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Review Paper

A Review: Cellulose and Cellulase drive sustainable biomass conversion

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Abstract

Due to its high cellulose content and abundance in agriculture and forestry leftovers, cellulosic biomass is a viable feedstock. Cellulose, the most prevalent biopolymer on Earth, is a complex carbohydrate polymer that serves as the structural backbone of plant cell walls. However, there is still a considerable difficulty in the effective conversion of cellulose into biofuels and other products with added value. Cellulase enzymes, which are produced by a variety of microorganisms and some plants, are essential for the breakdown of cellulose. Through an intricate enzymatic mechanism, these enzymes have the singular capacity to hydrolyse cellulose into fermentable carbohydrates like glucose. By creating a sustainable and eco-friendly method for the manufacture of biofuel, the discovery and use of cellulases have revolutionized the conversion of biomass. Microbial cellulases are an essential tool for converting cellulosic biomass into useful products, providing environmentally friendly options for chemicals, materials, and energy. Cellulase production, optimisation, and application are areas that require ongoing research and technical development if we are to realise the full potential of these enzymes and accelerate the transition to a more resource-conscious and sustainable future.

Keywords: Cellulose, bacterial isolates, cellulase, and the food sector.

Introduction

Cellulose is a biopolymer, the world's most plentiful and renewable carbon source. It is the most important component of plant cell walls, giving structural support and rigidity. Cellulose is a polysaccharide composed of hundreds of glucose molecules connected by -1,4-glycosidic linkages. However, cellulose's extremely crystalline structure makes it challenging to disassemble into its component glucose units, creating a considerable barrier to turning cellulose into useful goods.

Cellulase enzymes are a type of enzyme that breaks down cellulose into glucose molecules. These enzymes are produced by a range of microorganisms, including bacteria and fungi, as well as by some mammals, including termites. Endoglucanases, exoglucanases, and -glucosidases are the three primary types of cellulase enzymes. Endoglucanases break the cellulose chain's internal 1,4-glycosidic linkages, whereas exoglucanases split the cellulose chain's ends. The cellobiose molecules produced by endo- and exoglucanases are then hydrolyzed into glucose by -glucosidases.

Because of their potential for sustainable biomass conversion, cellulose, and cellulase enzymes have received a lot of interest in recent years. The capacity to degrade cellulose into its constituent glucose units opens new avenues for the manufacture of valuable products such as biofuels, bioplastics, and biochemicals. Furthermore, using cellulose as a feedstock for these products has the potential to reduce our reliance on fossil fuels while also lowering greenhouse gas emissions.

Cellulose

Cellulose is an organic substance that serves as the primary structural component of plant cell walls. It is a linear polymer composed of repeated -D-glucose units connected by -1,4-glycosidic linkages. One of the most abundant biopolymers on Earth is cellulose, with photosynthesis in plants, algae, and some bacteria producing an estimated 1011 tons per year. Cellulose offers an exceptional combination of qualities, including high tensile strength, low density, and biodegradability, making it an appealing material for a wide range of applications. Cellulose, for example, is used to make paper, textiles, food additives, and biofuels, and it has been studied as a potential biomaterial for tissue engineering and medication delivery[1].

Figure-1: Chemical structure of cellulose[1].

The high expense of turning cellulose into usable sugars, however, has prevented the use of cellulose as a feedstock for biofuels. Researchers are investigating several strategies, including the use of genetically engineered microbes and enzymes, to increase the effectiveness and lower the cost of this process[2]. Cellulose has been investigated for use in biomedical applications in addition to its potential usage in composites and biofuels. For instance, cellulose-based hydrogels have been created for tissue engineering and medication delivery. The antibacterial capabilities of cellulose nanocrystals and their possible application in wound dressings have also been studied[3].

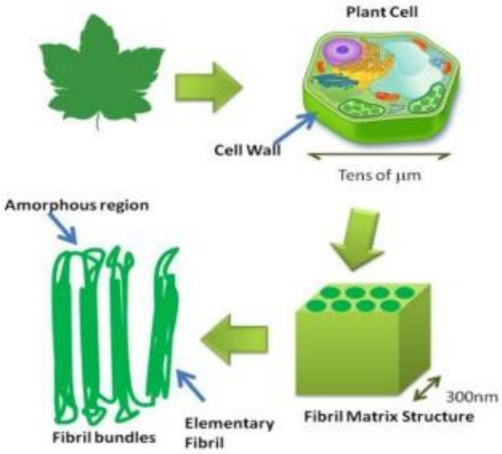

Figure-2: Fibril from cellulose.

For more than a century, scientists have been studying the structure and properties of cellulose using a range of techniques such as X-ray diffraction. In recent years, there has been an increase in interest in creating novel ways for producing and modifying cellulose, as well as investigating its potential applications in disciplines such as nanotechnology and sustainable materials[4].

Cellulose source

Cellulose is found throughout the plant kingdomin its natural state. In wood pulp or cotton fibers (cotton fibers are a virtually pure cellulose biological source). Cotton fibers contain approximately 98% cellulose, whereas wood contains 40-50% cellulose (Table-1)[5].

Other plant materials that can be used to make cellulose include maize cobs or stalks, soybean hulls, bagasse (sugar cane stalks), wheat straw, sugar beetroot pulp, bamboo, oat hulls, rice hulls, and fibers like jute, flax, and ramie[6]. Cellulose is found throughout the plant kingdom in its natural state. In wood pulp or cotton fibers (cotton fibers are a virtually pure cellulose biological source). Cotton fibers contain approximately 98% cellulose, whereas wood contains 40-50% cellulose. Rice husk, an agricultural waste product produced after rice milling, is one potential source of cellulose. The extraction of cellulose from rice husk has gained popularity in recent years because it provides a sustainable and low-cost source of cellulose. The viability of cellulose extraction from rice husk using a combination of chemical and mechanical techniques was examined in a study. According to the study, rice husk contains about 34% cellulose, which may be removed by utilizing an alkaline treatment, bleaching, and mechanical processing. A high degree of purity and a low level of crystallinity was achieved, which is ideal for many industrial applications. The study also found that extracting cellulose from rice husk was more energy-efficient and cost-effective than standard cellulose sources such as wood pulp. This is because rice husk is a plentiful waste product that does not necessitate considerable resources to gather and handle. The researchers showed that high-quality cellulose can be extracted from rice husks using a mix of chemical and mechanical techniques and that this process is more energy-efficient and economical than other sources of cellulose. This study has enormous ramifications for the creation of cellulose supplies that are affordable and sustainable, which might have a big impact on a variety of businesses[7].

Table-1: A summary of natural sources of cellulose[5].

Source	Cellulose content (%)
Rice straw	40-45
Ramie	70-75
Kapok	70-75
Jute	60-65
Hemp	75-80
Flax	70-75
Cotton	90-99
Bamboo	40-55
Baggbasses	35-45

Cellulose extraction methods

The acid hydrolysis technique, which includes the use of strong acids to break down cellulose into its constituent glucose monomers, is a common cellulose extraction method. This process was widely employed in the past, but it relates to several environmental concerns, including the production of vast amounts of waste acids and the release of hazardous byproducts such as sulphur dioxide and nitrogen oxides.

The alkaline extraction procedure, which uses alkaline solutions to break down the lignin and hemicellulose components of plant materials, leaving behind the cellulose fibers, is another cellulose extraction method. This approach is less harmful to the environment than acid hydrolysis, but it requires higher temperatures and longer processing durations.

Deep eutectic solvents, ionic liquids, and other non-toxic solvents are used in cellulose extraction procedures because of growing interest in creating ecologically friendly and sustainable systems. The ability of these solvents to dissolve cellulose with the least amount of negative environmental impact has been demonstrated.

The type of plant material being utilized, the desired purity of the extracted cellulose, and the extraction process's impact on the environment are all factors that influence the choice of cellulose extraction method[8].

Cellulose applications

Due to its plentiful availability and distinctive characteristics, cellulose, a biopolymer that occurs naturally, has drawn considerable interest. Wood, cotton, and other agricultural wastes are just a few examples of plant-based materials from which cellulose can be extracted using several methods. Cellulose has developed a wide range of uses over time, including in the textile, paper, packaging, pharmaceutical, and food industries. We will go through some of the important uses for cellulose and its derivatives in this overview. i. Paper and packaging: For thousands of years, the paper industry has been using cellulose, an essential part of paper. In addition to paper, cellulose-based products such corrugated boxes and packaging materials are commonly used due to their strength, biodegradability, and recycle-ability. ii. Textiles: Cotton and other cellulose-based fibres are widely utilised in the textile sector because they are great at absorbing moisture and are long-lasting and comfortable. Additionally, cellulose fibres can be chemically altered to create new functional fibres with enhanced qualities. For instance, rayon fibres are utilised in garments and home textiles, while cellulose acetate fibres are employed in cigarette filters. iii. Pharmaceuticals: In the pharmaceutical industry, cellulose and its derivatives, including methyl cellulose and hydroxypropyl cellulose, have applications as excipients, binders, and coatings. These substances are an essential part of pharmaceutical formulations because they increase medication solubility, stability, and bioavailability. iv. Food: Cellulose is added to food as a stabilizer, fiber-content booster, and texture-improving addition. In addition, cellulose derivatives including carboxymethylcellulose and microcrystalline cellulose are utilised in a variety of culinary products as thickeners, emulsifiers, and fat substitutes[9].

Cellulase: All living things produce biological molecules called enzymes. In general, these are known to as biocatalysts. Enzymes are increasing more and more in demand as hazardous chemicals are being replaced in the industrial sector by green chemistry technologies. It is essential in this situation that affordable enzyme substrates are readily available to make compound production on a broad scale feasible. Plant cell walls are a crucial component of the carbon cycle because the polysaccharides they contain can be utilized by bacteria as a source of carbon and energy. As an outcome, researchers from all around the world are working to understand the structural features of plant cell wall polysaccharides and have shifted their focus to identifying the enzymes responsible for breaking down these polysaccharides as well as the genes that produce them[10]. The microbial enzymes that degrade plant cell walls can also be used to produce biofuels, textiles, paper, detergents, and food for both humans and animals[11]. Enzymes from animals and plants are less stable than those from bacteria. They may be manufactured utilizing fermentation procedures with great consistency for less money, in less area, and with shorter production times. Additionally, process optimization is easy[12]. The main enzymes created for use in many industrial industries are those that break down plant cell walls, such as pectinase, xylanases, and cellulases. Cellulase hydrolyzes the 1,4-glycosidic linkages to cause cellulose degradation[13].

Cellulases are used in the textile industry[14,15], in detergents[16,17], in the pulp and paper industry[18], in improving the digestibility of animal feeds[19], and in the food industry[20]. Issues about the depletion of fossil fuels, the release of greenhouse gases, and the air pollution brought on by incomplete combustion of fossil fuels have increased interest in the ability to perform enzymatic hydrolysis of the lignocellulosic material using cellulases and hemicelluloses[21,22]. However, the cost of the enzymes required for raw material hydrolysis must be reduced, and their effectiveness in producing bioethanol must be enhanced, to make the process economically viable[23].

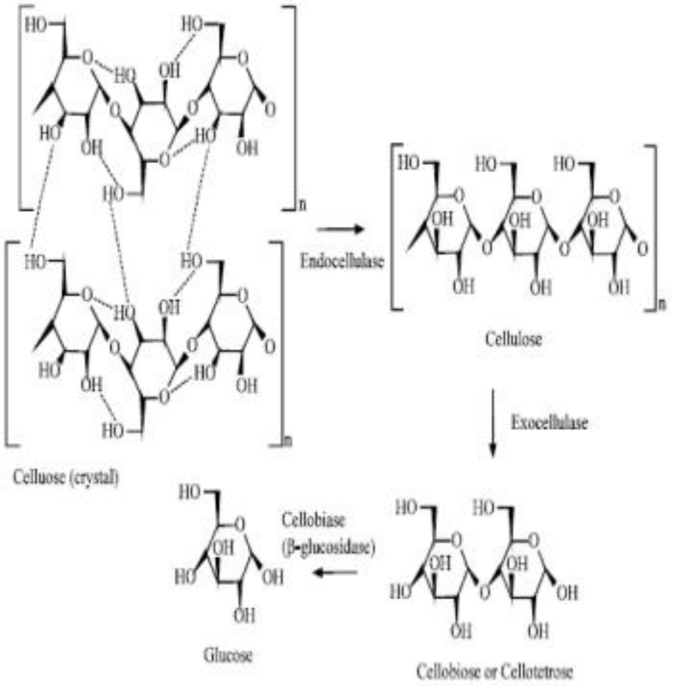

Figure-2: Mode of action of various components of cellulose.

Microbial cellulose

Cellulase-producing microorganisms: Bacteria that break down carbohydrates but cannot use proteins or lipids as growth fuel are known as cellulolytic bacteria. Bacteria that break down carbohydrates but cannot use proteins or lipids as growth fuel are known as cellulolytic bacteria[24]. While most fungi and some cellulolytic microorganisms, such as the bacteria Cellulomonas and Cytophaga, can use several different carbohydrates in addition to cellulose[25-26], anaerobic cellulolytic species can only use cellulose and/or its hydrolytic metabolites[27-28]. Own specie for the efficient procedure of cellulases are *Aspergillus* and *Trichoderma*[29]. Mandel's and Reese conducted several studies to produce cellulolytic enzymes from biowaste degradation processes by many microorganisms including fungi such as *Trichoderma*, *Penicillium*, and *Aspergillus* species, among others[30].

Microorganisms are primarily responsible for the majority of cellulose breakdown that occurs in nature. They address this challenge by utilizing a multi-enzyme system. Numerous extracellular enzymes with binding modules for different cellulose conformations were created by aerobic bacteria. Anaerobic bacteria contain a special extracellular multienzyme complex called the cellulosome. Cellulase preparations may degrade both natural celluloses (found in materials like filter paper) and modified celluloses like carboxymethyl cellulose and hydroxyethyl cellulose. In nature, cellulose coexists with substances like lignin, pectin, and hemicellulose. Other processes carried out by SERVA cellulases contribute to the breakdown of these elements and the deterioration of the cell wall. To achieve the desired surface effect, cellulase is utilized to alter the surface properties of cellulosic fibres[31].

Table-2: Cellulose degrading microorganisms.

Microorganism	Cellulose degradation mechanism	Ref.
Trichoderma reesei	Secretion of cellulase enzymes	32
Clostridium thermocellum	Cellulosome complex formation	33
Aspergillus niger	Secretion of cellulase enzymes	34
Cellulomonas fimi	Secretion of cellulase enzymes	35
Fibrobacter succinogenes	Cellulosome complex formation	36
Ruminococcus albus	Cellulosome complex formation	37
Bacillus subtilis	Secretion of cellulase enzymes	38

Waste from plants, or lignocellulosic, has been broken down using cellulase. Nigeria imports cellulase, an industrial enzyme, for use. Producing it from readily accessible sources, such as plant leftovers, will therefore aid in lowering importation expenses. More focus has been placed on the generation of cellulase by different organisms during submerged state fermentation, but it has been discovered that this is prohibitively expensive due to the high cost of process engineering. Cellulose and hemicellulose can be broken down and used by many bacteria as a source of carbon and energy. The ability of *thermophilic bacteria* to create the enzymes required for substrate destruction during composting determines their capability to assimilate organic materials[39].

Cellulase enzyme application

Textile Industry: Cellulases have risen to the third position among the groups of enzymes utilized in the industry[40]. Some of the main uses of this enzyme in the textile industry, particularly for wet processing, include biostoning of denim cloth biopolishing of textile fibres, softening of clothing, and removal of excess colour from fabrics[41]. In the textile business, Trichoderma reesei fungal cellulases are the most often used enzyme. Similarly, some of the sources of enzymes to be used in the decolorization and degradation of textile dyes includes actinomycetes from the genera Streptomyces and Thermobifida and other genera of bacteria, such as Pseudomonas and Sphingomonas[42]. The best cellulase applies in the present textile industry are generally known to be biostoning and biopolishing. Additionally, cellulases have been utilized in defibrillation[44], softening[45], and procedures that produce regional variations in fiber colour density[46,47].

Laundry and Detergent: The primary reason enzymes are used in the production of detergents is their capacity to remove stains. Applying alkaline enzymes in big quantities is the most recent development in this field. Protease, cellulase, -amylase, lipase, and mannanase, for instance, are frequently used in effective laundry detergents and automatic dishwashing products[48,49]. There has been a lot of research done on cellulases that have been derived from fungi *like Trichoderma sp. (T. longibrachiatum, T. reesei, T. viride, and T. harzianum), Aspergillus niger, Humicola (H. insolens* and *H. griseathermoidea), and Bacillus sp.* for application in detergents50. Cellulase must be thermostable and compatible with alkaline environments as well as other formulation elements for the detergent industry[51,52]. Alkaline cellulase, in particular enhances colour vibrancy and remove dirt from textiles[53].

Animal Feed Industry: To increase the nutritional value of forages, pectinases, hemicellulases, and cellulases are added to enzyme preparations[46]. Cellulases are used in feed processing, and this has been reported to improve feed digestibility and animal performance[54]. Additionally, cellulases break down oligosaccharides, beta-glucan, pectins, lignin, inulin, dextrins, cellulose, and arabinoxylans are examples of anti-nutritional compounds. By eliminating these chemicals, the nutritional value of feed and the health of animals are improved[55].

Pulp and Paper Industry

In the past ten years, there has been a substantial increase in interest in the use of cellulases in the paper and pulp manufacturing industry. Cellulase and hemicellulase mixtures have also been employed to biomodify fibre qualities in paper mills before or after beating pulp, with the goal of enhancing drainage and beatability[46]. Different forms of paper waste can be deinked with cellulases alone or in conjunction with xylanases[57] and improve drainage and run ability of paper mills58. Cellulase Use in the paper and pulp sector is still a developing field. Mechanical or biological techniques can be used for pulping. A mechanical process produces pulp that is stiff, bulky and contains a lot of particles, whereas a biochemical approach that uses cellulose results in 20–40% energy savings[59]. Aspergillus niger and Trichoderma reseed are two common fungi whose cellulases are employed for this. It is also claimed that bacterial cellulase called CelB enhances the qualities of paper60.

Biofuel and Biorefineries

Because of the ability to of cellulase enzyme to hydrolyse cellulose into glucose, a sugar that could potentially be fermented to ethanol, cellulases serve as important biofuel enzymes. Three stages are taken to decompose such biomass: pretreatment; saccharification, which involves enzymes; and fermentation. According to estimates, cellulolytic bacteria can bioprocess biomass to cut the cost of the process by 40%[61]. Recently, laws governing cellulosic ethanol was formed by a number of nations, and among its goals is the transition away from starchy or cane sugars as biomass resources towards cellulose-based materials[62]. This thermophilic bacteria, *Caldicelluloseruptor bescii*, can directly convert plant biomass into bioethanol, demonstrating its potential for ethanol production. Bioethanol synthesis from biomass is an important commercial use for this bacteria[63].

Food Industry

Cellulase can be utilized in the food sector in order to improve the nutritional quality of products[64]. Many of the aforementioned goals can be accomplished in the commercial sector with the help of enzymes. However, widespread acceptance of the use of cellulases in the food industry is still a long way off[65]. Potential uses for cellulase in the food business include fungi (*Trichoderma* and *Aspergillus*)[66].

Conclusion

According to the literature, the advantages of enzyme-based businesses over chemical-based ones include process safety, cheap refining costs, high yields, effective process management, and environmental friendliness. In the paper, pharmaceutical, detergent, and food sectors, enzymes, in particular cellulases may find use. Thermostatic capacitors are frequently employed because of their durability at high temperatures. The industries that produce food, animal feed, and beverages are now those that use cellulases most successfully.

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