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M Gogulavasan

UG Scholar, School of Agriculture and Animal Sciences, the Gandhigram Rural Institute (DTBU), Gandhigram, Dindigul, Tamil Nadu, India

G Santhosh Raja

UG Scholar, School of Agriculture and Animal Sciences, the Gandhigram Rural Institute (DTBU), Gandhigram, Dindigul, Tamil Nadu, India

S Dharun Kumar

UG Scholar, School of Agriculture and Animal Sciences, the Gandhigram Rural Institute (DTBU), Gandhigram, Dindigul, Tamil Nadu, India

M Harish

UG Scholar, School of Agriculture and Animal Sciences, The Gandhigram Rural Institute (DTBU), Gandhigram, Dindigul, Tamil Nadu, India

V Monishdarakeshwar

UG Scholar, School of Agriculture and Animal Sciences, the Gandhigram Rural Institute (DTBU), Gandhigram, Dindigul, Tamil Nadu, India

B Mahesh

UG Scholar, School of Agriculture and Animal Sciences, the Gandhigram Rural Institute (DTBU), Gandhigram, Dindigul, Tamil Nadu, India

P Papitha

Guest Faculty, School of Agriculture and Animal Sciences, the Gandhigram Rural Institute (DTBU), Gandhigram, Dindigul, Tamil Nadu, India

Corresponding Author:

P Papitha

Guest Faculty, School of Agriculture and Animal Sciences, the Gandhigram Rural Institute (DTBU), Gandhigram, Dindigul, Tamil Nadu, India

Sugarcane bagasse as a renewable feedstock for fiber and bioplastic production: A comprehensive review

M Gogulavasan, G Santhosh Raja, S Dharun Kumar, M Harish, V Monishdarakeshwar, B Mahesh and P Papitha

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Abstract

The environmental persistence of petroleum-based plastics has intensified the search for renewable and biodegradable alternatives derived from sustainable resources. Agro-industrial residues have emerged as promising feedstocks within the circular bioeconomy, among which sugarcane bagasse stands out due to its global abundance and high lignocellulosic content. This review summarizes the structure, composition, pretreatment strategies, and value-added applications of sugarcane bagasse, with particular emphasis on its conversion into fibers and bioplastics. Sugarcane bagasse primarily consists of cellulose, hemicellulose, and lignin, whose complex matrix requires mechanical, chemical, physico-chemical, or green solvent pretreatment to enhance fractionation and cellulose accessibility. Extracted cellulose can be processed into macrofibres, regenerated fibers, and nanocellulose, exhibiting high strength and reinforcement potential for composite materials. In parallel, bagasse components can be transformed into biodegradable plastics including cellulose-, hemicellulose-, lignin-, and microbial-based polymers, often blended with starch or chitosan and improved using plasticizers and functional additives. The resulting materials demonstrate favorable mechanical properties, biodegradability, and reduced environmental impact compared to conventional plastics, enabling applications in packaging, agriculture, disposable products, and emerging biomedical fields. Despite challenges related to biomass recalcitrance, moisture content, and large-scale processing, integrated biorefinery approaches and green processing technologies offer viable solutions. Overall, sugarcane bagasse valorization represents an effective pathway for waste management, fossil resource reduction, and sustainable material production, supporting the transition toward a circular and low-carbon bioeconomy.

Keywords: Sugarcane bagasse, agro-industrial waste valorization, lignocellulosic biomass, cellulose extraction, natural fibers, nanocellulose, biodegradable plastics, biopolymer composites, pretreatment methods, circular bioeconomy, sustainable materials, green packaging

Introduction

The pervasive environmental challenges posed by conventional plastic waste necessitate a global shift towards sustainable biomaterials, with agro-industrial waste emerging as a promising renewable resource (Ferreira *et al.*, 2023; Jamwal *et al.*, 2024; Mujtaba *et al.*, 2023) [25, 35, 52]. The sugarcane industry, a significant agricultural sector, generates substantial quantities of bagasse, a lignocellulosic by-product that has considerable potential for valorization into various value-added products (Kamboj, 2024; Teferi, 2025; Ndikumana, 2025) [38, 57, 79]. This review will comprehensively discuss the role of agro-industrial waste, particularly sugarcane bagasse, as a renewable resource in the face of environmental issues associated with plastic waste, the urgent need for sustainable biomaterials and the overarching objectives of research in this area.

The environmental impact of petroleum-based plastics is a critical global concern due to their non-biodegradability and detrimental ecological effects (Palanisamy, 2024; Weligama Thuppahige & Karim, 2021) [86]. These conventional plastics contribute significantly to pollution in terrestrial and marine ecosystems, leading to the accumulation of plastic waste and microplastic contamination in food chains (Narayanan *et al.*, 2023) [55]. The chemical properties that make plastics durable also contribute to their persistence as environmental pollutants, creating novel ecosystems known as the "plastisphere" on debris (Narayanan *et al.*, 2023) [55]. This ongoing accumulation has pushed humanity beyond the Planetary Boundary for "Novel

Entities," directly threatening the integrity of the biosphere. The continuous increase in plastic production and utilization underscores the urgency of finding sustainable alternatives (Narayanan *et al.*, 2023) ^[55]. In response to these environmental hazards, there is an escalating demand for eco-friendly substitutes for plastics, driving the development of sustainable biomaterials (Khamis *et al.*, 2026; Đorđević *et al.*, 2024) ^[23, 42]. This involves leveraging green chemistry principles to design materials with inherent degradation mechanisms and utilizing efficient, low-energy synthesis routes (Mujtaba *et al.*, 2023) ^[52]. Biomimicry, which emulates natural strategies, also offers powerful design solutions for sustainable materials. The ideal sustainable material would be derived from renewable feedstocks and possess properties that allow for its safe reintegration into natural cycles at its end-of-life (Mujtaba *et al.*, 2023) ^[52].

Agro-industrial waste represents an abundant, inexpensive, and renewable source for the production of sustainable biomaterials (Azelee *et al.*, 2020; Maqsood *et al.*, 2025) ^[8, 46]. Annually, tons of this waste are generated worldwide, often burned or discarded without proper utilization, despite being rich in sugars and other compounds of commercial interest (Riera & Maldonado, 2021) ^[69]. The valorization of agro-industrial waste aligns with the principles of a circular bioeconomy, which aims to minimize waste by recycling and reusing components (Đorđević *et al.*, 2024; Mishra *et al.*, 2023) ^[23, 48]. Examples of such waste include fruit processing residues, grain cleaning by-products, vegetables, and animal production discards (Ferreira *et al.*, 2023) ^[25]. Converting these biowastes into biomaterials through various strategies, including microbial fermentation, is a key area of research (Belkoshayev *et al.*, 2025; Mishra *et al.*, 2023; Chatterjee & Mazumder, 2024) ^[13, 19, 48].

Among the various agro-industrial wastes, sugarcane bagasse stands out as a highly promising lignocellulosic biomass (Teferi, 2025) ^[79]. It is a fibrous by-product of sugar extraction, produced in millions of tons annually, traditionally used for energy generation in sugar mills (Ndikumana, 2025; Zafeer *et al.*, 2023) ^[57, 89]. However, its rich composition primarily cellulose (~40-50%), hemicellulose (~20-25%), and lignin (~15-25%) makes it an excellent feedstock for a diverse range of value-added products (Teferi, 2025; Ndikumana, 2025) ^[57]. The global shift towards renewable resources and reduced fossil fuel reliance highlights the untapped potential of sugarcane bagasse for sustainable valorization (Ndikumana, 2025) ^[57].

Research and development efforts are focused on various applications for sugarcane bagasse, including the production of biofuels, bioplastics, construction materials, and agricultural inputs (Ndikumana, 2025) ^[57]. For instance, sugarcane bagasse can be converted into microcrystalline cellulose (MCC), which has significant applications in the pharmaceutical industry due to its versatile physical properties (Katakojwala & Mohan, 2020) ^[39]. It can also serve as a raw material for cellulose and nanocellulose-based materials, prized for their renewable nature, strength, rigidity, and environmental friendliness (Mubarak *et al.*, 2024) ^[51]. Furthermore, biocomposite materials using sugarcane bagasse and modified starch are being explored for potential packaging in the agro-industry, offering an eco-friendly alternative to petroleum-based plastics (Palanisamy, 2024; Fitch-Vargas *et al.*, 2023; Nababan *et al.*, 2025) ^[27, 54]. The production of activated carbons from sugarcane bagasse for the adsorption of phenolic pollutants also demonstrates

its utility as an environmental material (Khalil *et al.*, 2021) ^[40]. Extensive research is currently being done to develop efficient and cost-effective technologies for transforming biowaste into valuable products, thereby promoting sustainable management of agro-industrial residues (Teferi, 2025) ^[79]. This involves exploring innovative biorefinery and valorization strategies for sugarcane bagasse, integrating applications across food, health, economic, and industrial sectors (Teferi, 2025) ^[79]. The goal is to advance circular economy principles by identifying and overcoming challenges such as feedstock heterogeneity, pretreatment energy demands, and separation efficiency (Ndikumana, 2025) ^[57].

Moreover, researchers are investigating the use of enzymatic cocktails, often derived from microorganisms like *Aspergillus niger*, to hydrolyze lignocellulosic biomass and produce high-value chemicals (Antoniêto *et al.*, 2022; Abdelaliem *et al.*, 2023; Díaz *et al.*, 2022) ^[2, 5, 22]. The conversion of agro-industrial wastes like sugarcane bagasse into bioplastics and other biomaterials involves various processes, including thermochemical conversion (e.g., pyrolysis for bio-oil production) (Muñoz *et al.*, 2024; Jideani *et al.*, 2024) ^[36, 53], enzymatic hydrolysis (Antoniêto *et al.*, 2022; Díaz *et al.*, 2022) ^[5, 22], and microbial conversion (Belkoshayev *et al.*, 2025; Kee *et al.*, 2022) ^[13, 40]. For instance, microbial valorization can lead to the production of bacterial cellulose, a high-value product known for its purity, strength, biocompatibility, and biodegradability (Belkoshayev *et al.*, 2025) ^[13].

Studies also show that sugarcane bagasse cellulose fibres can reinforce starch-based bioplastics, improving their properties for packaging applications (Fitch-Vargas *et al.*, 2023; Nababan *et al.*, 2025) ^[27, 54]. The integration of these processes into biorefinery concepts is crucial for achieving a zero-waste circular economy (Đorđević *et al.*, 2024; Zhao *et al.*, 2022) ^[23, 91]. The overall scope of research in this area encompasses understanding and optimizing the utilization of agro-industrial waste to create a more sustainable future. This includes detailed characterization of the biomass, evaluation of different pretreatment methods, optimization of conversion processes, and assessment of final product properties and environmental impacts through methods like Life Cycle Assessment (LCA). By transforming these abundant and often underutilized resources into sustainable alternatives, the researchers aim to mitigate plastic pollution, reduce reliance on fossil fuels, and support the transition towards a robust circular bioeconomy (Khamis *et al.*, 2026; Mujtaba *et al.*, 2023; Carrillo-Rodríguez *et al.*, 2025) ^[15, 42, 52].



Fig 1: Sugarcane Bagasse

Sugarcane bagasse: Structure and composition

Sugarcane bagasse (SCB) as shown in Fig.1. is a significant lignocellulosic biomass residue obtained after the extraction of juice from sugarcane stalks, primarily utilized for sugar and ethanol production (Hiranobe *et al.*, 2024; Pan *et al.*, 2022; Ungureanu *et al.*, 2022) ^[31, 60, 82]. Its complex structure and chemical composition are central to its potential applications in biorefineries and various industries (Hiranobe *et al.*, 2024; Kusuma, 2015; Rocha, 2015) ^[31]

Chemical Composition

SCB is predominantly composed of cellulose, hemicellulose, and lignin, which are tightly linked structures responsible for the integrity of the plant cell wall (Rocha *et al.*, 2015) ^[70]. The relative proportions of these components can vary, but generally, SCB contains a substantial percentage of each as shown in Table.1. For example, one study characterized sugarcane bagasse as containing 39.52% cellulose, 25.63% hemicellulose, and 30.36% lignin (Tiwari *et al.*, 2022) ^[80]. Another study indicated that SCB typically comprises 30-45% cellulose, 20-25% hemicellulose, and 18-25% lignin (Ouedraogo *et al.*, 2023) ^[59]. These biopolymers form a complex, rigid structure known as lignocellulose as shown in fig.2. (Pan *et al.*, 2022; Singh *et al.*, 2024) ^[60, 74].

Cellulose: This is a linear polymer of D-glucose units linked by $\beta(1\rightarrow4)$ glycosidic bonds, which gives it a straight, extended, ribbon-like chain structure. Cellulose microfibrils are the primary load-bearing elements of the plant cell wall, possessing high tensile strength and forming semi-crystalline rods a few nanometers in diameter. The high cellulose content in SCB makes it attractive for composite materials (Kusuma, 2015) and serves as a crucial renewable energy source for producing biofuels when

hydrolyzed into fermentable sugars (Berhe & Sahu, 2017; Kong *et al.*, 2016) ^[14, 43].

Hemicellulose

Unlike cellulose, hemicelluloses are a diverse group of branched polysaccharides. They coat and tether cellulose microfibrils, forming a load-bearing network within the cell wall. Hemicellulose is an amorphous polymer that is typically shorter and extensively decorated with side chains, preventing it from crystallizing like cellulose.

Lignin

Lignin is an amorphous, aromatic polymer derived from phenylpropanoid precursors that infiltrates the secondary cell wall matrix, imparting rigidity, compression strength, and hydrophobicity. It acts as a protective shield for cellulose, contributing to the recalcitrance of biomass and making enzymatic hydrolysis challenging (Pan *et al.*, 2022) ^[60]. Lignin is crucial for the mechanical strength and durability of plant tissues. Lignin can be valorized for the production of phenolic resins and substituted hydroxycinnamic acids (Goyal & Kaur, 2022; Pinheiro *et al.*, 2017) ^[29, 64].

Ash and Extractives

SCB also contains minor amounts of ash and extractives. Ash content in raw bagasse can be as high as 8.71% (Pérez *et al.*, 2025) ^[63]. Another study on bagasse ash reported an average chemical composition of 65% silicon dioxide (SiO₂) (Abdalla *et al.*, 2024) ^[1]. Extractives are non-structural components that can be removed by solvents and include waxes, fats, and resins (Barbosa *et al.*, 2020) ^[10]. These components can influence the processing and utilization of bagasse (Ouedraogo *et al.*, 2023) ^[59].

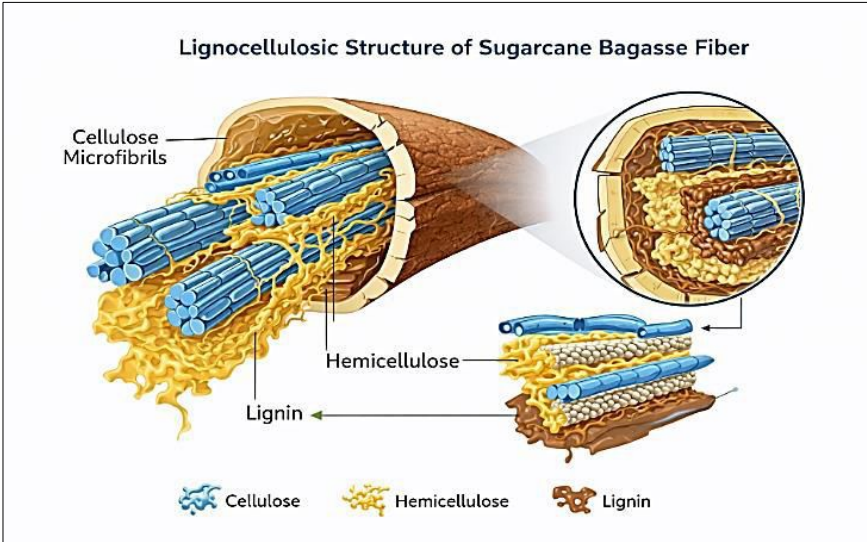


Fig 2: Lignocellulosic structure of sugarcane bagasse fiber

Table 1: Structure and composition of sugarcane bagasse

Component	Typical Content (%)	Structure Type	Function in Biomass	Reference
Cellulose	30-45% (up to 39.52%)	Linear $\beta(1\rightarrow4)$ D-glucose polymer	Load-bearing structural framework	Tiwari <i>et al.</i> , 2022; Ouedraogo <i>et al.</i> , 2023 ^[59, 80]
Hemicellulose	20-25% (up to 25.63%)	Branched amorphous polysaccharide	Connects cellulose microfibrils	Tiwari <i>et al.</i> , 2022; Ouedraogo <i>et al.</i> , 2023 ^[59, 80]
Lignin	18-30% (up to 30.36%)	Aromatic phenylpropanoid polymer	Rigidity, hydrophobic	Tiwari <i>et al.</i> , 2022; Pan <i>et al.</i>

			barrier	<i>al</i> , 2022 [60, 80]
Ash	Up to 8.71%	Inorganic minerals (mainly SiO ₂ ~65%)	Influences combustion behavior	Pérez <i>et al</i> , 2025 [63]
Extractives	Minor fraction	Waxes, fats, resins	Non-structural components	Barbosa <i>et al</i> , 2020 [10]

Physical and Morphological Properties

Sugarcane bagasse exhibits specific physical and morphological characteristics. Its mechanical properties are shown in Table.2 (Balaji *et al.*, 2014) [9]. It is described as a fibrous material with a rough surface. The particle size distribution (PSD) for sugarcane bagasse typically shows a mean geometric diameter of 0.722 mm (Pérez *et al.*, 2025) [63]. Its fibrous nature makes it a valuable reinforcement in composite materials (Devadigam *et al.*, 2020; Tadesse, 2025) [21, 78]. The bulk density of SCB is relatively low, typically around 120-180 kg/m³, which can impact storage and transportation costs (Singh *et al.*, 2024) [74]. The vascular bundles surrounded by parenchyma cells in SCB contribute to its mechanical strength and resistance to degradation. Its physical characteristics are relevant for applications such as bioenergy (Athira *et al.*, 2020; Pérez *et al.*, 2025) [7, 63] and as a construction material where it can

be incorporated into adobes to improve physicomechanical properties (Chantit *et al.*, 2024; Ouedraogo *et al.*, 2023) [18, 59].

Table 2: Mechanical properties of sugarcane bagasse

Properties	value
Tensile strength (MPa)	290
Young's modulus (GPa)	17
Density [g/cm3]	1.25

Availability and Global Production

Sugarcane is a major crop globally, and its processing generates substantial quantities of lignocellulosic biomass, including bagasse (Hiranobe *et al.*, 2024; Ungureanu *et al.*, 2022) [31, 82]. Brazil is the world's largest producer of sugarcane, generating 185 million tons of solid residues per harvest (Rocha *et al.*, 2015) [70].

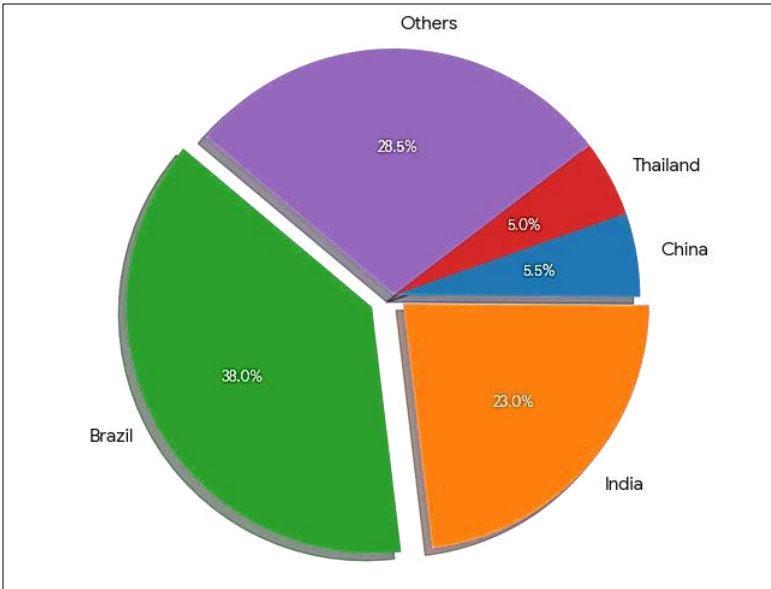


Fig 3: Share of global sugarcane production by country (2024-2025).

(Adapted from Sugar: World Markets and Trade, by the U.S. Department of Agriculture, 2024) [83]. Globally, sugarcane processing produces over 279 million tons of solid and liquid waste annually (Ungureanu *et al.*, 2022) [82]. Other significant producers of bagasse include India and China (Abdalla *et al.*, 2024; Toscano Miranda *et al.*, 2021) [1, 81]. This abundance makes SCB a highly available and renewable agricultural waste material (Iwuzor *et al.*, 2023; Tadesse, 2025) [34, 78].

Challenges in Direct Utilization

Despite its abundance and versatile composition, direct utilization of SCB faces several challenges:

- **Recalcitrance:** The complex lignocellulosic structure, where cellulose microfibrils are embedded in a matrix of amorphous hemicellulose and lignin, makes the biomass resistant to deconstruction (Pan *et al.*, 2022) [60]. This "biomass recalcitrance" limits the accessibility of enzymes to cellulose, posing a significant hurdle for

biofuel production (Pan *et al.*, 2022) [60]. Pretreatment technologies are essential to break down this intricate structure and enhance enzymatic saccharification (Algayyim *et al.*, 2022; Hongdan *et al.*, 2013; Tiwari *et al.*, 2022) [4, 32, 80].

- **High Moisture Content:** Raw sugarcane bagasse typically has a high moisture content (around 40-50% on a wet basis), which reduces its usable energy content and can impose an energy penalty during thermochemical conversion processes like pyrolysis (Athira *et al.*, 2020; Pérez *et al.*, 2025) [7, 63].
- **Low Bulk Density:** The low bulk density of SCB increases the cost of storage and transportation. Pelletization is one technique to address this limitation (Singh *et al.*, 2024) [74].
- **Seasonal Variability:** Sugarcane is a seasonal crop, leading to fluctuations in bagasse availability and creating logistical challenges for continuous industrial processes.

- **Ash Content and Fouling:** The presence of ash, particularly silica, can cause fouling and operational issues in thermal processes, such as boilers (Abdalla *et al.*, 2024; Fioranelli & Bizzo, 2023) ^[1, 26].
- **Economic Challenges:** Sustainability is questioned due to technoeconomic challenges associated with pretreatment, detoxification, and microbial tolerance to inhibitors (Pan *et al.*, 2022) ^[60].

Despite these challenges, ongoing research focuses on developing sustainable methods for valorizing SCB into biofuels, biochemicals, and advanced materials (Hiranobe *et al.*, 2024; Kusuma, 2015; Singh *et al.*, 2023) ^[31, 75]. SCB represents a significant sustainable feedstock for advanced materials like bioplastics and nanocellulose (Hossam & Fahim, 2023; Singh *et al.*, 2022) ^[33, 76]. Effective utilization necessitates comprehensive pretreatment and fractionation to overcome its recalcitrant structure (Nasution *et al.*, 2022; Zhang *et al.*, 2021) ^[56, 90].

Pretreatment and Fractionation of Sugarcane Bagasse

The primary goal of pretreatment is to disrupt the intricate lignocellulosic structure to enhance accessibility for subsequent processing (Arora *et al.*, 2023) ^[6].

Mechanical Pretreatment

Involves physical methods like milling and grinding to reduce particle size, though it is energy-intensive and usually requires secondary treatments (Motaung & Mokhothu, 2016) ^[50].

Chemical Pretreatment

Alkali Treatment (NaOH)

Effective in delignification and hemicellulose removal, improving cellulose purity (Hamin *et al.*, 2022; Tiwari *et al.*, 2016) ^[30, 80]. For instance, sodium carbonate solutions at

140 °C have improved biogas and ethanol production (Nosratpour *et al.*, 2018) ^[58].

Acid Hydrolysis

Dilute acid hydrolysis (e.g., sulfuric acid) primarily targets hemicellulose removal (Barrameda *et al.*, 2023; Tiwari *et al.*, 2016) ^[12, 80], though it may form inhibitory compounds.

Organosolv

Uses organic solvents to extract lignin and hemicellulose while preserving cellulose. Two-stage hydrothermal/ethanosolv processes have proven effective for fractionation (Pongchaiphol *et al.*, 2021) ^[65].

Deep Eutectic Solvents (DES)

These are green alternatives with low toxicity and high recyclability (Chyerochana *et al.*, 2025; Mardawati *et al.*, 2025; Raj & Singh, 2024; Wang *et al.*, 2023; Xian *et al.*, 2024) ^[20, 47, 66, 85, 87].

Physico-Chemical Methods

Steam Explosion: High temperature and pressure followed by rapid reduction effectively deconstructs biomass for bioethanol or PHA production (Barciela *et al.*, 2023; Barrameda *et al.*, 2023; Espirito Santo *et al.*, 2020; Pereira Marques *et al.*, 2021) ^[11, 12, 24, 62].

Hydrothermal Treatment: Hot-compressed water extracts hemicelluloses (like xylose) without additional chemicals (Sukhbaatar *et al.*, 2014) ^[77], fitting well into two-stage processes (Pongchaiphol *et al.*, 2021) ^[65].

Biological Pretreatment: The eco-friendly, biological methods, such as those using white-rot fungi, are generally slower and more challenging to scale for industrial applications (Singh *et al.*, 2023) ^[75].

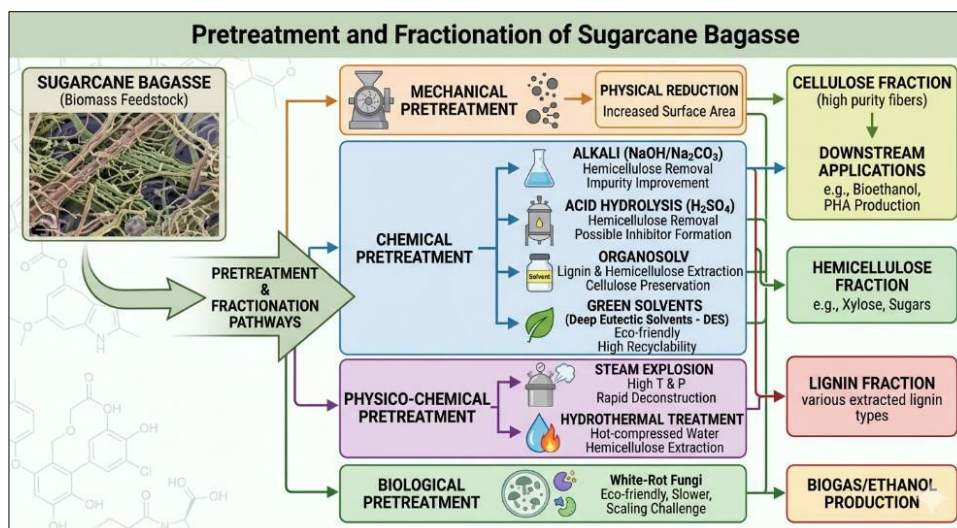


Fig 4: Schematic representation of pretreatment and fractionation pathways for sugarcane bagasse.

Effect of Pretreatment on Cellulose Recovery

The effectiveness of pretreatment is often evaluated by the recovery yield and purity of cellulose, as well as the removal efficiency of lignin and hemicellulose (Arora *et al.*, 2023) ^[6]. For instance, alkaline pretreatment under mild conditions significantly increased the enzymatic saccharification of sugarcane bagasse, which contained

39.52% cellulose, 25.63% hemicellulose, and 30.36% lignin (Tiwari *et al.*, 2016) ^[80].

Production of Fibre from Sugarcane Bagasse

Sugarcane bagasse is a rich source of cellulose, making it suitable for producing various types of fibres for industrial applications (Chandel *et al.*, 2023; Chandra Mohan *et al.*,

2018; Saelee *et al.*, 2014) [16, 17, 71]. The various methods of fibre extraction is shown in fig.5.

Cellulose Extraction Methods: These generally involve chemical and mechanical treatments to isolate cellulose from other components. An environmental-friendly method combining steam explosion and xylanase has been investigated for cellulose extraction (Saelee *et al.*, 2014) [71]. Mild chemical pretreatment followed by acid hydrolysis has been used to derive nanocrystalline cellulose from sugarcane trash (Joshi & Manjare, 2024) [37].

Alkali Mechanical Fiber Extraction

This typically involves alkaline treatment (e.g., mercerization) followed by mechanical refining to produce microfibrils suitable for reinforcement (Hamin *et al.*, 2022) [30].

Regenerated Cellulose Fibers

Methods using solvents like NaOH/urea or ionic liquids can dissolve cellulose and regenerate it into fibers with specific properties, enabling textile-grade filaments.

Nanocellulose (CNF, CNC) Production

Nanocellulose, including cellulose nanofibrils (CNF) and cellulose nanocrystals (CNC), are high-strength nanomaterials. CNF can be extracted from sugarcane leaf pulp using DES as a reinforcing agent in bioplastics (Mardawati *et al.*, 2025) [47]. An easy method for nanocellulose extraction involves a modified acid hydrolysis route from sugarcane bagasse, bypassing multiple steam explosion steps (Reshmy *et al.*, 2020) [67]. Acidic DESs have also been widely applied for nanocellulose production, offering green and cost-effective advantages (Wang *et al.*, 2023) [85].

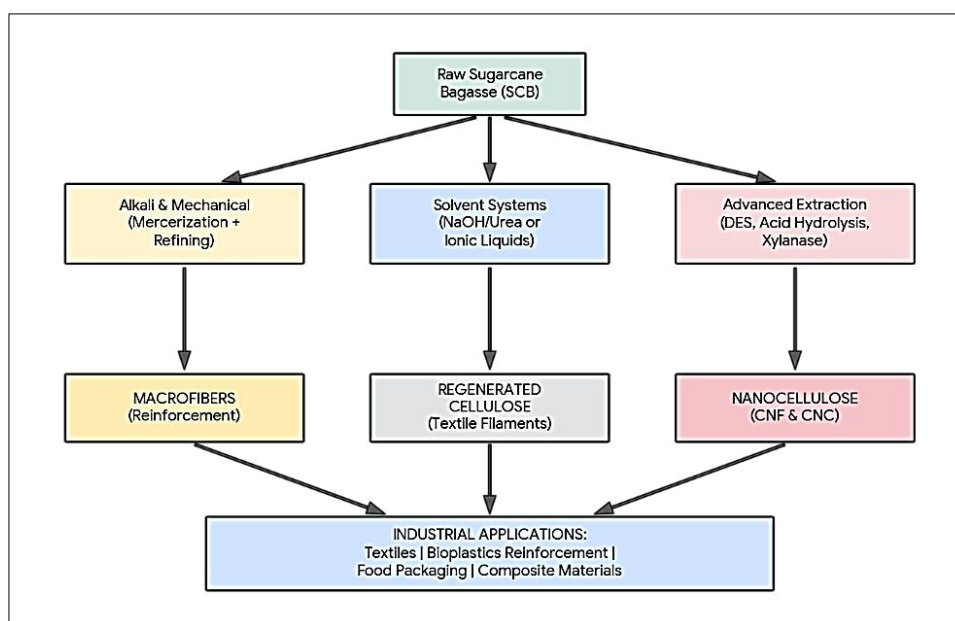


Fig 5: Fibre extraction methods from sugarcane bagasse

Characterization of Bagasse Fibers

FTIR

Fourier-transform infrared spectroscopy (FTIR) is used to confirm structural changes, such as the loss of lignin bands (around 1510 cm^{-1}) and hemicellulose bands (around 1730 cm^{-1}) after pretreatment (Silva *et al.*, 2017) [73].

SEM

Scanning electron microscopy (SEM) reveals morphological features, such as the fibrillar network of cellulose fibers after treatment (Motaung & Mokhothu, 2016) [50].

XRD

X-ray diffraction (XRD) helps determine the crystallinity index, which typically increases after effective delignification and hemicellulose removal (Motaung & Mokhothu, 2016) [50].

Tensile Strength and Thermal Analysis

These analyses quantify the mechanical strength and thermal stability, crucial properties for material applications (Fitch-Vargas *et al.*, 2023; Hamin *et al.*, 2022) [27, 30].

Applications of Bagasse Fibers: Bagasse fibres find diverse applications, including textile fibers, reinforcement in composites, paper and packaging, and biomedical materials (Chandel *et al.*, 2023; Singh *et al.*, 2022) [16, 76]. For example, cellulose nanofibrils from sugarcane bagasse can serve as eco-friendly ductile reinforcement in starch films for packaging (Ribeiro *et al.*, 2025) [68].

Bioplastic Production from Sugarcane Bagasse

Bioplastics derived from sugarcane bagasse components offer a sustainable alternative to conventional petroleum-based plastics (Chyerochana *et al.*, 2025; Hossam & Fahim, 2023; Yong *et al.*, 2024) [20, 33, 88].

Cellulose-Based Bioplastics: Cellulose films, often plasticized with glycerol or sorbitol, exhibit moderate barrier properties but can have poor moisture resistance (Ribeiro *et al.*, 2025) [68]. Microcrystalline cellulose derived from sugarcane bagasse has been used in nanocomposite films for food packaging (Pandian *et al.*, 2023) [61].

Hemicellulose-Based Films

Hemicellulose films are generally more hydrophilic but can improve the flexibility of bioplastic formulations.

Lignin-Based Biopolymers

Lignin, extracted during bagasse fractionation, can impart UV resistance, antioxidant activity, and enhanced thermal stability to bioplastics (Luo *et al.*, 2023; Zhang *et al.*, 2021) [45, 90]. Lignin/chitosan composite films have been fabricated with improved strength and toughness for food preservation (Luo *et al.*, 2023) [45].

Starch/Chitosan Blended Bioplastics with Bagasse

Starch-based biocomposites reinforced with plant fibres, including sugarcane bagasse cellulose fibres, provide an excellent alternative to synthetic packaging materials (Hamin *et al.*, 2022; Schutz *et al.*, 2025) [30, 72]. Polyhydroxyalkanoates (PHA), a type of biodegradable bioplastic, can be produced from sugarcane bagasse using microbial fermentation (Yong *et al.*, 2024) [88].

Plasticizers and Additives

Beyond the pretreatment and fractionation discussed, the functionalization of bagasse-derived biopolymers requires specific additives to meet industrial standards. Plasticizers like glycerol and sorbitol are commonly incorporated to improve the flexibility and overall processability of the resulting bioplastics (Ribeiro *et al.*, 2025) [68]. To further enhance mechanical performance, citric acid may be employed as a crosslinking agent, while the integration of essential oils provides necessary antimicrobial properties, particularly for food packaging applications (Pandian *et al.*, 2023) [61].

Film Formation Techniques

The fabrication of bioplastics from sugarcane bagasse involves several key processing techniques to achieve the desired material form. Solution casting is frequently utilized for the production of uniform thin films with high clarity. For continuous production and compounding with reinforcing fibres, extrusion serves as a vital thermal processing method (Fitch-Vargas *et al.*, 2023) [27]. Additionally, compression moulding is employed to form thicker, structurally robust composites and finished bioplastic products (Fitch-Vargas *et al.*, 2023) [27].

Properties of Bagasse Bioplastics

The final properties of bagasse-derived bioplastics are primarily dictated by their structural composition and the integration of reinforcing agents. The incorporation of bagasse fibers, particularly in the form of nanocellulose, has been shown to significantly enhance the tensile strength and overall mechanical performance of these materials (Mardawati *et al.*, 2025; Ribeiro *et al.*, 2025) [68]. Furthermore, the barrier properties which determine resistance to oxygen and water vapor permeation are highly sensitive to the specific bioplastic formulation, particularly the concentration of plasticizers and the degree of nanofiller dispersion. From an environmental perspective, these materials are inherently biodegradable, with their chemical structure (specifically the presence of ester bonds) facilitating breakdown in alignment with circular economy principles (Hossam & Fahim, 2023; Yong *et al.*, 2024) [33, 88]. Additionally, functional properties such as antimicrobial activity can be strategically enhanced through the incorporation of additives like essential oils or chitosan, making them highly suitable for advanced packaging applications (Pandian *et al.*, 2023) [61].

Applications of Bagasse-Based Bioplastics

Food Packaging

A significant application due to their biodegradability and potential to replace fossil-based plastics (Hamin *et al.*, 2022; Mardawati *et al.*, 2025; Pandian *et al.*, 2023; Ribeiro *et al.*, 2025; Singh *et al.*, 2022) [30, 47, 61, 68, 76]. Modified atmosphere packaging (MAP) systems, while traditionally using synthetic materials, could potentially benefit from advanced bioplastics.

Agricultural Mulch Films

Biodegradable bioplastics can reduce plastic pollution in agriculture by serving as environmentally friendly mulch films.

Disposable Products

Bagasse pulp is a promising material for producing biodegradable plates and single-use tableware, offering an attractive alternative to traditional plastic products (Hossam & Fahim, 2023) [33].

Biomedical Uses

While not extensively detailed for bagasse-derived bioplastics in these sources, cellulose-based materials generally have potential in healthcare, including wound dressings and scaffolds (Chandel *et al.*, 2023) [16].

Comparative Advantages over Petroleum Plastics

Environmental Benefits

Bagasse-based bioplastics reduce reliance on fossil resources and contribute to alleviating plastic pollution (Chyerochana *et al.*, 2025; Hossam & Fahim, 2023; Mardawati *et al.*, 2025; Singh *et al.*, 2022) [20, 33, 47, 76].

Economic Feasibility

The valorization of sugarcane bagasse, an agricultural waste product, can improve economic viability through the production of high-value bioproducts (Singh *et al.*, 2022; Teferi *et al.*, 2025) [76, 79].

Life Cycle Assessment (LCA) and Carbon Footprint Reduction

LCA studies indicate that bioplastics can significantly reduce carbon footprints, potentially by 40-70% compared to petroleum plastics, by avoiding fossil inputs and supporting a circular bioeconomy (Hossam & Fahim, 2023) [33]. The detailed processing of lignocellulosic biomass involves overcoming its inherent recalcitrance, where cellulose is locked in a tough matrix with lignin and hemicellulose. Pretreatment aims to break open this structure, followed by enzymatic hydrolysis to liberate fermentable sugars or isolate cellulose fibers. The structural difference between starch (alpha-linkages, helical) and cellulose (beta-linkages, straight) explains their distinct biological roles; cellulose's beta-linkages form straight, rigid chains with extensive hydrogen bonding, giving it immense tensile strength suitable for structural materials. This structural integrity is critical for its use as a reinforcing agent in bioplastics. The biorefinery concept emphasizes transforming renewable plant matter into fuels, chemicals, and materials, with lignocellulosic biomass being a challenging but valuable resource (fig.6.).

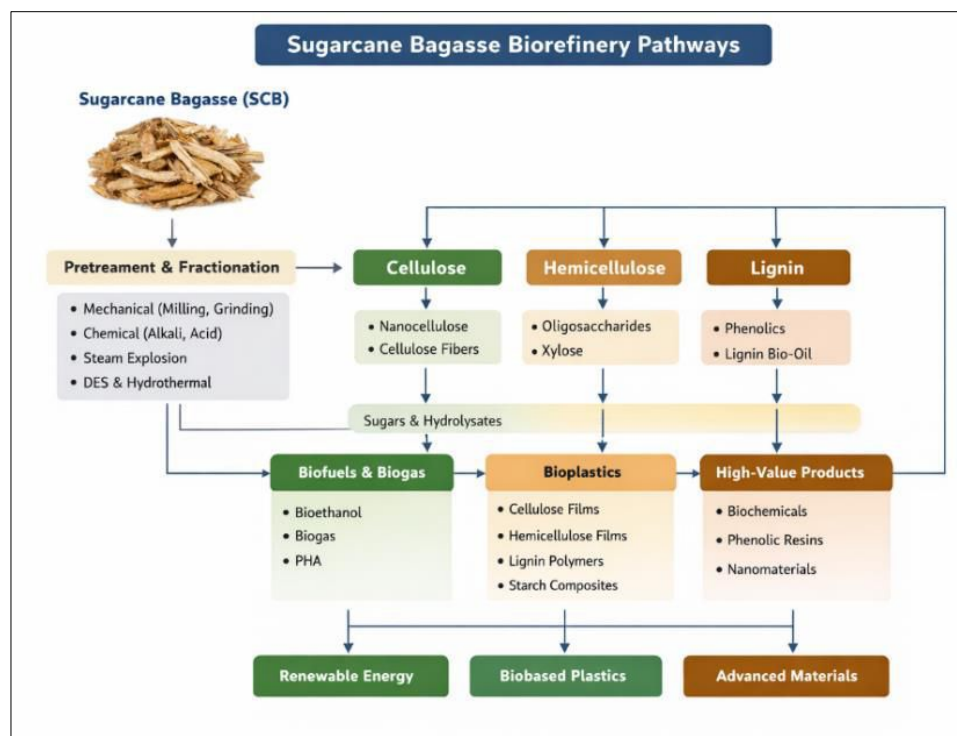


Fig 6: Sugarcane bagasse biorefinery pathways

Conclusion

Sugarcane bagasse is an abundant lignocellulosic agro-waste with strong potential as a renewable raw material for sustainable materials. Through suitable pretreatment and fractionation methods, its major components cellulose, hemicellulose, and lignin can be converted into value-added products such as fibers, nanocellulose, and biodegradable plastics. Bagasse-based bioplastics and fiber composites show improved mechanical properties, biodegradability, and reduced environmental impact compared with petroleum-based plastics. Although challenges related to processing efficiency and large-scale production remain, integrating bagasse valorization into biorefinery systems can support circular bioeconomy goals and significantly reduce plastic pollution.

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