until reaching a pH of 7. Then it was filtrated and washed by 70%(v/v) methanol as well as 70%(v/v) ethanol (Figures 8 and 9).

The obtained powder was dried in the oven at 80°C for 12 hours, named as-synthesized CMC (*Carboxymethylcellulose*) (in Figure 10). The 2.88 g of synthesized CMC was dissolved in 120 ml of distilled water following by stirring at room temperature until it was completely dissolved (as shown in Figure 11). Then the 0.72 g of polyethylene glycol (PEG) was added and homogenized for 20 mins.


Figure 7. Powder after drying.


Figure 8. Cellulose mixed with NaOH.

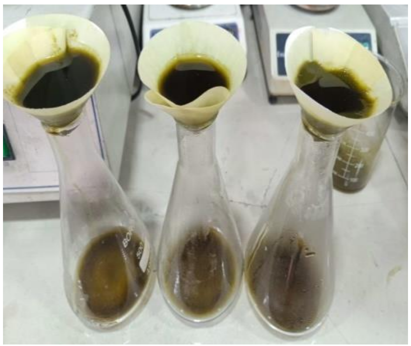
Figure 9. Filter the CMC.


Figure 10. CMC powder.

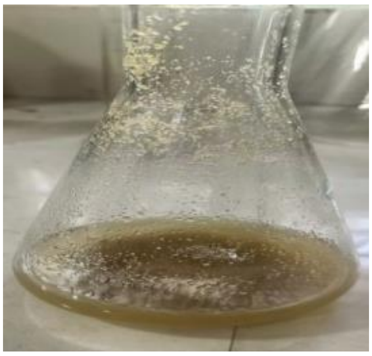
Figure 11. CMC-PEG Solution

Production of Bioplastic Film

The 25 g of as-received powder was mixed with 750 ml of 1% (w/v) NaClO2, and the pH was adjusted to 4 with acetic acid. The mixture was continuously stirred at 80°C for 2 hours to eliminate lignin. Following that, the product underwent filtration and washing with distilled water before being dried at 80°C for 12 hours. The resulting powder already demonstrated a notable cellulose content.

The resulting cellulose, weighing twelve grams, was then combined with 240 milliliters of 95% (v/v) ethanol and 15 milliliters of 55% (w/v) NaOH. After 30 minutes of stirring at room temperature, 12 g of monochloroacetic acid were added to the mixture.

The combined mixture was stirred at 60°C for 6 hours. After this step, the product underwent neutralization with acetic acid until achieving a pH of 7. It was then filtered and washed with 70% (v/v) methanol and 70% (v/v) ethanol, respectively. The final powder was called the synthesized CMC after it was dried for 12 hours at 80°C in an oven.

RESULTS AND DISCUSSION

The CMC powder derived from water hyacinth exhibited a pale yellow-brown colour. The final result is obtaining film of the CMC-PEG as shown in Figure 12.

In 2023, researchers developed bioplastics using jackfruit seed starch with glycerol as a plasticizer, aiming to optimize the starch to plasticizer ratios for enhanced bioplastic properties [12]. Another innovative use of organic waste involved the creation of bioplastics from pectin extracted from citrus fruit and apple peels. Through aqueous extraction, the obtained pectin was transformed into bioplastic using citric acid, glycerol, carboxymethylcellulose, and water [13].

A separate study in 2023 focused on producing starch-based bioplastic from Cordia dichotoma leaves, employing a heat extraction method to create a brownish-thin plastic film [14]. While bioplastics are increasingly replacing traditional plastics, challenges in their disposal persist. A study explored the use of cellulose diacetate in eyewear, analyzing hydrothermal carbonization (HTC) as a pre-treatment before anaerobic digestion [15].

The potential of Opuntia Ficus indica and Ipomoea batatas to produce biofilms similar to those found in commercial plastics was studied. This work aimed to create bioplastics from Opuntia Ficus indica reinforced with Ipomoea batatas starch. Pectin from Opuntia Ficus indica was extracted, and then it was mixed with glycerine, acetic acid, cinnamon powder, and clove powder. According to reference [16], the resultant bioplastic showed promising mechanical characteristics.

Figure 12. CMC-PEG granules (Immature film).

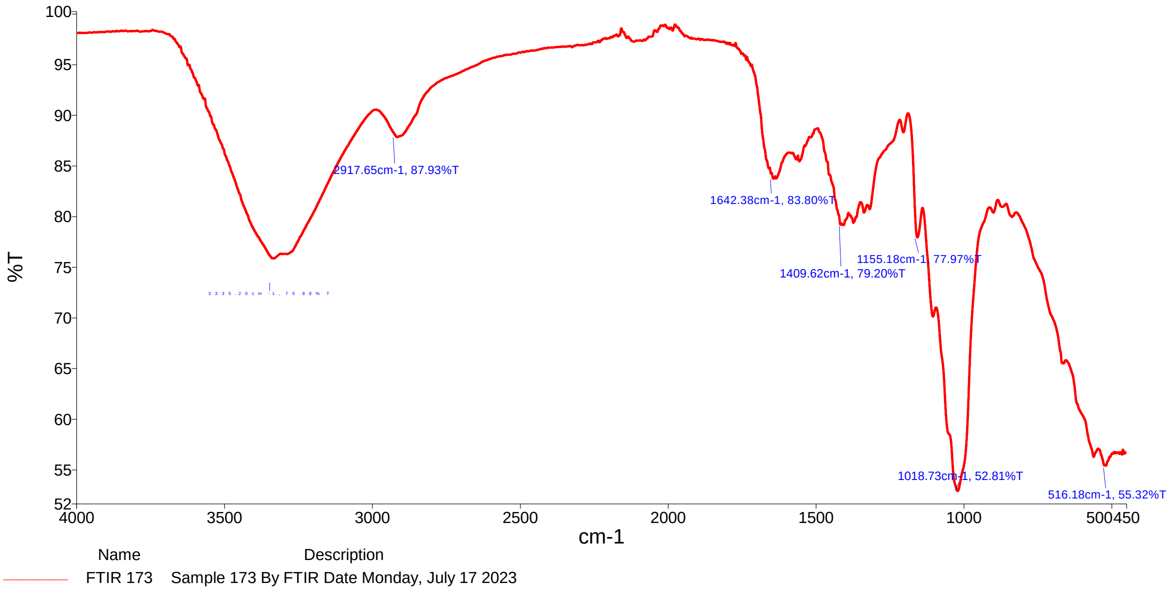

Figure 13. FTIR analysis of CMC (carboxymethylcellulose) powder.

FTIR (Fourier Transform Infrared Radiation) analysis was employed to assess the presence of compounds in various bioplastic samples. For example, the functional group alteration of CMC powder was investigated using FTIR spectra (Figure 13) , indicating peaks and groups associated with metal loading and the biomass's utility (Table 1). Additionally, the spectra of CMC-PEG film displayed nine wavelengths, each corresponding to specific functional groups (Figure 14). This analytical approach aids in understanding the structural and chemical characteristics of the bioplastics developed in these studies.

Table 1. FTIR absorption peaks and their respective chemical functional group.

Peaks	Assignments
3335.20cm^{-1}	Stretching N-H asymmetric
2917.65cm^{-1}	Stretching C-H
1642.38cm^{-1}	C_5 methylated cytosine
1409.62cm^{-1}	CH_3 asymmetric deformation Stretching C-N, deformation N-H, deformation C-H
1155.18cm^{-1}	C-O stretching vibration n (C-C) diagnostic for the presence of a carotenoid structure, most likely a cellular pigment
1018.73cm^{-1}	n(CO), n(CC), d(OCH), ring (polysaccharides, pectin)
516.18cm^{-1}	C□ = C□ torsion and C-OH_3 torsion of methoxy group (4) C□ = C□ torsion and ring torsion of phenyl (1)
3340.40cm^{-1}	Stretching N-H asymmetric
2887.37cm^{-1}	Stretching C-H
1341.93cm^{-1}	CH2 wagging. Collagen Stretching C-O, deformation C-H, deformation N-H
1100.29cm^{-1}	Stretching PO_2 2 symmetric (phosphate II)
1030.72cm^{-1}	Collagen
1054.93cm^{-1}	νC-O & δC-O of carbohydrates Shoulder of 1121 cm^{-1} band, due to DNA
962.37cm^{-1}	C-O deoxyribose, C-C d(C55O) (polysaccharides, pectin)
842.05cm^{-1}	Left-handed helix DNA (Z form) $C_3$0 endo/anti (A-form helix) conformation
558.76cm^{-1}	C□ = C□ torsion and ring torsion of phenyl (1). CH out-of-plane bending vibration

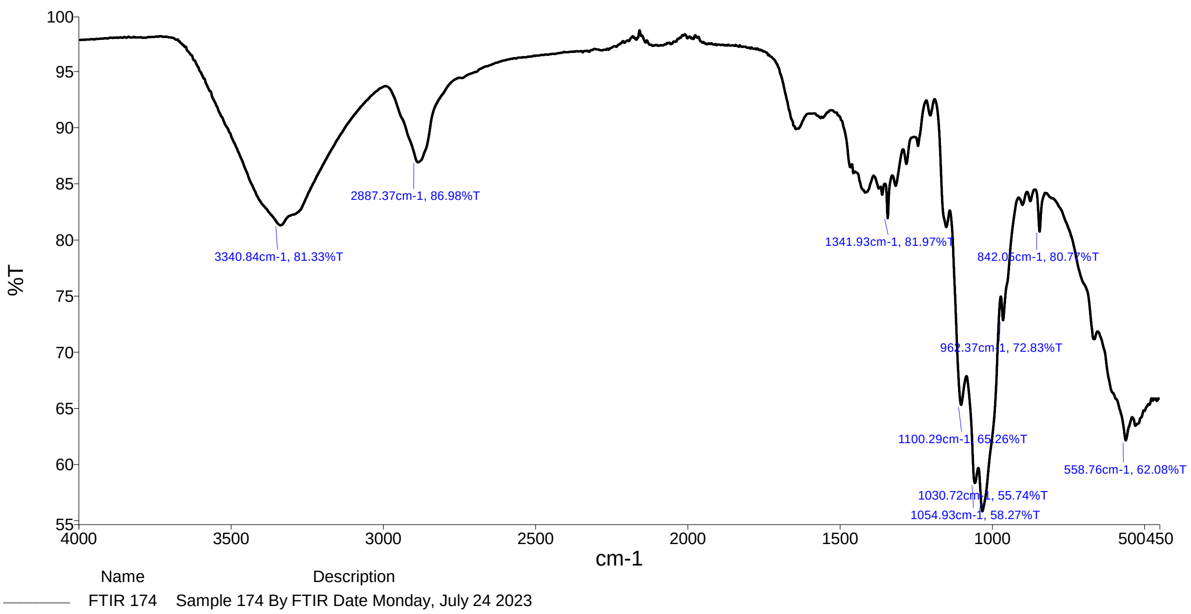

Figure 14. FTIR analysis of CMC-PEG mixture.

CONCLUSIONS

Water hyacinth, an aquatic plant with global environmental repercussions, serves as a valuable raw material for CMC-based bioplastic due to its high cellulose content. The cellulose extraction process involves sequential removal of hemicellulose and lignin from the water hyacinth stem, resulting in abundant cellulose for CMC (carboxymethyl cellulose) bioplastic film production. This sustainable approach not only repurposes water hyacinth but also contributes to reducing plastic waste, a pervasive threat to living organisms and ecosystems. The water hyacinth used in this study was sourced from Kali Nadhi near Medical, Meerut, emphasizing local environmental impact.

In-depth analysis through FTIR analysis revealed various functional groups such as phenyl and methoxy groups, stretching phenomena like C-H and N-H stretching, and structural components like carotenoids, carbohydrates, and collagen. This comprehensive exploration paves the way for innovative strategies to overcome plastic pollution and underscores the potential of biodegradable CMC-based bioplastics in creating a more sustainable future.

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