

**SUSTAINABLE CELLULOSE EXTRACTION FROM
WEEDS FOR BIOPOLYMER SYNTHESIS AND
APPLICATION**

PROJECT WORK

Submitted in partial fulfillment of the requirement for the
award of bachelor of technology degree in Biotechnology

By

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DEPARTMENT OF BIOTECHNOLOGY

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**SATHYABAMA INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)**

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BONAFIDE CERTIFICATE

This is to certify that this project report is the bonafide work of **PRAVEEN S (40230034)**, who carried out his project work entitled "**SUSTAINABLE CELLULOSE EXTRACTION FROM WEEDS FOR BIOPOLYMER SYNTHESIS AND APPLICATION**" under our supervision from September 2023 to March 2024.

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I, Praveen S (40230034), hereby declare that the project work entitled **“SUSTAINABLE CELLULOSE EXTRACTION FROM WEEDS FOR BIOPOLYMER SYNTHESIS AND APPLICATION”** done by me under the guidance of **Dr. D. Inbakandan** (external guide) and **Dr. Prabhakar Singh** (internal guide) at Centre for Ocean Research, Sathyabama Research Park, Sathyabama Institute of Science and Technology is submitted in the partial fulfillment for the requirements of Bachelor of Technology degree in Biotechnology.

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A handwritten signature in blue ink, appearing to read 'Praveen S.' followed by a stylized flourish.

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ABSTRACT

This study focuses on the sustainable extraction of cellulose from weeds as an alternative and eco-friendly source for cellulose-based materials. Weeds, often considered as agricultural nuisances, possess cellulose-rich fibers that can be utilized in various applications. The extraction process involves environmentally benign methods to obtain high-quality cellulose from weeds, aiming to reduce the dependence on traditional sources such as wood pulp. The extracted cellulose is then subjected to a controlled acetylation process to synthesize cellulose acetate. Cellulose acetate is a versatile biopolymer widely used in the production of films, fibers, and other materials. The synthesis process is optimized for efficiency and sustainability, with a focus on minimizing chemical waste and energy consumption. The physicochemical properties of the extracted cellulose and synthesized cellulose acetate are characterized using advanced analytical techniques. These properties include molecular weight, crystallinity, thermal stability, and structural composition. Additionally, the potential applications of the obtained cellulose acetate are explored, including its suitability for biodegradable plastics, textile fibers, and other biocompatible materials. This research contributes to the development of sustainable materials by utilizing weeds as a valuable cellulose source and adopting eco-friendly synthesis processes. The findings provide insights into the feasibility of using alternative biomass for cellulose extraction and the potential applications of cellulose acetate in various industries, aligning with the growing need for environmentally conscious and renewable materials.

Keywords: Cellulose extraction, Weed cellulose, Cellulose synthesis, Cellulose acetate

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CHAPTER - 1

INTRODUCTION

Cellulose is the major component of the plant biomass. Since it is made by all true plants (Kingdom Plantae), from the current point of view, cellulose is considered the most abundant naturally occurring organic compound on Earth. Cellulose metabolism is an important part of the biosphere's carbon cycle. This carbohydrate is found primarily in plant cell walls, where its main function is to provide structural support and protection to the cells. It can be also found in several other types of organisms such as bacteria, fungi, animal tunicates and even amoeba, although the content of cellulose in these species is negligible when compared with plants (Chen, 2014; Dufresne, 2012). Cellulose is continually produced by different living species every day in the biosphere, providing a total annual production around 1.5 tons (Klemm et al., 2005). Thereby, cellulose is a renewable (naturally replenished) resource widely available all over the world. Further, it is biodegradable, returning to the natural carbon cycle by simple rotting, and non-toxic to living organisms, including humans.

Cellulose has always played an important role in the life of man, from prehistoric to present time, and its applications could even represent a landmark in the understanding of human evolution. Natural cellulose-based materials, such as wood, have been utilized to many purposes for thousands of years, e.g., as source of heat for warming, cooking and industrial production; as engineering materials for buildings, bridges, ships, furniture, utensils etc. In its almost pure form, such as cotton and flax fibres, cellulose has also been used since a long time ago, as clothing and writing material going back to the time of Egyptian pharaohs (Kamide, 2005; Pérez & Mazeau, 2004). The first industrial scale product based on cellulose was created from nitrocellulose and camphor by the Hyatt Manufacturing Company in 1870, corresponding to the first thermoplastic polymer material under the trade name of celluloid (Klemm et al., 2005).

Currently, cellulose has a great economic importance, because it is used as feedstock in numerous industries and gives rise to a broad spectrum of products and materials, ranging from packaging to biomedical field. The paper and cardboard industries are the largest consumers of cellulose. Only a small amount of cellulose

used is used to produce textile fibres, films and a larger number of cellulose derivatives, such as cellulose ethers and esters (Dufresne, 2012; Klemm et al., 2005; Moon et al., 2011; Varshney & Naithani, 2011). For instance, carboxymethylcellulose is a cellulose derivative utilized in foodstuffs, pharmaceuticals, cosmetics, detergents, paints, coatings, adhesives and plastics etc. Although cellulose can be derived from a variety of sources (such as: cotton, jute, flax, ramie, sisal, bagasse, bamboo etc), wood is presently the most important raw material for commercial production of cellulose (Siró & Plackett, 2010).

When it comes to sustainable raw materials for future demands on energy, chemicals and materials, cellulose definitely has great importance on account of its abundance and renewability, but still today is underutilized. For this reason, intensive research efforts have been devoted to seeking efficient processing technologies for conversion of this biomass into multiple value-added bioproducts. Therefore, cellulose is a promising versatile resource with potential to decrease the dependence on petroleum-based products and at the same time attends the increasing need for environmentally friendly, biocompatible products and carbon-neutral (Cherubini, 2010; Olsson & Westman, 2013). Nevertheless, numerous technical challenges must be overcome to enable the efficient and profitable utilization of cellulose for the production of energy, chemicals and materials.

1.1 CELLULOSE STRUCTURE

Cellulose has been used for centuries in highly diverse applications, however its chemical composition, structure and morphology remained very long ignored. Though the early work of Braconnot concerning the acid hydrolysis of the substance constituting plant cell walls goes back to the beginning of the 19th century (Braconnot, 1819), it was the French chemist Anselme Payen (1795–1871) who established that the main constituent of all plant cells has a unique chemical structure (Payen, 1838) and coined the word “cellulose” (Latin: rich in small cells) for the first time in 1838. In his studies, Payen described that when various plant tissues were treated with acid-ammonia treatment, followed by subsequent extraction in water, alcohol and ether a constant fibrous material was formed. He deduced the molecular formula to be $C_6H_{10}O_5$ by elemental analysis, and observed the isomerism with starch (Klemm et al., 2005; Pérez & Mazeau 2004). It is only later, due to the pioneering works of the

German chemist Hermann Staudinger (1881-1965) at the beginning of the 20th century that the macromolecular nature of cellulose was recognized. Through acetylation and deacetylation of cellulose, he suggested that its structure does not merely consist of an aggregation of D-glucose units. Rather, the glucose units were found to be linked to each other covalently to form long molecular chains. This, along with Staudinger's research with other chain molecules (e.g. natural rubber), marked the discovery of the polymeric state of molecules and represents the origin of polymer science. Staudinger's research on macromolecules was acknowledged by the award of the Nobel Prize in Chemistry in 1953 (Klemm et al., 2005; Mülhaupt, 2004; Pérez & Mazeau 2004; Staudinger, 1920, 1926).

Despite the degree to which cellulose has been investigated, its molecular structural features have not been identified with absolute clarity and new information appeared in the literature constantly by employing technological advances alongside conventional analytical tools. Thus, the progress of knowledge on cellulose is closely linked to the evolution of characterization techniques, such as X-ray diffraction, neutron scattering, electron microscopy, ^{13}C solid state nuclear magnetic resonance etc (Dufresne, 2012; O'Sullivan, 1997). Several reviews and books have already been published reporting the state of knowledge of this fascinating polymer (Fengel & Wegener 1989; Gardner & Blackwell, 1974; Habibi et al., 2010; Hon, 1994; Kamide, 2005; Klemm et al., 2005; Kovalenko, 2010; O'Sullivan, 1997).

Cellulose displays unusual physical and chemical properties arising from its structural architecture, such as:

- I. Highly hydrophilic nature. However, it is insoluble in water and in most conventional organic solvents. Even such a short oligosaccharide as cello heptose is virtually insoluble. This does not mean that cellulose interacts poorly with water - a cellulose surface is very hydrophilic, e.g. cotton fibres can absorb 10 times its own weight of water (Monica et al., 2009).
- II. Good thermal stability. But it decomposes prior to the onset of melting, i.e. it is a non-thermoplastic material.
- III. Resistant to chemicals attack. Cellulose is relatively resistant to chemical derivatization, and added groups are seldom evenly distributed. Nevertheless,

there is a large industry based on derivatization of cellulose, as previously mentioned.

- IV. Good mechanical properties. Cellulose form fibres with high tensile strength and stiffness, which makes the cellulose fibres useful e.g. as reinforcing element in polymeric composites.
- V. Low density and thermal conductivity.

Therefore, in order to understand properly the macroscopic properties of cellulose it is essential to acquire knowledge of its structural architecture from the atomic scale, all the way up to the macro scale. In that case, the cellulose biosynthesis, its supramolecular structures and hierarchical organization inside the cell wall must be considered. Besides this, it is important to examine how interactions at and between the various levels of structure have important and often quite specific influences.

1.2 MOLECULAR FEATURES OF CELLULOSE

Cellulose is a semicrystalline long chain linear homopolymer, consisting of β -D-glucopyranose (glucose) molecules covalently linked through acetal functions formed by β -(1,4)-glycosidic bonds (Fig 1.1), i.e. β -type glycosidic bond between the hemiacetal group of anomeric carbon atom C1 of one D-glucose and the hydroxyl group at C4 of the adjacent molecule. This glycosidic bond has a strength on the order of ~ 360 kJ/mol. Since a molecule of water is lost when an alcohol and a hemiacetal react to form an acetal linkage, each glucose molecule in cellulose is referred to as anhydro glucose unit (AGU). The AGUs are joined to one another in head-to-tail orientation and the C–O–C angle between two AGU rings is $\sim 116^\circ$. To accommodate the preferred bond angles of this acetal oxygen bridges formed by β 1-4 links, each AGU ring is rotated 180° in the plane with respect to its neighbor. In this manner, two adjacent AGU rings define the repeating structural unit of cellulose polymer, known as cellobiose. However, the chain length of cellulose is expressed in the number of constituent AGUs (degree of polymerization, DP), and hence, the chemical formula of cellulose is $(C_6H_{10}O_5)_n$.

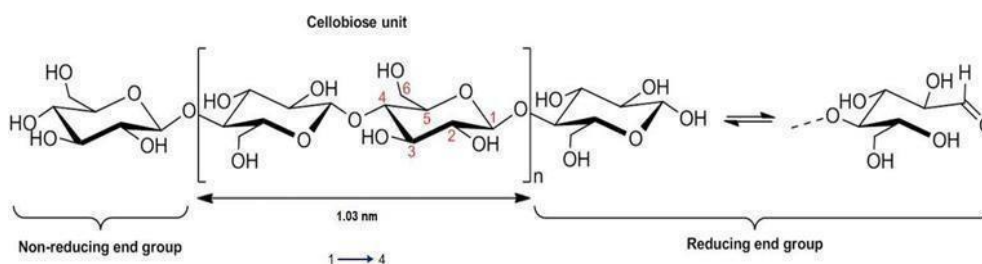


Figure 1.1 Structure of cellulose molecule, representing the cellobiose unit as the repeating structural unit having a periodicity of ~1.03 nm and showing the quite different terminal groups non-reducing end (left) and reducing end (right).

Taking the cellobiose as the basic unit, cellulose can be considered as an isotactic polymer of cellobiose. Each of the AGU ring contains three hydroxyl groups. The hydroxyl group at the C6 position is a primary alcohol, while the hydroxyl groups at the C2 and C3 positions are secondary alcohols. These hydroxyl groups are all accessible sites for chemical reactions. Unlike simple alcohols, however, the reactivity of these hydroxyl groups is usually controlled more by steric factors and molecular interactions than would be expected on the basis of the inherent reactivity of the different hydroxyl groups. The cellulose molecule has a directional chemical asymmetry with respect to the termini of its chain axis: one end is a hemiacetal which is in equilibrium with the aldehyde structure (i.e. the reducing end); and the other end has a pendant hydroxyl group, the nominal non-reducing end (Dufresne, 2012; Habibi et al., 2010; Klemm et al., 2005; Pérez & Mazeau 2004).

The β configuration allows cellulose to form long, straight, “fully extended” chains, i.e. molecular chains are stretched out in a straight line, in the opposite to the 1-4 glucan of α -anomers, amylose, which is hexicalled shaped. All β -D-glucopyranose rings adopt a $4C_1$ chair conformation, the lowest free energy conformation of the molecule, in which, the glycosidic bonds and the ring substituents are all positioned in the ring plane (equatorial), while the hydrogen atoms are in the vertical position (axial) (Kovalenko, 2010; Pérez & Mazeau 2004; Varshney & Naithani, 2011). This way, as represented in Figure 1.2, the cellulose molecule takes the form of a flat ribbon with hydroxyl groups protruding laterally along the extended chain and, as a consequence, these hydroxyl groups are readily available for hydrogen bonding, either within the same cellulose chain (intramolecular) or between different chains (intermolecular).

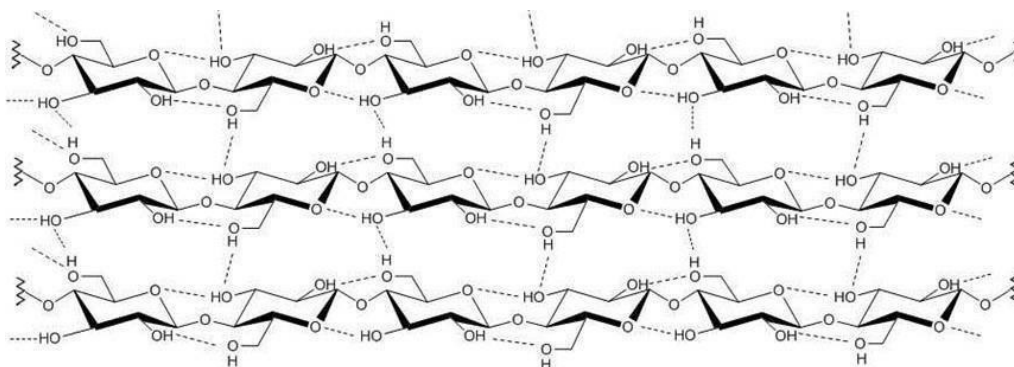


Figure 1.2 Schematic drawing of the intra- and intermolecular hydrogen bonding network in cellulose

The presence of intramolecular hydrogen bonds is of high relevance with regard to single-chain conformation of cellulose, since they hinder the free rotation of the rings along their linking glycoside bonds resulting in the stiffening of the cellulose chain. These intramolecular hydrogen bonds between adjacent AGU rings stabilize the glycosidic linkage in so much that the rigidity and the linear integrity of the polymer chain are enhanced. The intermolecular hydrogen bonds, in turn, are thought to be mostly responsible to interchain cohesion, and thus, also to the aggregation state of cellulose (from sheet-like to fibrillar aggregates), also known as supramolecular structure (Djahedi et al., 2016; Dufresne, 2012; Habibi et al., 2010; Varshney & Naithani, 2011).

Another important feature arising from the flat ribbon-like shape of cellulose molecule and the positioning of its hydroxyl groups and hydrogen atoms in the pyranose ring (OH groups are equatorial, while the H atoms are oriented axially to the ring plane) is the formation of sites with markedly distinct polarities: the hydrophilic sites parallel to the ring plane and the hydrophobic sites perpendicular to the ring (Jarvis, 2003; Li & Renneckar 2011; Medronho & Lindman, 2014; Yamane et al., 2006). This feature is depicted in Figure 1.3, and is expected to considerably influence both the microscopic (e.g. interactions) and macroscopic properties (e.g. solubility) of cellulose.

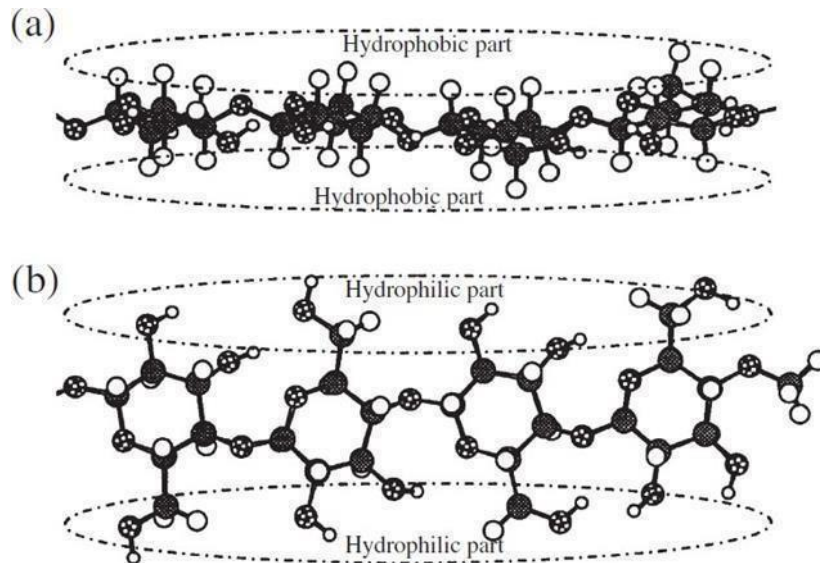


Figure 1.3 Hydrophilic and hydrophobic parts of cellulose molecule. (a) Hydrophobic sites of cellulose molecule in side view of glucopyranose ring plane showing the hydrogen atoms of C–H bonds on the axial positions of the rings, (b) hydrophilic sites of cellulose

1.3 CELLULOSE MICROFIBRILS AND HIERARCHICAL ORGANIZATION OF PLANT FIBRES

Fibre is a generic term referring to material that has a length (that is long axis) many times greater than its diameter (most often 100 times greater in length than in diameter). For these materials the ratio between the length (L) and the diameter (D) (i.e. fibre length divided by diameter), known as aspect ratio (L/D), is normally greater than 100. They are usually circular or nearly circular and are significantly stronger in the longer direction. Due to the strength and stiffness of fibres, they are the predominantly used reinforcements for advanced composites (Campbell, 2010). The fibres are classified according to their origin, which can be natural, artificial or synthetic. Specifically, the natural fibres can be divided into three groups: plant fibres, animal fibres and mineral fibres. Plant fibres are examples of complex systems developed by nature. Owing to their roles in the biological universe and to industrial applications, plant fibres are biodegradable materials of great importance today. Due to their unique structure the plant fibres can be considered as naturally occurring composites, in which the semicrystalline cellulose microfibrils act as reinforcing elements to a relatively amorphous matrix mostly made up of lignin and hemicellulose. While the matrix (lignin and hemicellulose) acts as a natural barrier to microbial degradation and serves as mechanical protection, the cellulose microfibrils have the

function to provide rigidity and structural stability to the cell wall of the fibres (Célino et al., 2013; John & Thomas, 2008; Silva et al., 2009a). Plant fibres consist therefore of cellulose microfibrils aggregate.

The plant fibres are essentially composed of cellulose, hemicelluloses (or polyoses) and lignin. So, plant fibres are often called lignocellulosic fibres. However, besides these components, plant fibres also contain pectins, extractives, waxes and minerals etc. The proportion of plant fibre constituents depends on parameters like botanical origin, maturation time, climatic conditions, age of the plant etc (Célino et al., 2013; John & Thomas, 2008; Silva et al., 2009a).

Hemicelluloses are not a form of cellulose, but are short chain, amorphous polysaccharides with 500–3000 monomer units with acidic groups. They include xyloglucans, xylans, glucomannans and galactoglucomannans. Their composition and structure are reviewed in Ebringerova et al. (2005). Lignin is an amorphous, complex phenolic macromolecule; the biosynthesis and structure of lignin are discussed in detail by Boerjan et al. (2003). Pectins are a group of polysaccharides rich in galacturonic acid units; for review on their composition and structure, see Brejnholt (2010).

From a structural point of view, plant fibres are multicellular in nature and consist of bundles of elongated mostly cylindrical honeycomb cells which have different sizes, shapes and arrangements depending on the source of the plant fibre (Dufresne, 2012). Fibres may occur in almost any part of a plant: stems, leaves, fruits, seeds, etc. Their primary function is to provide mechanical support to the plants, although fibres in some species also participate in water transport.

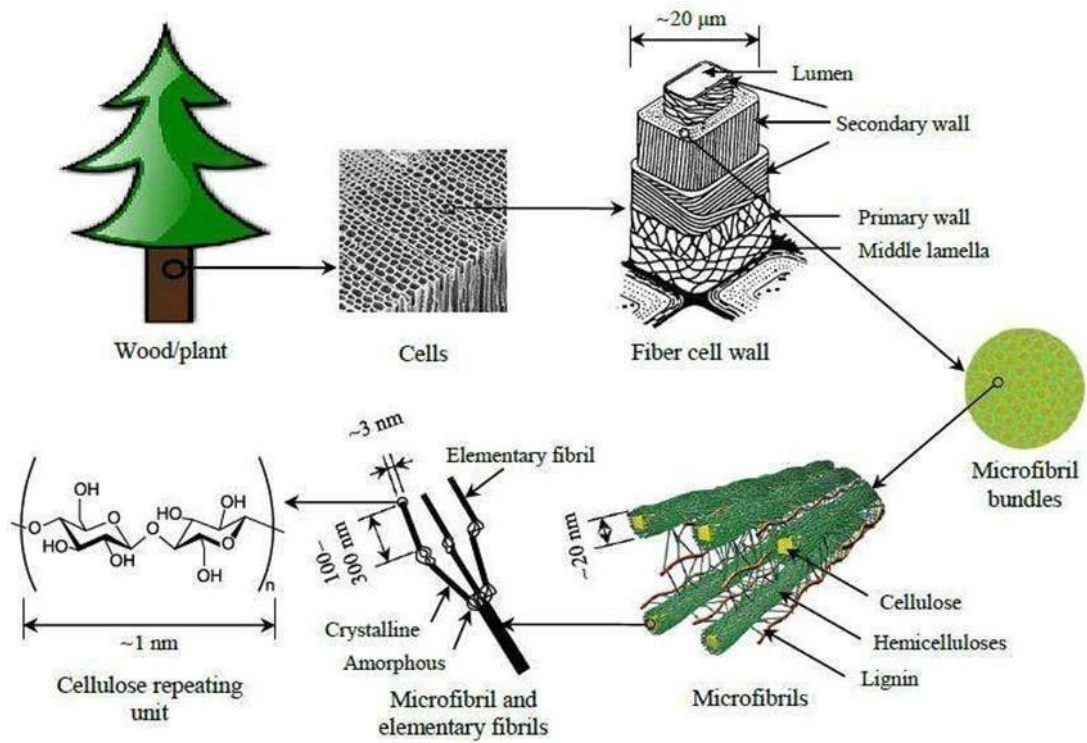


Figure 1.4 Schematic diagram for the hierarchical structure: from tree to cellulose (adapted from Fengel & Wegener 1989; and Ritter 2008)

CHAPTER – 2

LITERATURE SURVEY

2.1 HEMICELLULOSE

Hemicellulose is another component of a plant's cell walls. While cellulose has a crystalline, solid structure that is resistant to hydrolysis, hemicelluloses have a slightly firm, amorphous structure. It is a type of branched chain structured carbohydrate that has the formula $(C_5H_8O_4)_n$ (DP 100– 200). (Klass, 1998). The composition and structure of hemicellulose is significantly different among different biomasses. However, most hemicelluloses contain some basic residues of sugar including d-xylose, d-glucose etc. In their ramified structures, they usually contain 50–200 Units. More gases and less tar are generated by hemicellulose in comparison to cellulose (Milne, 2002). Hemicellulose has high solubility in weak alkaline solutions and can be readily hydrolyzed by dilute base or acid.

2.2 LIGNIN

Lignin is an essential part of the plant's secondary cell wall. It is an incredibly complex, strongly ramified, phenylpropane polymer. It is one of the world's most plentiful organic polymers (exceeded only by cellulose). It is the third major component of woody biomass cell walls. Lignin is a cellulose fibre cementing agent with neighbouring cells. Benzene rings are the dominant monomeric units of the polymers. It is like glue in a cardboard package, created in a special way by gluing papers together. In the middle of the lamella, which mostly consists of lignin, neighbouring cells and tracheids are stucked together. Even sulfuric acid is extremely insoluble in lignin (Klass,1998).

2.3 CELLULOSE

The most common organic compound on Earth, cellulose, is the primary structural factor of biomass cell walls. Cotton has a volume that ranges from 90 percent (by weight) to 33 percent for most other plants. Cellulose is a long-chain polymer with the generic formula $(C_6H_{10}O_5)_n$, a high degree of polymerization (10,000), and a large molecular weight (500,000). It has thousands of crystalline units that are made up of several glucose molecules. This structure provides it with high strength, allowing it to provide the skeletal structure of most terrestrial biomass (Klass, 1998). Cellulose is

primarily composed of d-glucose, which is composed of six sugars or hexose sugars. Despite being a carbohydrate, cellulose is extremely insoluble and cannot be digested by humans. It is a major component of wood, accounting for 40 to 44 percent of the dry weight. During biomass gasification, cellulose contributes significantly to tar.

2.4 WEEDS

Weeds are plants considered undesirable in a particular context, often conflicting with human preferences and goals. (Bridges et al., 1994) The challenges associated with weeds arise when they compete with crops, leading to potential yield loss (Holzner, W. et al., 1982). Weeds can be broadly categorized based on their characteristics, and understanding their ecological role reveals their significance in natural processes like ecological succession. Herbicides play a crucial role in weed management, but it's essential to distinguish between references to the crop or the weed when discussing control measures. An ecological perspective highlights weeds as evidence of nature striving for ecological balance, especially in areas where human activities disrupt native vegetation. This introductory insight into weeds emphasizes their impact on agriculture, the environment, and the importance of sustainable management practices.

2.4.1 *Typha latifolia*

Typha Latifolia is a perennial herbaceous plant (PHP) that belongs to *Typha* family with about twelve different species spread throughout the world (Rezig et al. 2016). The water ponds, rivers, lakes, and drainage ditches are the very feasible place to grow. Leaves looks like a massive blade of grass having approximate length of three to eleven feet with one inch wide (Bajwa et al. 2015). These leaves consist of lignified fibre cables (LFC) in sheath and nonlignified fibre cables (NLFC) in leaf blade (Witztum and Wayne 2016a). Approximately 30–40% of Fibre cables (on weight to weight) extracted from the leaves.

Application of natural fibres in textile sector will control the environmental pollution (Dedeepya, Dharma Raju, and Jayananda Kumar 2012) (Ramanaiah, Ratna Prasad, and Hema Chandra Reddy 2011). *Typha Latifolia* plants grow easily at sources of wet lands and available more in quantity. The fibre properties such as mechanical, physical, chemical, and thermal are very important for the textile applications. These properties have an influence on the final product properties. *Typha*

Latifolia fibres used to produce natural fibre reinforced composites and composite panels since it is having an advantages like good tensile strength, long fibre length, availability, and easily biodegradable (Ly et al. 2019) (Ramanaiah, et al., 2011) (Dedeepya et al., 2012)(Bajwa et al. 2015)(Wuzella et al. 2011). *Typha Latifolia* and polypropylene fibre blended needle punched nonwoven fabrics sound absorption characteristics were studied for building, automotive and transportation applications (Moghaddam et al. 2016). Natural fibres also can be used in various applications such as paper products, geotextiles, nonwovens, and evaporative cooler pads for house hold made from coconut coir fibre (Bidin et al. 2015) (Shrivastava et al.,2014)(Hindoliya et al., 2014). According to previous studies (Witztum and Wayne 2016b) (Mortazavi and Kamali Moghaddam 2010) has done work on few tensile and morphological characteristics.

2.4.2 *Phragmites karka*

Phragmites karka, known as common reed, is one of the most common species found mostly around lakes, rivers, and streams. To the best of our knowledge, there is no research reported in the literature for *P. karka*' use as a potential candidate and natural source in cellulose production. Among several attempts with a wide variety of natural materials, *P. karka* may hold a prominent potential based on its characteristics such as easy availability, low cost, enormous productivity and worldwide distribution. Limited availability of natural freshwater resources are needed for many functions; sustainable use and protection of water sources are becoming more important day by day. Here, cellulose fibrils were extracted from *P. karka*, a new, abundant and low-cost source, via chemical extraction process. Morphological, structural characterization of the cellulose fibrils were obtained during the extraction process and reported.

2.4.3 *Eichhornia*

Many natural resources available in world has the potential to be more utilized; however, the development of the usage of the available natural resources in this world have not been explored yet. One of the most abundant plants in India is water hyacinth (*Eichhornia crassipes*). This plant growth rate can damage the aquatic environment; thus, they are often regarded as weeds (A. R. Fachry et al., 2010). Some important substances contained in the water hyacinth are cellulose 64.51%, pentose 15.61%,

lignin 7.69%, silica 5.56%, and ash 12% (Aini et al., 2013). The higher cellulose content in water hyacinth made it being used as a potential component for extraction of cellulose. However, the isolation of water hyacinth cellulose is generally carried out through the extraction stage using toluene (Rachmawaty et al., 2013), which can cause acute poisoning in the human central nerve (A. Rahmat et al., 2019). In the longterm can trigger anemia and damage to DNA in the blood, bone marrow, and liver. Therefore, modifying the water hyacinth cellulose isolation method is required. The previous research has succeeded in innovating cellulose isolation through the stages of bleaching and alkalization. The objective of this study is to conduct research into making modified cellulose isolation methods using safer bleaching and alkalization methods. In the final, the isolated cellulose was then applied as the reinforcing agent in synthesis.

2.5 DEGREE OF POLYMERIZATION OF CELLULOSE

The size of the cellulose molecule, indicated by the degree of polymerization (DP) or molecular weight (MW), has a great influence on the mechanical, solution, biological, and physiological properties of cellulose. It is believed that a β (1-4) linked glucan with DP around 20–30 can offer all properties of cellulose (Dufresne, 2012; Klemm et al., 2005; Kobayashi et al., 2001). Values of DP ranging from hundreds and several tens of thousands have been reported. The DP is heavily dependent on the source of the original cellulose (e.g., 10 000 in native wood, 15 000 in cotton), and in less degree on the isolation and purification methods (e.g., 250 – 500 in regenerated cellulose). The combination of procedures required to isolate and purify cellulose inevitably causes some degradation during analysis resulting in chains scission. The values of DP obtained are therefore minimal and depend on the method used to determine it. For the same reasons, the distribution of chain lengths of cellulose is not well established. Nonetheless, some authors suggest that the molecular mass distribution must be homogeneous for cellulose of a given source (Dufresne, 2012; Fengel & Wegener 1989; Habibi et al., 2010; Klemm et al., 2005; Varshney & Naithani, 2011).

In its commonly used form, isolated cellulose is always a polydisperse polymer, viz., like nearly all polymers it is a mixture of molecules that have the same basic composition but differ in the chain length. Thereby, the molecular mass and the DP of

cellulose can only be considered as average values. Since cellulose often has a high DP, the fibrils are quite long. For example, given a glucose unit as 0.515 nm long, for DP value of 10 000, the cellulose molecules may have average length around 5 μm by considering stretched chains.

2.6 CELLULOSE BIOSYNTHESIS AND CELLULOSE MICROFIBRIL FORMATION

In nature, cellulose does not occur as an isolated molecule, but it is found as assemblies of individual chains forming a fibre-like structure. This is because cellulose is polymerized as individual molecules, which undergo spinning and crystallization in a hierarchical order at the site of biosynthesis resulting in fibrillar supramolecular structures (Habibi et al., 2010). That way, the biosynthesis of cellulose can be described as a complex sequential multistep phenomenon, involving coupled processes (i) the enzymatic polymerization of individual β -(1,4)-D-glucopyranose chains from glucose monomers, and (ii) the assemble of these glucan chains, through spinning and crystallization, to form fibrillar supramolecular structures (Dufresne, 2012).

2.7 SEMI-CRYSTALLINE NATURE OF CELLULOSE

Several studies carried out at the sub-microscopic scale emphasized the discontinuous character of microfibrils (i.e. the biphasic nature of its structure). Experimental evidence was provided by wide angle (Fink et al., 1987) and small angle X-ray diffraction (Grigoriew & Chmielewski, 1998), solid state ^{13}C NMR (nuclear magnetic resonance) experiments (Earl and VanderHart, 1981), and tensile tests performed on cellulose fibres (Ishikawa et al., 1997). the crystallization follows very closely the polymerization of glucopyranose residues in a way that allows the present proteins of the TCs to govern the microfibril crystalline form. As a basic rule, microfibrils can be considered as a slender rod- like element composed of highly ordered regions (the cellulose crystals) linked along the fibre axis by less organized ones.

CHAPTER – 3

AIM AND OBJECTIVES

3.1 AIM

To extract and characterize cellulose from different locally available plant source and to synthesize cellulose acetate for further applications.

3.2 OBJECTIVES

- To extract cellulose from the weeds.
- To characterize the extracted cellulose.
- To synthesize cellulose acetate using the extracted cellulose.
- To characterize the synthesized cellulose acetate.
- To optimize extraction methods to efficiently isolate cellulose.

CHAPTER – 4

MATERIALS AND METHODS

4.1 PLANT SAMPLE COLLECTION FOR CELLULOSE EXTRACTION

Three plant samples were chosen for the cellulose extraction based on the previous literature study. *Typha latifolia*, water hyacinth and *Phragmites karka* were collected from the water bodies in the Chennai locality. Once the samples were collected, they were transported to the laboratory and washed with distilled water to remove the dirt and stored in room temperature for further experiments

4.2 EXTRACTION OF CELLULOSE FROM *Typha Latifolia*

Typha Latifolia leaves was collected from the nearest water ponds and dried by exposing to sun for a week of 7–10 days. The *Typha latifolia* stems were first washed, cleaned, and then dried. The fibre separating process was done manually by striking the stems. After major amount of moisture dried out, further the leaves were absolutely dried in hot air oven at a temperature of 105°C till the evaporation. Dried leaves subjected to chemical treatment by sodium hydroxide (NaOH) with the extraction parameters such as time and chemical concentration The fibres were then dried for 4 days to remove the moisture. Next, the fibres were cut into small pieces and milled to pass through a mesh screen.

4.2.1 Fibres preparation

Dried *Typha Latifolia* leaves were cut to 10 cm length. For the chemical retting of fibres two factors was selected for the study, first one is chemical concentration in the bath and second was treatment time. Treated leaves were washed thoroughly to remove impurities. Further washed fibres were neutralized by using acetic acid with 2 gpl concentration for 30 min, then rinsed with the hot water and finally dried. The prepared *Typha Latifolia* sp. fibres were treated with 1 M NaOH at 90 °C for 1 h. The sample-to -solution ratio is 1:20 (g/mL). The washing process was carried out repeatedly to reach the neutral pH, and then the samples were dried at 60 °C for 4 h. The sample then undergoes the process of treating with 1 M NaOH solution and 1 M H₂O₂ at 50 °C for 1.5 h. The weight ratio of the sample and the solution used in this process was 1:20 (g/mL). The sample was then dried at 60 °C for 4 h.

4.2.2 Cellulose isolation and extraction

Cellulose was isolated by acid hydrolysis, and this process was conducted by dispersing the sample in 1 M H₂SO₄ at 45 °C for 45 min with a ratio of 1:20 (g/mL). The utilization of 45 °C in acid hydrolysis is better than 65 °C (Dong et al., 1998). Filtering and washing with distilled water were carried out repeatedly to obtain a normal pH. Centrifugation for 30 min at a speed of 10,000 rpm was repeated three times, followed by sonification for 30 min. Samples were dried at 60 °C for 4 h and followed by open air drying. The samples were then blended and sieved through meshes.

4.3 EXTRACTION OF CELLULOSE FROM WATER HYACINTH

The water hyacinth was dried in the sun for 7 days. Dry water hyacinth was washed and cut into small pieces, then mashed using a blender until a sample size of less than 1 mm was obtained. A sample of 15 g of dried water hyacinth was bleached using sodium hypochlorite (NaOCl) with a ratio of 1:20 (w/v). The bleaching process was carried out at a heating temperature of 75 – 80 °C and kept stirring at a speed of 590 rpm for 4 hours. The bleached samples dispersion was neutralized using distilled water until the pH reached 7. The sample was decanted and filtered to separate from the filtrate. The neutralized sample was refluxed using 150 mL of 17.5% sodium hydroxide (NaOH) for 3 hours at a heating temperature of 45 °C and stirred with a speed of 500 rpm. The residue as the powder was again neutralized using distilled water until pH reached 7 and then was dried under room temperature for 2-3 days.

4.4 EXTRACTION OF CELLULOSE FROM *Phragmites karka*

Firstly, *P. karka* samples were boiled in distilled water at 100 °C for 3 h to remove water-soluble impurities. The cooled mixture was filtered and washed with distilled water (M. Fardioui et al., 2016). Then, the biomass was stirred in NaOH solution (5%, 10 mL) at 70 °C for 2 h. After this process, sample was filtered out and washed with distilled water until neutral pH was obtained. As a final step, the sample was mixed with NaOH (4%) and H₂O₂ (7%) solution (1:1 v/v) at 60 °C for 2 h (S.A. Nascimento et al., 2018). All treatments were practised three times. After each treatment, the sample was washed with distilled water.

4.5 BLEACHING

The chemical bleaching was carried out in polypropylene bags with 5% (v/v) H₂O₂, 0.1% MgSO₄ in for 45 min, at 70 °C under medium consistency of 5% (w/v) and pH 12 (adjusted with concentrated NaOH solution). At the end of the process, the material was washed with distilled water at 70 °C until the pH reached a value of 7.

4.6 CELLULOSE ACETATE SYNTHESIS

Cellulose acetylation was conducted using the following processes: initially 10 g of cellulose and 24 mL glacial acetic acid were mixed and stirred at 40 °C for 1 hour. Furthermore, 1 ml sulfuric acid and 60 ml glacial acetic acid were added, and stirred again for 45 minutes at the same temperature. The mixture was cooled to 18.3 °C and then 28 mL acetic anhydride was added. Thereafter, 1 mL sulfuric acid and 60 ml glacial acetic acid were added to the mixture, and acetylation time of 3 hours at a temperature of 40 °C. Furthermore 67% acetic acid was added to the mixture at 40 °C for hydrolysis process as long as 15 hours at room temperature. After doing acetylation and hydrolysis, cellulose acetate was precipitated by adding distilled water drop by drop and stirred to obtain powder precipitate. The resulted powder precipitate was washed with distilled water until pH 7.0 (Rodrigues Filho et al., 2005) and dried in an oven at 50 °C.

4.7 CHARACTERIZATION OF CELLULOSE

4.7.1 ATR-FTIR

The functional groups of untreated, alkali-treated, bleached fibrils of *P. karka* were analysed using a Fourier Transform infrared Spectrometer (FTIR) within the range of 400–4000 cm⁻¹ with an ATR (Attenuated Total Reflection) attachment.

4.7.2 X-Ray diffraction analysis

X-ray diffraction is used most often to identify crystalline phases by comparison to a known database, measure atomic spacings (with the use of appropriate standards), measure structural properties of the crystalline phases present (e.g., preferred orientation and particle size), and to probe atomic arrangements in amorphous materials. The XRD scans were performed. XRD samples were prepared by pressing raw materials between two glass slides into flattening sheets. The identification of crystalline materials is often aided by chemical analysis in order to identify the elements present. The mass fractions of the phases present in a sample

can be determined by comparison to known standards. Since XRD is relatively quick and is usually a non-destructive technique, it is often one of the first methods employed in the characterization. The electron diffraction pattern is similar to an X-ray diffraction pattern in that diffraction occurs when the Bragg condition is satisfied. The Bragg equation ($n\lambda = 2d\sin\theta$) relates the wavelength (λ) of the electrons, the angle (θ) of the electron beam with respect to a set of diffracting planes, and the spacing (d) between those planes, which is determined by the crystal structure of the material examined. One challenge when working with electron diffraction is that electrons are often multiply scattered by the sample, which can complicate the interpretation of electron diffraction patterns (Burleson et al. 2014).

CHAPTER – 5

RESULTS AND DISCUSSION

5.1 CELLULOSE EXTRACTION AND ISOLATION

Hemicellulose and lignin were removed by treatment NaOCl and NaOH. NaOCl can oxidize lignin which is insoluble in water, resulting in carboxyl groups in lignin and increasing solubility in water. Product substances can also be introduced to some oxidized groups, such as aldehydes, ketones, and carboxylic acids in the cellulose chain. Lignin and hemicellulose will dissolve in such solvents. Then the cellulose will precipitate (Wang T et al., 2021). Delignification using NaOH causes the OH⁻ bonds of the alkaline solution to break the lignin-cellulose bonds. The lignin structure wraps the cellulose in it will open. When the lignin bonds begin to open, there will also ruin cellulose by OH ions more quickly, then cellulose dissolves in the solvent (Larasati I A et al., 2019).

Acid chloride functions as a penetration agent of hydronium ion to amorphous cellulose areas, followed by fragmentation hydrolysis of glycosylation site unit that produces crystals more regularly (Kian L K et al., 2017). Cellulose will dissolve in HCl solution. The released H₃O⁺ will move towards the glycosidic bond. At the same time, the glycosidic bond is weakened by Cl⁻. The H-bond structure of cellulose is then exposed after the cleavage of the glycosidic bonds. This reaction leads to produce glucose by reducing sugar of the same or higher yield. During hydrolysis, protonation of the acid forms hydronium ions (H₃O⁺) (Garba Z N et al., 2019). The sonication process causes the amorphous regions to loosen and defective the crystalline regions of the cell wall. Longitudinal fibrillation occurs due to sonication. After the hydrolysis process with HCl, the crystal region will be more accessible than without the treatment. Thus, the crystallinity will be higher (Wardhono E Y et al., 2019).

To isolate the cellulose from lignin, hemicellulose, and other impurities, the isolation process was conducted through three main stages, namely the process of initial treatment in the form of drying, cutting, bleaching, and alkalization stage. The cellulose is embedded in the hemicellulose matrix, which acts as a link between cellulose and lignin fractions and support to give rigidity to the structure of lignocellulose (S. Pujiasih et al., 2018). The isolation began with the process of bleaching to eliminate the content of lignin and other impurities presented in water

hyacinth fibres. Bleaching was done using sodium hypochlorite (NaOCl) solution. NaOCl in water produced hydroxyl ions and hypochlorous acid (HOCl), which is a strong oxidizer that breaks lignocellulosic bonds (delignification) and ether bonds in the lignin structure.

The lignocellulose and lignin terminator oxidation terminating reaction—in which lignin was separated from the cellulose—was indicated by the formation of wet solid material in the form of a yellowish-white pulp. After that, the next stage of the alkalization using NaOH was performed. This stage aims to remove the remaining lignin and hemicellulose, which were separated from the cellulose structure. The process of alkalization causes the oxidizing cellulose (A. S. Maryan et al., 2016). The process of alkalization caused the breakdown of ester bonds, which connecting lignin to hemicellulose in the complex lignin-carbohydrate network. As a result of this bond breakage, the complex lignin carbohydrate network was disrupted, allowing the lignin component to be dissolved (A. A. Modenbach et al., 2014). Furthermore, the presence of oxidizers ClO and OH also causes oxidation reactions on cellulose to cellulose with aldehyde and carboxylic groups (A. S. Maryan et al., 2016, R. Rachmawaty et al., 2013). The success of the isolation process of cellulose was assigned from the white color of the product increased (R. Rachmawaty et al., 2013). Weed samples experienced a lot of shrinkages when undergoing the process of bleaching and alkalization, around ~ 50% of the mass.

5.2 CELLULOSE YIELD PERCENTAGE

In this investigation, the cellulose extraction process from various plant species revealed distinct yield percentages. Notably, the extraction from 1 kg of *Typha* plant material resulted in a yield percentage of 16%, yielding 160 g of cellulose. Conversely, processing 1 kg of *Eichhornia* plant material yielded a lower yield percentage of 2%, with only 13 g of cellulose obtained. Meanwhile, the extraction from 1 kg of common reed plant material demonstrated a yield percentage of 9%, producing 88 g of cellulose. These findings underscore the variability in cellulose yield among different plant species and highlight the potential implications for cellulose extraction processes in drainage-adjacent ecosystems. We can conclude that *Typha* plant has the highest yield percentage (16%), followed by common reed (9%) and *Eichhornia* (2%).

5.3 ATR-FTIR CHARACTERIZATION

5.3.1 ATR-FTIR spectrum of *Typha latifolia*

Typha Latifolia leaf generally consists of 55–60% cellulose, 10–15% hemicelluloses, 25–30% lignin, and 5–10% non-cellulosic materials including wax and ash (Mortazavi et al., 2010, Chakma, Cicek, and Rahman 5). Leafs were subjected to sodium hydroxide with various concentrations and time intervals for separation of fibre and non-fibrous materials (NFM). Leaf was having the strong bonds of C-H stretching of alkyne at wave length (WL) of 3286.65 cm^{-1} to 3337.36 cm^{-1} . At 2850.48 cm^{-1} and 2918.04 cm^{-1} WL strong C-H stretching of alkane groups, also having at 1726.69 cm^{-1} strong C = O stretching of α,β -unsaturated ester or formats and 1618.59 cm^{-1} C = C stretching α,β -unsaturated ketones observed (Merck n.d.). The above bonds found in lignin, pectin, hemicelluloses and others. In extraction process bonding between NFM coated on the fibre becomes weak at different processing parameters. These will be removed in the washing process and it clearly shows in FTIR spectrum. Figure

5.1. clearly shows the peaks in the fibre FTIR spectrum. The peaks in the fibre spectrum indicates that due to treatment and after extraction specified groups pertaining to cellulose are present and the other groups were removed.

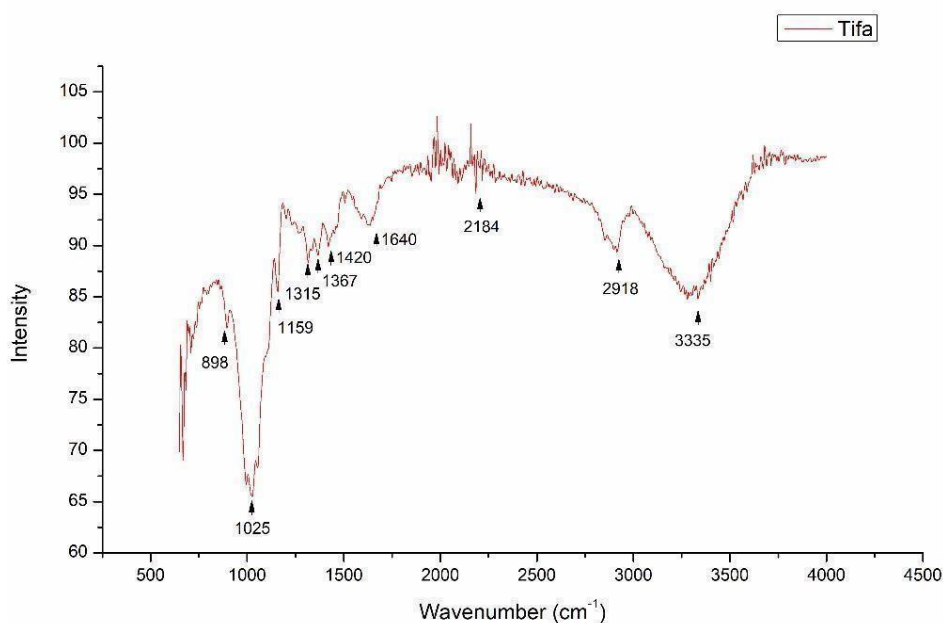


Figure 5.1 ATR-FTIR spectrum of cellulose extracted from *Typha Latifolia*

5.3.2 ATR-FTIR spectrum of *Eichhornia crassipes*

The analysis of the success isolation process of cellulose from water hyacinth was studied from the analysis of functional groups of isolated powder using the FTIR spectrophotometer as shown in Fig. 5.2. Fig 5.2 shows the FTIR spectra of powder of extracted cellulose. The FTIR spectra of water hyacinth after treatment with NaOCl and NaOH have significant results. The peak at wavenumbers $\sim 3420\text{ cm}^{-1}$ corresponds to the hydroxyl (—OH) group (A. L. M. P. Leite et al., 2017, Q. Meng et al., 2013, B. H. Stuart et al., 2004, M. T. Sundari et al., 2012). The absorption of the —OH group obtained after water hyacinth treated with both NaOCl and NaOH is noted. The changing of the feature peak of the —OH group observed at $\sim 3400\text{ cm}^{-1}$ indicates that the hydrogen bonds previously presence in both inter and intra-cellulose, lignin, and hemicellulose were already disrupted.

The observable peak at wavenumbers $\sim 2930\text{ cm}^{-1}$ corresponds to C—H vibrations (B. H. Stuart et al., 2004, V. Hospodarova et al., 2018). After the isolation process, the intensity of the vibrational peaks at the wavenumber indicates the severity of the chains between lignin, hemicellulose, and cellulose. In addition, the observable peak at wavenumber $\sim 2850\text{ cm}^{-1}$ from the NaOCl treatment results is more visible showing an indication of a change in the group —C—H to =C—H , which can originate from an aldehyde group formed from the oxidation of the group —OH . It is estimated that the process of further oxidation has also been strengthened by the appearance of absorption at wavenumber $\sim 1620\text{ cm}^{-1}$, which is a representation of the C=O group originating from the carboxylic group (R. Rachmawaty et al., 2013). The absorption peak at $\sim 1620\text{ cm}^{-1}$ produced is also the O—H group of H_2O absorbed (R. Rachmawaty et al., 2013, A. L. M. P. Leite et al., 2017). The absorption peaks for the C—H and C=O vibrations contained in the polysaccharide ring of cellulose are shown at wavenumber $\sim 1325\text{ cm}^{-1}$, while the vibrations of C—O—C in the pyranose ring are indicated by peak F at wavenumber $\sim 1065\text{ cm}^{-1}$ (W. T. Wulandari et al., 2016). Based on this FTIR analysis, all functional group uptake observed in the FTIR spectra, as shown in Fig. 5.2 corresponds to the cellulose structure, which concludes that the method used in this is proven as a method that successfully can be used to isolate cellulose from water hyacinth plants.

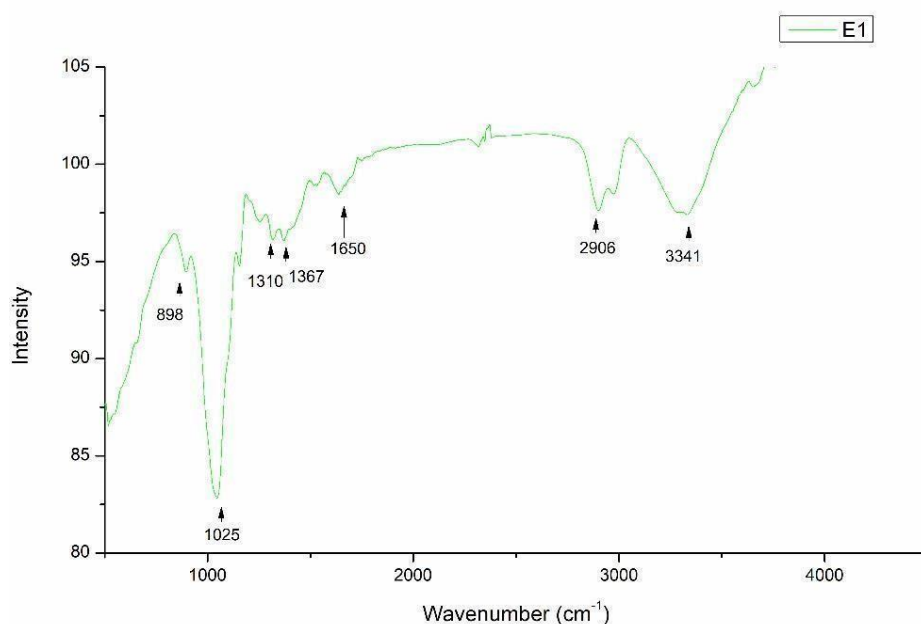


Figure 5.2 ATR-FTIR spectrum of cellulose extracted from *Eichhornia crassipes*

5.3.3 ATR-FTIR spectrum of common reed

FTIR spectroscopy was utilized to observe the chemical composition and the changes in the structure of *P. karka* fibrils after the extraction process. The FT-IR spectra of fibrils are depicted in Fig. 5.2. According to the spectrum of the *P. karka*, the peak around 1732 cm^{-1} refers to the acetyl and uronic ester groups of hemicellulose or indication of the ester linkages of the carboxylic groups of the ferric and p-coumaric acids of lignin and/or hemicellulose (M. Sain et al., 2006, A. Alemdar et al., 2008, C. Uma Maheswari et al., 2012). This peak disappeared after alkali treatment. The absorption band observed at 1507 cm^{-1} in treated plant sample is ascribed to C = C stretching vibrations of lignin aromatic rings (M. Sain et al., 2006). The peak of 1237 cm^{-1} in the structure overlaps with = C-O- axial asymmetric strain of the ether, ester and phenol groups of lignin (C. Uma Maheswari et al., 2012, Y. Li et al., 2016), . The absorption bands at 1599 and 1455 cm^{-1} correspond to the C\H deformation in methyl, methylene, and methoxyl groups of lignin (C. Uma Maheswari et al., 2012). The peaks were not present in the FT-IR spectra of alkaline treated *P. karka* fibrils; therefore these findings lead us to conclude that significant amount of lignin and hemicellulose have been removed from the plant's structure during alkali pretreatments (B. Deepa et al., 2015, D.Y. Kim et al., 2016). The peaks at 1428, 1367,

1316, 1160, 1029 and 896 cm^{-1} are related to the CH_2 bending vibration, C-O-C pyranose ring skeletal vibrations, $\text{C}=\text{O}$ stretching and $\text{C}\backslash\text{H}$ rocking vibrations of cellulose (C. Uma Maheswari et al., 2012). In the treated and extracted fibrils, a wide absorption band between 3300 cm^{-1} and 3500 cm^{-1} corresponding to stretching vibrations of the free $-\text{OH}$ groups in cellulose were also recorded (J. Łojewska et al., 2005, C.J. Chirayil et al., 2014). After extraction steps, the increase in the intensity and width of the observed peak in this region is significant.

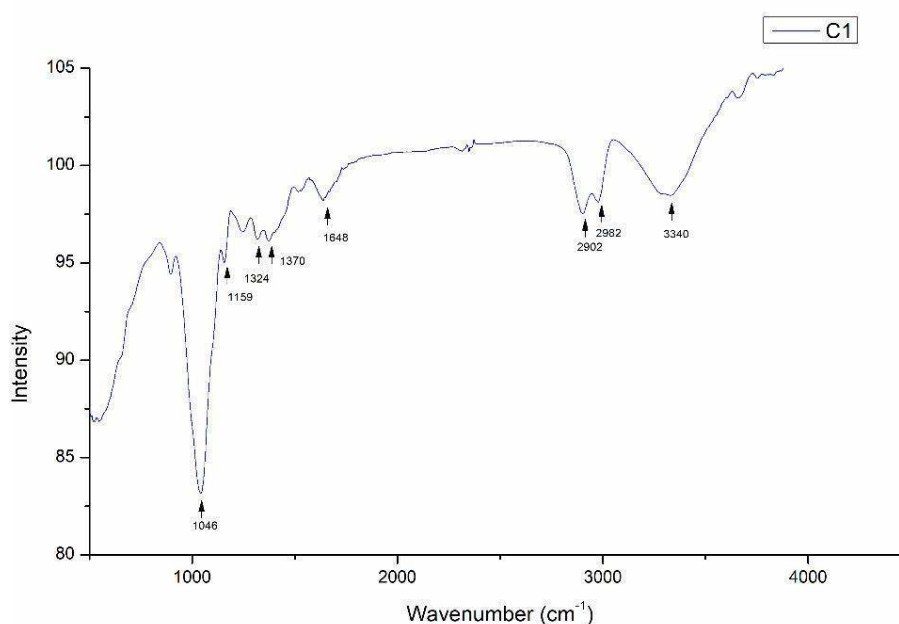


Figure 5.3 ATR-FTIR spectrum of cellulose extracted from *Phragmites karka* common reed

5.3.4 ATR-FTIR spectrum of cellulose acetate

Samples of CA were analysed by FTIR in order to compare the structure of the materials before and after the synthesis of cellulose derivative. Initially, the samples were dried at 60 C and subsequently cooled for 30 min. For the analysis, 1.5 mg of sample were prepared, by compressing. The same samples were prepared as reference. The spectra were measure in the region 4000–400 cm^{-1} in a spectrophotometer. The resulting spectra were normalized for better comparison.

Five main changes in the CA were observed:

1. Decrease of the band in 3400 cm^{-1} , corresponding to the stretching of OH groups of cellulose as result of the free OH group replacement for the acetyl groups (Rodrigues Filho et al., 2008);
2. Rise of the band in 1750 cm^{-1} , corresponding to the stretching of C O bond of ester carbonyl, which is present in the structure of the acetyl groups (Rodrigues Filho et al., 2008);
3. Decrease of the band in 1650 cm^{-1} , corresponding the absorption of water (Barud et al., 2008);
4. Rise of the band in 1360 cm^{-1} , corresponding to the vibration of C H bond, which is present in the structure of the acetyl groups (Cao et al., 2007);
5. Rise of the band in 1220 cm^{-1} , corresponding to the vibration of C O bond, which is responsible for the link between cellulose and acetyl group (Cao et al., 2007);

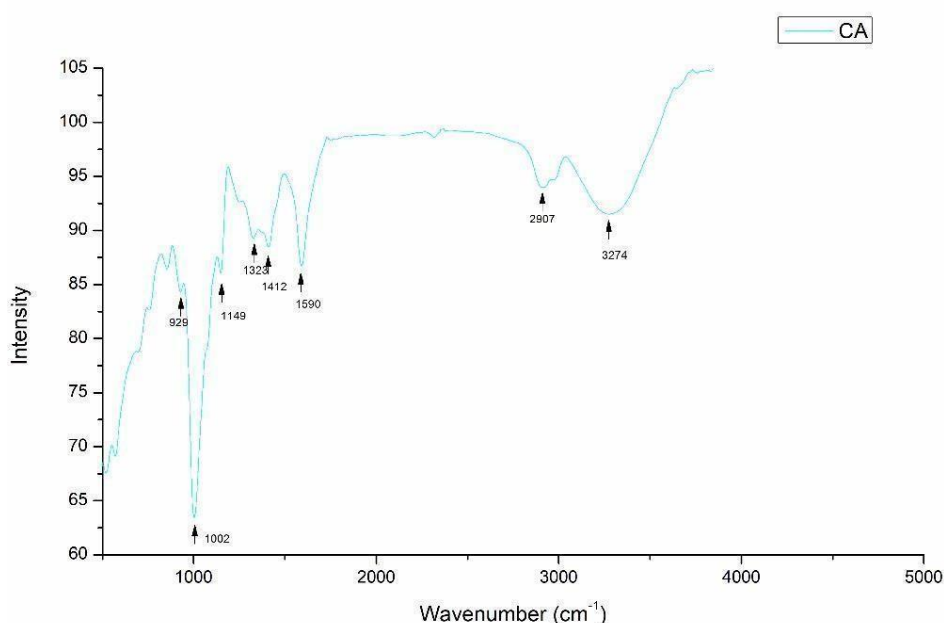


Figure 5.4 ATR-FTIR spectrum of synthesized cellulose acetate

5.4 XRD CHARACTERIZATION

5.4.1 XRD analysis of *Typha latifolia*

Study of standard data confirmed that the synthesized material has a crystalline phase. The cellulose structure was typical, exhibiting a broad peak at approximately

$2\theta = 16.5^\circ$, 22.5° , and 34.6° cellulose crystallinity has been discovered to be connected with absorption capacity. (Ling, Z., Wang, T., Makarem, M. et al).

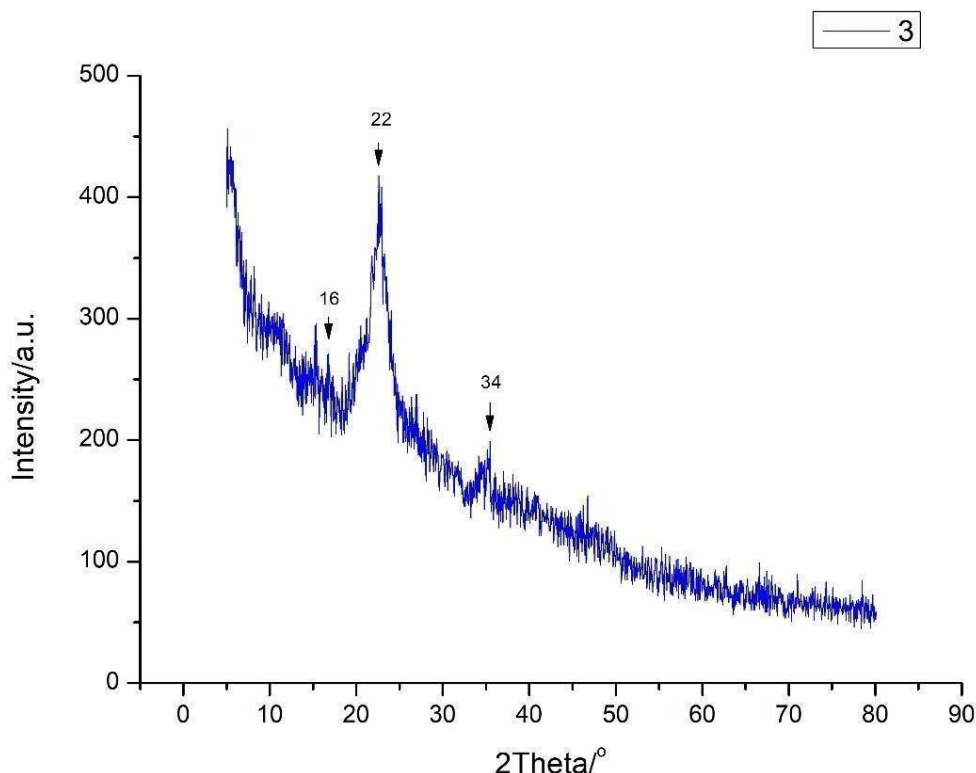


Figure 5.5 XRD spectrum of cellulose extracted from *Typha Latifolia*

5.4.2 XRD analysis of *Eichhornia crassipes*

The XRD pattern of fibre has the similar diffractive pattern to that of *Typha Latifolia*. There are two peaks at ($2\theta = 22.6^\circ$ and 16°) which are indicated the crystal structure of cellulose. This result was indicated the presence of intra and inter-molecular hydrogen bonding occurring in the cellulose through hydroxyl group that can trigger the formation of crystal order in the cellulose as reported by Sunil et. al. (J. C. C. S, N. George et al., 2016).

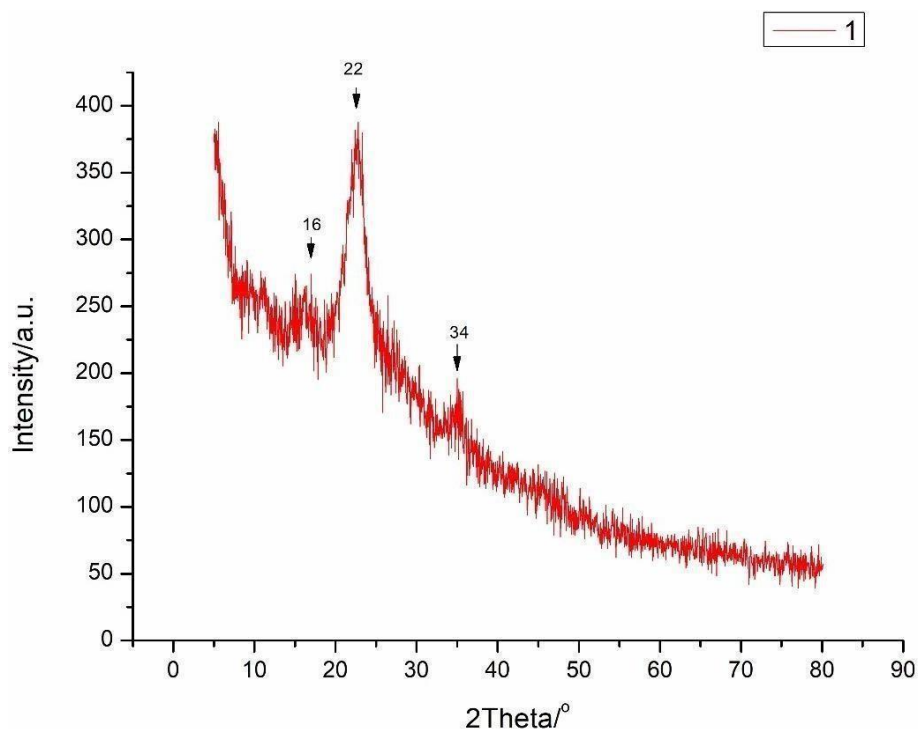


Figure 5.6 XRD spectrum of cellulose extracted from *Eichhornia crassipes*

5.4.3 XRD analysis of common reed

Study of standard data confirmed that the synthesized material has a crystalline phase. The cellulose structure was typical, exhibiting a broad peak at approximately $2\theta = 16.5^\circ$, 22.5° , and 34.6° . cellulose crystallinity has been discovered to be connected with absorption capacity. (Ling, Z., Wang, T., Makarem, M. et al).

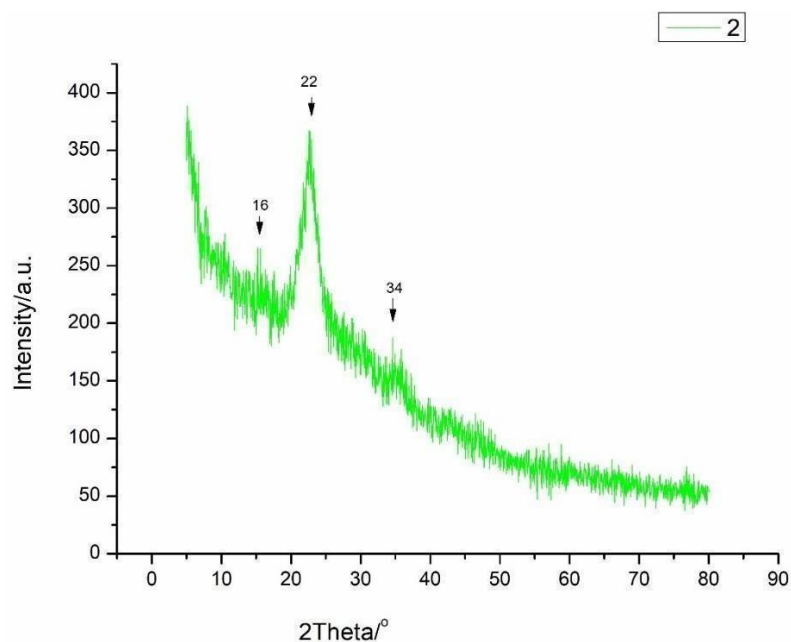


Figure 5.7 XRD spectrum of cellulose extracted from *Phragmites karka*

5.4.4 XRD analysis of cellulose acetate

Figure shows the X-ray diffraction pattern for sample. Study of standard data confirmed that the synthesized material has a crystalline phase. The peak and relative intensities obtained for the sample match with the literature values. The cellulose acetate structure was typical, exhibiting broad peaks at approximately $2\theta = 31^\circ$, 45° , 56° and 75° .

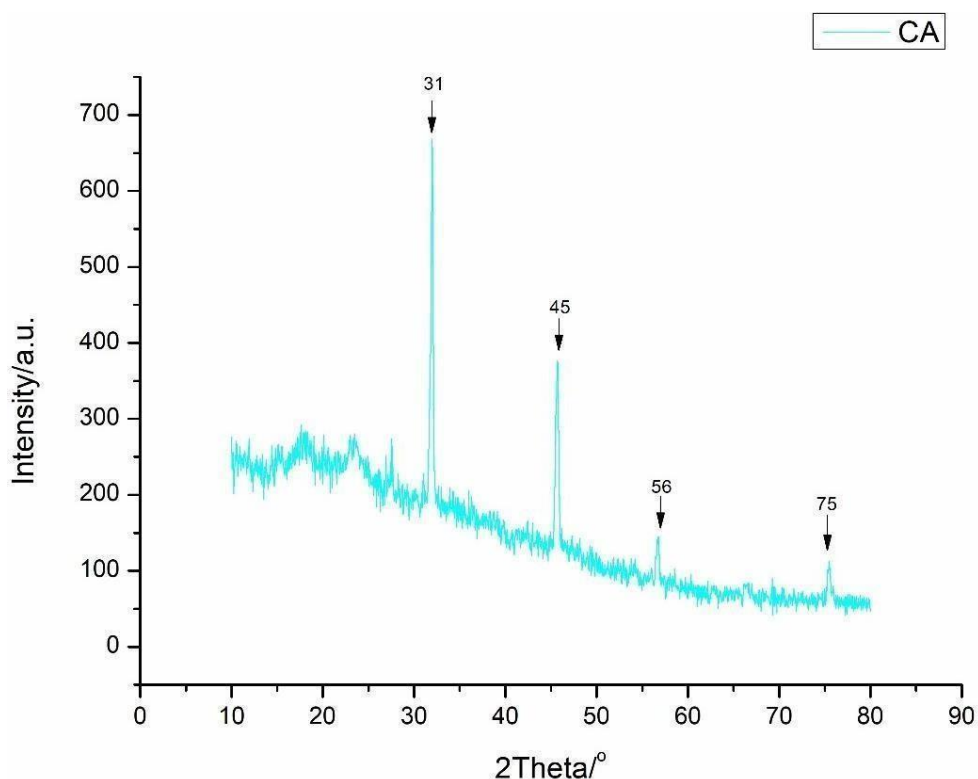


Figure 5.8 XRD spectrum of synthesized cellulose acetate

CHAPTER – 6

SUMMARY & CONCLUSION

The extraction of cellulose from weeds and the subsequent synthesis of cellulose acetate offers promising avenues for sustainable material development. By harnessing cellulose from readily available weed sources, such as agricultural residues or invasive plants, researchers can tap into a renewable and abundant resource. Through efficient extraction methods, cellulose can be isolated and processed into cellulose acetate, a versatile polymer with various applications including in textiles, films, and biomedical materials. This process not only reduces dependence on traditional cellulose sources like wood pulp but also addresses environmental concerns by repurposing unwanted plant matter. Additionally, the synthesis of cellulose acetate from weeds contributes to the circular economy by converting waste into valuable products. Overall, this approach underscores the potential of biomaterials derived from weeds in fostering sustainability and innovation in material science.

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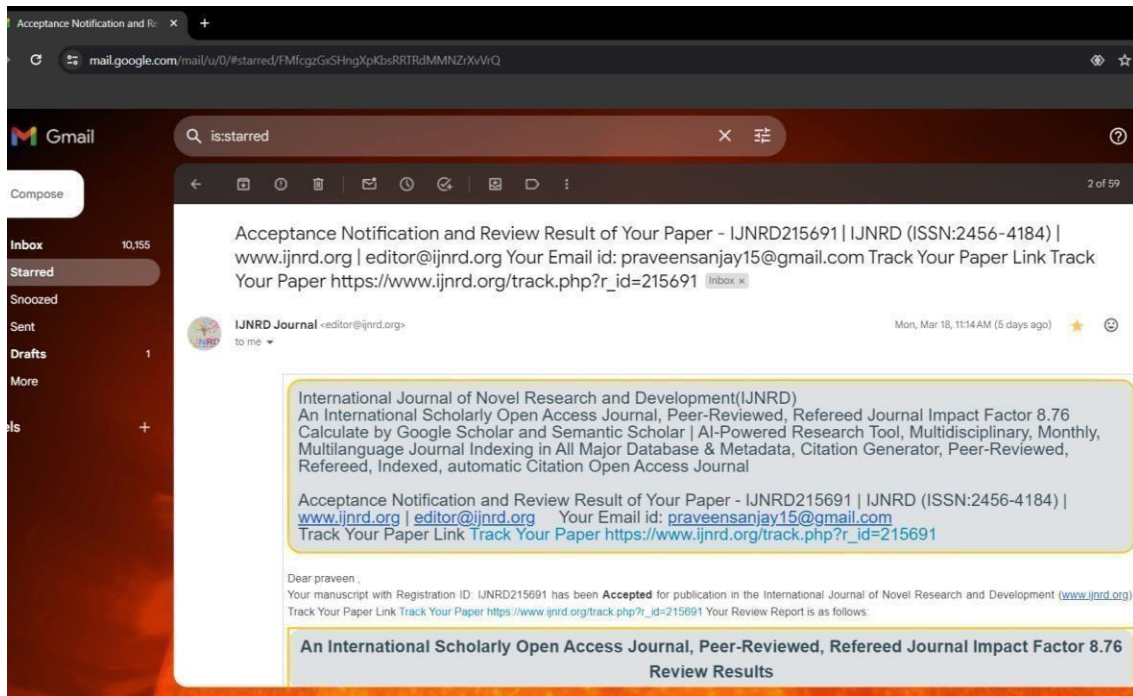
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Internal Guide Name : Dr. Prabhakar Singh

External Guide Name : Dr. D. Inbakandan

PO / PSO / PEO / SDG	Justification
PO7	Elimination of weeds such as Typha, Eichhornia, Common reed for extraction of cellulose and synthesis of cellulose acetate which leads to achieving environmental sustainability.
PSO3	Extraction of cellulose using bioprocess techniques such as pre alkaline, alkaline with steam explosion treatment. This enables efficient extraction of cellulose for synthesis of cellulose acetate.
PEO1	Cellulose extracted from weeds offer sustainable alternatives, aligning with global goals for technological excellence. Leveraging strong fundamentals and domain knowledge, modern technologies enhancing their properties and applications. By staying updated with advancements, the synthesised cellulose acetate from weeds provide effective solutions for environmental and technological challenges. Embracing cellulose extracted from weeds drives innovation towards a more sustainable and resilient future.
SDG15	Cellulose from weeds promote land sustainability. Derived from plant sources, they offer eco-friendly alternatives across industries. This shift minimizes habitat degradation and fosters biodiversity conservation. Embracing cellulose from weeds supports a greener future for life on land.

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