

Raw Materials for Paper Industries in India

Raju K. Chalannavar ¹, Hosamani PA ² and Ravindra B. Malabadi ^{1, 3, *}

¹ Department of Applied Botany, Mangalore University, Mangalagangothri-574199, Mangalore, Karnataka State, India.

² Department of Botany, Bangurnagar Arts, Science and Commerce College, Dandeli-581325, Karnataka State, India.

³ Miller Blvd, NW, Edmonton, Alberta, Canada.

Global Journal of Engineering and Technology Advances, 2026, 27(03), 080-093

Publication history: Received on 12 April 2026; revised on 05 May 2026; accepted on 02 June 2026

Article DOI: <https://doi.org/10.30574/gjeta.2026.27.3.0142>

Abstract

India has a total of approximately 900 paper mills, with around 550 to 570 of these units currently operational. The pulp and paper industry in India is the 5th largest industrial sector in India. India accounts for approximately 5% of global paper production and ranks 15th globally in terms of total output. The Indian paper industry draws its raw materials from three primary sources: 1) waste or recycled paper, 2) wood-based fibers, and 3) Agriculture crop residues. India's paper industry is dominated by the packaging and paperboard category, followed by printing and writing paper. However, high dependency on wood for the production of pulp and paper production creates major environmental problems, like global warming, greenhouse gas emissions, deforestation, and dwindling fibrous wood resources. In India, wastepaper collection primarily relies on an informal network of rag-pickers, small scrap dealers, and local aggregators who manually gather, sort, and supply used paper for recycling. This decentralized and unorganized system leads to inefficiencies in wastepaper recovery. Currently, the main agricultural waste crop straws being used as raw materials for pulping include Industrial *Cannabis sativa* (hemp) fiber, jute fibers, okra stalks, grasses, banana stem, cotton straw, sunflower straw, millet grains straw, date palm trees, corn stalks, wheat straw, sugarcane bagasse, rice straw, coconut shell, bamboo, reeds, rice, sorghum stalks, kenaf and other materials. However, the high silica content of straw fibers, which makes the pulp recovery process challenging, is also one of the most significant issues with the chemical pulping of agricultural residues. The Indian paper industry struggles with high raw material costs, rising imports, and supply chain issues, while outdated technology, poor fiber quality, and strict environmental norms further pressure profitability and sustainability. India's paper industry is facing raw material price volatility, with wastepaper prices declining due to weak demand, while wood pulp costs have surged because of supply disruptions and geopolitical issues.

Keywords: Agricultural residues; Environmental issues; Fibre; India; Paper and Pulp; Wood; Waste paper

1. Introduction

India has a total of approximately 900 paper mills, with around 550 to 570 of these units currently operational [1, 3, 4, 7, 8, 9-26, 28]. The industry is highly fragmented, producing over 25 million tonnes of paper annually. The pulp and paper industry in India is the 5th largest industrial sector in India. India accounts for approximately 5% of global paper production and ranks 15th globally in terms of total output [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. The industry provides 0.5 million direct and 1.5 million indirect employment. It is estimated turnover was ₹80,000 crores in 2024. There are 900 paper mills in India, with most of them being located in Gujarat, Maharashtra and Uttar Pradesh. Ballarpur, located in Maharashtra, is home to the largest paper mill in India, known as Ballarpur Industries Limited (BILT) [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. This paper mill is one of the largest in the country and produces a significant portion of India's paper supply, particularly newsprint and writing paper. China is the leading largest paper producer in the world. The country is also called "Paper Inventor". The paper we know was born in China about 1900 years ago. The industry's growth is

* Corresponding author: Ravindra B. Malabadi

driven by rising demand for corrugated and household paper products. As the fastest-growing paper market worldwide, India is poised for significant expansion, aligning with the country's economic growth [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Paper serves multiple purposes, including carrying, wrapping, protecting, packaging, and functioning as a container. To meet increasing demand, India needs to add around 1 million tone per annum (TPA) of integrated pulp, paper, and paperboard production capacity beyond the current levels [1, 3, 4, 7, 8, 9-26, 28-39, 57-60-103].

The pulp and paper mills in India producing nearly 6.8 million tons of paper, paper board and newsprint out of which 5.8 million tons accounts for the paper and paper board and the remaining is newsprint [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. The paper mills in India can be broadly classified in to three categories. Mills that have integrated, largely forest based operations and produce over 100 TPD are classified as large mills. These mills are 33 in number but account for 36% of the total production. Medium size mills having a capacity between 50-100 TPD using agro based fibrous raw materials are 165 in number [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. These account for 29% of the total production [1-10-66]. The mills up to 50 tons consists mostly of the units using waste paper as the fiber base. These mills are 510 in number and account for 35% of the total production. In the past few years, many mills, which were earlier using renewable crop residues as fiber base shifted to using recycled fiber in the face of the CREP norms, which stipulated the use of chemical recovery for these units manufacturing paper from the virgin pulp employing agro based fibrous raw material [1, 3, 4, 7, 8, 9-26, 28-39, 57-60].

Hard and softwood fibers are the foundation of the global pulp and paper industry. They account for up to 90 % of traditional raw materials used in paper production [1-13-35]. The demand for paper has increased over the last four decades, driven by economic development [1-24-66]. However, traditional sources of fiber are not keeping up with this demand. Global paper consumption rose sharply from about 187 million metric tons in 2005 to 400 million in 2013, reaching 500 million metric tons by 2020 [1-10-66]. Experts suggest that by 2050, global paper and pulp production could reach between 700 and 900 million metric tons, which is equivalent to approximately 58 kg of paper per person worldwide [1-14-48]. Notably, an estimated 30 % of today's paper is used for purposes that were less significant just a decade ago [1-8-60]. This heavy reliance on wood fiber is linked to severe environmental challenges, including deforestation increased greenhouse gas emissions, and accelerating climate change [1-10-66]. Forest depletion impacts ecosystems and public health, making it crucial to limit traditional wood pulp use and focus on sustainable practices [1-10-66]. Despite the dominance of wood fibers in paper production, growing environmental concerns have increased interest in sustainable alternatives [1-10-66]. Non-wood plant fibers are emerging as viable substitutes, offering both ecological and processing benefits [1-10-66-102]. These biodegradable materials offer versatile applications, from packaging to writing paper, providing an eco-friendly solution that reduces waste while delivering both environmental and economic benefits [1-24-66]. Non-wood fibers contain lignocellulosic fibres composed of cellulose, hemicellulose, and lignin, which are effective for producing quality paper with lower resource demands [1-10-37-33-56-66]. Agro-based paper production is increasingly recognized as a sustainable and cost-effective alternative to traditional wood pulp production [1-10-66]. Agricultural waste, industrial crops, and naturally occurring plants, such as bamboo, straw, and hemp, offer viable fiber sources with short growth cycles, providing a steady supply and mitigating wood scarcity concerns [1-10-66]. Compared to wood-based methods, agro-based paper production requires up to 90 % less water and 60 % less energy [1-8-66-103].

2. Indian Paper Industry Market Value

India's paper and pulp sector is witnessing the most rapid expansion globally. There is a consistent rise in the need for various paper commodities, encompassing packaging materials, writing and printing papers, as well as niche paper products [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. India's paper sector is at the forefront of recycling endeavors, advocating for the use of repurposed paper to safeguard natural assets and lessen ecological footprints. Renowned for its eco-friendly methods, the industry in India is also recognized for its commitment to sustainability and utilization of renewable resources [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Globally, 410 million tons of paper are used each year, and India's usage accounts for 22.05 million tons of this total, representing 4.72% of worldwide paper consumption. India's paper usage has been on an upward trajectory, correlating with the country's economic growth starting in the early 1990s. However, the international paper and pulp mills sector has seen a slight downturn in the last half-decade, largely due to the adoption of digital media and a move toward paperless communication in many advanced economies. The market value of the Indian paper and pulp sector stood at USD 14.75 billion in 2023; and it is projected to grow to USD 35.57 billion by 2030. This growth is anticipated to occur at a compound annual growth rate (CAGR) of 13.4% throughout the forecast period [1, 3, 4, 7, 8, 9-26, 28-39, 57-60-103].

The paper industry in India is highly clustered even though it demonstrates resilience, with revenues reaching ₹ 80,000 crores in FY24 at an annual growth of about 8.2 per cent per annum. The four main segments of the industry—printing and writing paper, newsprint, packaging paper and board, and specialty paper—serve diverse markets both

domestically and internationally[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. The industry is distributed into small, medium, and large paper factories and mills, with over 900 mills scattered across the nation, with a majority of these mills existing in the plateau region of the country. The geographical spread of the industry, as well as the market, is mainly responsible for the regional balance of production and consumption[1, 3, 4, 7, 8, 9-26, 28-39, 57-60].

India's paper manufacturing landscape is vast, comprising over 900 mills, of which 550 are operational. The regional distribution of paper mills reflects this specialization. States like Gujarat and Tamil Nadu excel in packaging-grade paper production, catering to the growing demand for sustainable and e-commerce-driven packaging solutions[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Andhra Pradesh and Odisha are emerging as centers for specialty papers, including food-grade and decorative varieties. Meanwhile, Uttarakhand, with hubs like Kashipur, is renowned for producing high-quality printing paper that meets the demands of educational institutions and government procurement programs [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Due to their strategic location and industrial ecosystem, Maharashtra and West Bengal remain critical for newsprint and commercial printing applications. India's largest paper mill is the **Ballarpur Industries Limited (BILT)** unit located in the Chandrapur district of Maharashtra. BILT is renowned as India's largest manufacturer of writing and printing paper.

In India, **Karnataka State**, is home to about 17 paper mills, which account for roughly 5.48% of India's total paper production capacity. While there are many smaller, unorganized, or specialized producers, the Karnataka state hosts several major industrial pulp and paper manufacturers [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. 1) **West Coast Paper Mills Ltd. (Dandeli)**: West Coast Paper Mills Limited (WCPM) is a publicly traded company on the Indian stock exchanges that operates as the flagship enterprise of the Kolkata-based **S.K. Bangur Group**. The company is promoted and controlled by the Bangur family, with **Shree Kumar Bangur** serving as the Chairman and his son, **Virendraa Kumar Bangur**, serving on the Board of Directors. The Bangur family originated from **Didwana**, a town in the Marwar region of Rajasthan, India. In the early 19th century, brothers Mugneeram Bangur and Ram Coowar Bangur migrated from Rajasthan to Calcutta (now Kolkata) to build what would become one of India's largest business empires. Established in 1955, the Mill is located at **Dandeli** in Uttara Kannada district in Karnataka. One of the largest producers of writing, printing, and packaging paper in India. 2) The South India Paper Mills Ltd. (Nanjangud, Mysuru): Specializes in producing packaging paperboards and kraft paper. 3) The Mysore Paper Mills Ltd. (Bhadravathi): A prominent, historically state-backed mill operating in the Shivamogga district. 4) Jodhani Papers Private Limited (Doddaballapura): A key manufacturer of kraft paper and paper bags. 5) Dev Kiran Paper Mills Pvt. Ltd. (Bengaluru): Manufacturer of high-quality recycled unbleached kraft paper used in packaging. 6) The Bangalore Paper & Pulp Mills produces high-quality kraft paper, corrugated paperboards and paper products used in various industrial applications. 7) South India Paper Mills, headquartered in Nanjangud near Mysore, is a well-established paper manufacturer in Karnataka. The mill has produced a wide range of paper products, including writing and printing paper, packaging paperboards, and newsprint. 8) The Mysore Paper Mills is a government-owned paper mill. It produces newsprint, writing and printing paper, and specialty paper products. 9) **Belgaum Paper and Board Mills** is engaged in the production of kraft paper and corrugated boards. The mill caters to the packaging needs of various industries, including textiles, food, and electronics, in Karnataka and neighbouring states. 10) Sri Varahaswamy Paper Mill and Packaging is a well-established paper manufacturer. It specializes in craft paper production and packaging solutions for a wide range of industries. 11) The South India Paper Mills is a prominent player in the paper industry. It produces writing and printing paper, packaging paperboards, and specialty paper products [1, 3, 4, 7, 8, 9-26, 28-39, 57-60].

3. Raw material for Paper Industries in India

The raw materials used in the Indian paper industry are a complex blend of sustainability-focused practices and resource availability challenges[1-10-66]. The industry draws its raw materials from three primary sources: 1)waster or recycled paper, 2) wood-based fibers, and 3) Agriculture crop residues [1-10-66]. These materials are critical for supporting the industry's diverse production needs, including packaging paper, printing, writing paper, and specialty papers. Among these sources, recycled paper accounts for 52 per cent of the raw material base, reflecting the industry's strong emphasis on circular economy practices [1-10-22-49-54-66]. Wood-based fibers contribute 28 per cent, primarily for producing high-quality paper grades, while agro-residues, such as sugar cane bagasse, rice straw, maize straw, sorghum straw and wheat straw, make up the remaining 20 per cent [1-10-66]. Agro-residues offer a sustainable and cost-effective alternative, especially in sugarcane-rich states like Uttar Pradesh and Maharashtra, but their seasonal availability remains a challenge [1-10-66]. Agricultural residues, such as hemp and sugarcane bagasse, present higher concentrations of cellulose and lower levels of recalcitrant lignin when compared to the average woody biomass, and also present higher annual growth rates when compared to trees [1-11-34-46-66]. Nonetheless, on a global scale, forest woods still account for over 40% of the main raw material for producing paper, while agricultural residues account for less than 30% [1-4-61-103].

3.1. Waste or Recycled paper

In India, wastepaper collection primarily relies on an informal network of rag pickers, small scrap dealers, and local aggregators who manually gather, sort, and supply used paper for recycling[1-10-66]. This decentralized and unorganized system leads to inefficiencies in wastepaper recovery, with India achieving a paper recycling rate of around 30-35 per cent, significantly lower than developed countries, where rates exceed 60-70 per cent (Indian Paper Manufacturers Association, IPMA) [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. The lack of a structured collection mechanism results in substantial paper waste being either incinerated or disposed of in landfills, limiting the availability of high-quality recovered fibre for the domestic paper industry. Additionally, the absence of standardized segregation at the source further contaminates the collected wastepaper, reducing its usability in high-quality paper production[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. The heavy reliance on manual collection also exposes the paper industry to supply chain disruptions and inconsistent raw material availability, making it dependent on expensive imports. India imports 35 per cent of its recovered paper needs, incurring significant costs and foreign exchange outflows (Central Pulp & Paper Research Institute, CPPRI). Moreover, the informal nature of the collection system results in poor working conditions and low incomes for waste collectors, discouraging efficiency improvements. A lack of government-backed incentives and infrastructure for systematic wastepaper recovery further hampers efforts to strengthen the domestic recycling ecosystem[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Addressing these challenges through policy reforms, formalized waste collection networks, and advanced recycling technologies could enhance domestic wastepaper recovery and reduce dependency on imports[1, 3, 4, 7, 8, 9-26, 28-39, 57-60].

3.2. Wood based pulp

The paper industry is heavily dependent on wood pulp and recycled fiber, which act as the main raw materials for the industry. Accordingly, Indian paper mills rely heavily on imports to meet raw material demands, which exposes them to international supply chain risks and currency volatility[1-10-66]. Currently, 70-75 per cent of paper and paperboard consumed in India are recycled grade, requiring about 20 million tones of wastepaper annually[1-10-66]. Given India's low per capita paper consumption of 15 kg, one of the lowest in the world whereas for USA, it is around 320 kg, 129 kg for EU (European Union), 45 kg in Asia and 75 kg in China, compared to the global average of 58 kg, any increase in consumption significantly impacts overall demand, i.e., an increase of 1 kg in per capita consumption will lead to a demand of 1 million tones of paper products[1-10-66]. The shift from wood-based to recycled paper – evidenced by the reduction of wood usage from 80 per cent in the 1980s to 20 per cent today – indicates a continued rise in demand for recovered fiber[1-10-66].

The main wood pulp for paper industries in India are 1) Bamboo, *Eucalyptus* species, *Albizia lebbbeck*, *Albizia falcataria*, *Gmelina arborea*, Mango tree, Teak (*Tectona grandis*), *Melia dubia*, *Leucaena leucocephala*, *Acacia auriculiformis*, and *Dalbergia sissoo* (Rose wood), *Dalbergia latifolia*, *Causiriana* spp, *Acacia* species, *Melia azardicta*, *Azardicta indica*, Pine trees (*Pinus kesiya*, *Pinus roxburghii*, *Pinus gerardiana*, *Pinus wallichiana*, *Pinus caribeeae*) [1-10-66].

Dalbergia sissoo (commonly known as Indian Rosewood or Shisham) is a fast-growing, nitrogen-fixing hardwood native to South Asia[1-10-66]. It is highly valued in the paper industry as a short-fiber pulpwood. Its high basic density and strong fibers make it an excellent sustainable raw material for manufacturing high-quality writing and printing papers[1-10-66]. Recognized as one of India's four main timbers— alongside *Tectona grandis* (Teak), *Shorea robusta* (Sal), and *Cedrus deodara* (Cedar)—it is prized for its robustness, flexibility, and endurance, making it a preferred material for construction and various other utilities [1-10-66]. *Dalbergia sissoo* is also an ideal species for reforestation projects in challenging environments, such as saline and alkaline terrains, mining areas, and eroded landscapes[[1, 3, 4, 7, 8, 9-26, 28-39, 57-60].

Melia dubia, also known as Malabar Neem, is a fast-growing tree species valued for its diverse applications ranging from agro-forestry to the timber industry. Its wood properties, including basic density, fiber dimensions, and chemical composition, vary with age, influencing its suitability for pulp and paper production[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. *Melia dubia* exhibits favorable wood properties for pulp and paper quality, with basic density, fiber dimensions, and cellulose content improving with tree age, suggesting the optimal harvesting period for high-quality pulp is at 4 to 5 yr [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. *Melia dubia* is a species that can be used in agro-forestry and farm forestry plantation programs due to its many uses, including pulp-wood, timber, fuel wood, and plywood.

Leucaena leucocephala, commonly known as the White Lead tree, demonstrated versatile applications and environmental benefits, particularly in the contexts of agroforestry, phytoremediation, and material production[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Additionally, *L. leucocephala* suitability for biomass and paper production, even from its varieties like giant leucaena, underscores its potential for sustainable agro-forestry renewable energy source,

supporting industries. *Acacia auriculiformis*, commonly known as ear-leaf acacia, is recognized for its significant contribution to the timber and pulpwood industry due to its desirable wood properties[1, 3, 4, 7, 8, 9-26, 28-39, 57-60].

Paper is mainly made from softwood and hardwood trees like pine, spruce, fir, eucalyptus, birch, and poplar, which provide cellulose fibers. Softwood trees give strength, while hardwood trees make the paper smoother. *Pinus kesiya* (commonly known as Khasi pine) is a valuable softwood species native to Northeast India particularly, Shillong, Meghalaya state. In the Indian paper industry, it is utilized as a source of long-fibered pulp to improve the tensile strength and tear resistance of paper. It is primarily harvested from regional plantations, particularly in states like North East Indian States, Meghalaya, Assam, Arunachal Pradesh, Nagaland, Sikkim, Manipur, Odisha, Tamil Nadu, and West Bengal [1, 3, 4, 7, 8, 9-26, 28-39, 57-60].

Pinus roxburghii commonly known as Chir pine is one of the six pines in India and the most widely occurring species among *Pinaceae* family. It is also known as Himalayan long needle pine, long leaved Indian pine, Indian chir pine or chir. Pine needles shed from pine trees decay very slowly, form a carpet on the forest floor and are a major cause of frequent forest fires. The abundantly available unutilized pine needles are rich source of lignocellulosic biomass, goes waste, and its management through sustainable utilization has been a challenge[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. In India pine forests are found in Meghalaya, Jammu and Kashmir, Haryana, Himachal Pradesh, Uttarakhand, parts of Sikkim, West Bengal and Arunachal Pradesh[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Pine trees shed pine needles in large amount during summer season and form a thick carpet on the forest floor. Pine needles are being used as a fuel for domestic purposes in the mid-altitude villages of the Indian Himalayan region such as Uttarakhand, Himachal Pradesh and Jammu, Meghalaya and Kashmir states that produces about 159 lakh tones of pine needles every year[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Pine foliage or commonly referred as pine needles are abundantly available unutilized forest based lignocellulosic biomass. Pine needles decays very slowly in comparison to other forest biomasses, it is not served as a fodder, and the piled up pine needles are a major cause of frequent incidences of forest fires, however, it is a source of biomass fuel. Furthermore, the dry pine needles causes depletion of groundwater table as it hinders water absorption by the soil. Additionally, the dry pine needles form a carpet on the forest floor which blocks a major part of sunshine reaching the ground, thereby hindering the growth of native grasses which the cattle can feed upon[1, 3, 4, 7, 8, 9-26, 28-39, 57-60].

The Indian paper industry primarily relies on a mix of wood/bamboo (sourced from social/agro-forestry), agricultural residues, and recycled waste paper[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Due to strict forest conservation regulations, the industry sources over 90% of its virgin pulp materials from farm-grown trees and non-forest lands. Wood of *Melia azadirachta*, *Neolamarkia chinensis*, *Casuarina* spp and *Eucalyptus* spp are used for making paper pulp.

Tamil Nadu Newsprint and Paper Limited (TNPL) Ltd, 67 Anna Salai, Guindy, Chennai-600 032, India. is state owned integrated pulp and paper industry situated in southern most state of India and produce around 4,00,000 tons of paper per annum[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Tamil Nadu Newsprint and Papers Limited (TNPL) is a prominent Indian manufacturer of writing and printing paper, paperboards, cement, and energy. Incorporated in 1979 by the Government of Tamil Nadu, the Chennai-based company operates globally and is one of the largest paper producers in Asia. TNPL has 300 Tones per day (TPD) hardwood fibre-line along with 550 TPD bagasse fibre line to meet its pulp requirement. TNPL had setup biotechnology and bio-energy research facility under the existing R & D Department to work on identification, selection and multiplication of improved pulpwood clones of *Eucalyptus* and other alternate fast growing hardwood species through modern biotechnological methods to meet pulpwood and also bio-energy need[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. The **plant tissue culture** facility has one million plants per annum capacity and optimized protocols for many improved Eucalyptus pulp wood clones to use as clonal mother plants at Clonal Production and Research Centre of Plantation Department using mini cutting process[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. TNPL clonal production facility has capacity of 15 million seedlings per annum and already covered 52,000 acres of pulp wood plantation and plan to cover additional 15,000 acres every year. As a part ongoing research activity, one *Melia dubia* clone for bio-energy/pulpwood and one *Dalbergia sissoo* clone and three clones of eucalyptus, (each one from *E. urograndis*, *E. tereticornis*, and *E. camaldulensis*), were identified based on its biomass productivity, as well as, pulp quality and yield[1, 3, 4, 7, 8, 9-26, 28-39, 57-60].

Wood accounts for the largest proportion of papermaking material, offering a good fiber aspect ratio, minimal miscellaneous cell content, and higher pulping yield. Various types of wood are available throughout the year; however, not all wood types are suitable for pulping[1-10-66]. Moreover, their suitability depends on their growth cycle, cultivation cost, processing complexity, and economic benefits. In general, the wood used is divided into the following two types: hardwood and coniferous wood. Hardwood pulp materials include eucalyptus, poplar, and birch [1-4-20-33-40-56-66]. Compared to hardwood, softwood offers a longer fiber length, greater toughness, better stretchability, and high-quality paper production [1-36-66]. The most commonly used pine materials in the pulping industry are larch,

Pinus sylvestris (P. sylvestris), Scotch pine, and Korean pine. However, with increasing global demand from the pulping industry and issues surrounding environmental resources and the sustainable development of forests, increased restrictions have been implemented on the use of wood as a raw material[1-10-66-103].

Non-wood raw materials, such as straw, and recycled fibers, and waste newspapers, are increasingly being developed for pulping [39]. Compared to wood fiber, non-wood fiber is predominantly used in countries with a limited wood supply. However, even in non-restricted countries, the use of non-wood fiber materials for pulping is increasing [1-40-66]. Therefore, non-wood fibers have the potential for development as raw materials for pulping. Non-wood raw materials for pulping primarily include waste crop straws and non-wood crops. Before being used as pulping raw material, a large amount of this waste straw is directly burned in the open land due to its low value and inconvenience in treatment, causing considerable smog production and substantial environmental damage[1-10-66].

3.3. Agricultural Residues (Non woody plant source)

Currently, the main waste crop straws being used as raw materials for pulping include hemp fiber, corn stalks, flax straw, wheat straw, canola straw, sugarcane bagasse, rice straw, coconut shell, banana stem, bamboo, reeds, sorghum stalks, kenaf, date palm (*Phoenix dactylifera* L.), and other materials [1-10-66-86-103]. Flax (*Linum usitatissimum*) is a bast fiber plant known for its long fibers, making it an excellent source of pulp for paper production. Both date palm and reed fibers, with the addition of starch, demonstrated strong potential for producing high-quality paper suitable for diverse applications[1-10-66-81]. Traditionally, hemp as a fiber plant has been used for the production of apparels, fabrics, papers, cordages and building materials. The hurds, as waste by-product of fiber production, were used for bedding of animals, the seeds for human nutrition, e.g., as flour, and the oil for a wide range of purposes, from cooking to cosmetics[66-68-102]. Wheat Straw (*Triticum aestivum*): It is the by-product of wheat which left over wheat grains are harvested. It consist mainly of cellulose 29-35%, lignin 16-21%, Silica 3-7% and ash 4-6%[1-10-66-81]. Sugarcane bagasse (*Saccharum officinarum*): It is outer stalk of sugarcane left after the process of crushing and extraction of sugar from sugarcane. Its average fibre length and fibre width is about 1.7 mm and 0.02 mm respectively[1-10-68-81-102]. It contains cellulose 55%, lignin 18-24%, Silica 0.7-3 %, Ash 1.5-5%. Among all types of fibers, it is low cost but it have a drawback as it contains pith which causes difficulties during pulp washing and affects quality pulp yield [1-10-66-102]. Rice Straw (*Oryza sativa*): It is a by-product of rice produced after paddy is harvested. It consists of cellulose (28-36%), Lignin (12-16%), Ash (15- 20%) and Silica (10-15%). Rice straw have certain drawbacks such as high cost, difficult to collect and storage, also contain high content of silica[1-10-66-103]. Corn stalk (*Zea mays*): It is the stem of a corn plant. Its average fibre length is about 1.6 mm and average fibre width is about 0.03 mm. Its contain 36-38% cellulose, Lignin 18-19% and few amount of silica and ash. Some types of cereal straw are also used as a raw material for the production of paper. Cereal straw which includes rye (*Secale cereal*), oat (*Avena sativa*) and barley (*Hordeum vulgare*). From these, rye straw is the best raw material for pulp production due to its availability, greater yield and high strength properties of its pulp[1-10-66]. Banana stems (*Musa acumintha*): After the collection of banana fruits, the stem can be used as a raw material for the production of paper. It is a cheapest and easily available raw material which is used to prepare the different types of paper such as writing paper, printing paper, tissue paper etc. Its average fibre length is about 1.55 meter, cellulose content 59.3%, lignin 17.5% and few amounts of silica and ash[1-10-66-103]. Cotton Stalk (*Gossypium*): It is one of the good side products of cotton crop. About 24 million tons of cotton plant stalks are generated in India per annum. The average length of cotton stalk fibers is 0.5-0.8 mm and average fibre diameter is of 0.02-0.04 mm[1-10-66-103]. For making the cotton as possible source of raw material for papermaking process, various studies have been conducted. When cotton stalk is blended with other pulps, it will produce good quality paper. For e.g. – Generally, the tear index of cotton stalk is low but if its pulp is blended with jute pulp, it will increase the tear index of paper[1-10-66-81-103].

The use of forest resources to make pulp has increased in recent years, having a variety of industries, such as furniture manufacturing, construction, and others, using wood as a raw material [1-10-34-45-56-66-103]. The pulp and paper industry relies primarily on the uses of fibrous wood. This overreliance on fibrous wood is linked to significant environmental problems, including deforestation, greenhouse gas emissions, and global warming [1-5-34-45-66-103]. Other raw material that also bear cellulosic fiber structures, such as non-woody plants, could therefore be considered for the manufacturing of pulp and paper to lessen the environmental problems associated with its use, as non-woody plant source materials reduce the amount of wood used in the papermaking process, considering that around 60% of cellulose fibre is produced from non-wood materials, such as hemp fiber, jute fibers, grasses, reed, bamboo, corn stover, sugarcane bagasse, and others[1-10-66-103]. Some Asian markets, such as China and India, rely heavily on sugarcane bagasse and wheat straw, both of which contribute to approximately 70% of the requirement to the pulp industry as raw materials [1-7-47]. These agricultural residues have the potential to replace woody lignocellulosic biomass since they can be sustainable and affordable sources of cellulosic fiber[1-10-66]. Their remnants are structurally similar to other plant fibers utilized in production, in terms of composition and physical and chemical characteristics [1-8-56].

Agricultural residues, like hemp, jute, banana stems, kenaf, rice and wheat straw, and sugarcane baggase as the raw material for paper production[1-10-66-103].

At the same time, people's demand for high-quality paper products has also greatly promoted the development of the industry. As the main raw material for pulping, wood has a slow growth cycle and logging regulatory restrictions. The gradually shrinking supply cannot meet the rising demand[1-10-66]. Herbs, which also contain a large amount of fiber, could become an important choice for pulping raw materials in the future due to their fast growth, large reserves, and easy availability. In the context of today's rapid development of bio-modification technology, it is increasingly convenient to develop herbal plants that are suitable for the pulping industry[1-10-66]. It is expected that more plant raw materials with a good fiber length, high yield, and suitable for paper making will be used in the future. At the same time, man-made fiber technology is developing rapidly, and man-made fibers represented by viscose fiber, acetate fiber, and cupro fiber are also expected to become an important source of raw materials for pulping in the future. However, wood subject to many limitations as a raw material for pulping, but traditional pulping methods that are extensive, high in alkali, and have a high dosage of chemicals are also being gradually phased out due to shortcomings such as high pollution, high energy consumption, and high costs[1-10-66]. As early as more than 2000 years ago, people created the earliest paper by using natural bacteria to decay raw materials without using chemicals. With the vigorous development of biotechnology, microorganisms have been modified and used in various industries[1-10-68]. In the pulping industry, biological agents such as bacterial strains and enzymes that are efficient and suitable for the pulping environment are constantly being discovered and utilized. Due to their advantages, such as mild use conditions, high efficiency, and specific recognition sites, biological agents can reduce energy consumption in the pulping production process, reduce the emission of pollutants later, and save pulp production costs[1-10-68].

In the future, the pulping industry will not only need to develop known non-wood raw materials to improve the physical properties of its pulp but also continue to look for paper-making raw materials that are comparable in strength to wood raw materials and are easier to obtain[1-10-66]. At the same time, with the support of biotechnology, biological agents that are suitable for various environments can be transformed. Therefore, in the future, with the application of new technologies and new processes, chemical pulping technology and biological pulping can be perfectly combined, making the pulping and papermaking production process more environmentally friendly and efficient so that the pulping industry can develop more vigorously[1-10-68].

In addition to natural plant materials, wastepaper, and newspapers are valuable raw materials for pulping. Refinement after de-inking can rejuvenate wastepaper, giving it a new appearance and life [1-66]. Bamboo reed, which can be extensively planted in saline-alkali land, offers further potential. It not only aids in controlling saline-alkali terrain but also grows quickly. After reaching maturity, the stems that survive the winter possess fibres with a good aspect ratio, rendering them suitable as raw materials for pulp and paper. In addition, non-plant fibres have been explored as raw materials for pulping. To alleviate the increasing global environmental problems and the growing shortage of wood resources in the pulping industry, researchers have developed new materials for pulping. Cellulose synthesized by microorganisms has emerged as a promising new material [1-68]. Research in this area mainly focuses on innovative materials such as nanocellulose and composites and has expanded in recent years[1-10-66].

4. Disadvantages of use of Agricultural Crop residues

The disadvantage of using agricultural residues is that, traditionally, their pulp mills run on smaller scales and they tend to be bulkier. Straw, like many other agricultural residues, usually presents high water content levels, reaching up to 70% on a weight basis, which needs to be dropped to levels around or below 25% to avoid microbial spoilage [1-12-68]. Drying straw fibers presents unique challenges; since its fibers are frequently shorter than those in softwoods, they typically drain more slowly. The high **silica** content of straw fibers, which makes the pulp recovery process challenging, is also one of the most significant issues with the chemical pulping of agricultural residues [1-13-63]. Chlorine-free bleaching techniques cannot produce agriculture residue pulps, with a high degree of brightness, due to their anatomical and chemical characteristics [1-14-68-103]. Several hundred chlorinated compounds were discovered in the bleaching waste liquors, which pose health dangers, including liver and kidney damage, hormone issues, and reduced gonad development in many living things found inside water bodies [1-15-68]. Soil and marine life fertility are seriously threatened by the polluted effluent discharges of bleached wastewater [1-15-66-103].

Environmentally friendly technologies, such as enzymatic treatments, offer low-cost alternatives for bleaching pulps. Xylanase is frequently employed in the pretreatment of pulp bleaching[1, 3, 4, 7, 8, 9-26, 28-39, 57-60, 68, 69, 70]. It alleviates the drawbacks of agricultural residues by reducing the chlorine dioxide amount used for bleaching purposes up to 20%, without affecting pulp quality[68, 69, 70]. Plant pollution can be decreased through O₂ delignification, totally chlorine free processes, elemental chlorine free technologies, oxidative alkaline extraction, replacement of Cl₂ with ClO₂,

using different pretreatment, and improved pulp washing [1-17-66-103]. Extended delignification focuses on removing extra lignin before bleaching the pulp and dramatically lowering the chlorine concentration [1-18-60]. For example, the kappa number of rice straw can be reduced by up to 43% by delignification [1-19]. As a result, the chemical requirements of the bleaching sequence will be decreased, and the pollutant load will be reduced significantly [1-20-66-103].

5. Regional based Raw material

India's approach to raw material sourcing is regionally diverse, with states specializing in specific materials based on their agro-climatic conditions and industrial capabilities. Uttar Pradesh, for instance, is a leading producer of sugarcane bagasse, derived from its substantial sugarcane production [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. This state also hosts one of the largest clusters of recycling mills, making it a vital contributor to the industry's raw material supply. Gujarat stands out for its robust recycling infrastructure, contributing 22 per cent of the recycled paper supply nationally. Tamil Nadu leads in wood-based fiber production, supported by extensive agro-forestry initiatives and high-quality pulp output. Andhra Pradesh has emerged as a hub for specialty paper production, with significant investments in clonal plantation programs to enhance wood supply [1, 3, 4, 7, 8, 9-26, 28-39, 57-60-79]. Maharashtra and West Bengal also play critical roles, leveraging their sugarcane byproducts and historic paper production ecosystems, respectively. Bamboo and softwood were the primary raw materials for the global paper industry for a long time. However, due to their shortages, the industry began exploring alternatives, particularly agricultural residues like sugarcane bagasse. The sugar industry, one of India's largest agro-based sectors, produces bagasse as a by-product of cane sugar production. Traditionally, it has been burned in boilers for steam generation, but it holds greater potential, such as in paper production. India currently produces 1.8 million tones of paper annually, expected to nearly double in the next five years [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. With 80 per cent of raw materials sourced from forests, dwindling forest cover has led to an ecological crisis. Despite this, most sugarcane bagasse in India is still burned for steam in sugar mills, with 96-97 per cent consumed this way. Despite these advancements, challenges persist. The recycling rate of wastepaper in India is only 43 per cent, far below the global average of 55-60 per cent [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. This inefficiency is compounded by the fragmented nature of the waste collection system and limited public awareness about recycling benefits. States like Gujarat and Uttar Pradesh contribute significantly to recycling efforts, accounting for 22 per cent and 18 per cent of the national total, respectively. However, Maharashtra and West Bengal lag behind, with logistical inefficiencies and inadequate infrastructure impacting their contributions [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. To address these issues, the industry has called for nationwide investments in modernized waste collection systems and public awareness campaigns to promote recycling practices. Several strategies have been proposed to address the industry's raw material challenges. Enhancing wastepaper recovery rates through the establishment of nationwide collection centres is a priority. Additionally, expanding agro-forestry programs to states like Odisha and Karnataka could further reduce dependency on imports. Financial incentives for farmers cultivating pulpable wood, coupled with investments in modernized recycling infrastructure, could transform the raw material landscape [1, 3, 4, 7, 8, 9-26, 28-39, 57-60].

6. Indian Paper Industry Categories

India's paper industry is dominated by the packaging and paperboard category, followed by printing and writing paper. Specialty papers (particularly tissue) segment is emerging as the fastest growing category [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Packaging and paperboard is the largest and fastest-growing segment, driven by FMCG, textiles, pharma, e-commerce, and the ban on single-use plastics. [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Printing and writing paper holds a significant share, supported by rising literacy, education initiatives, and government spending; copier paper is a key growth driver. Specialty papers, especially tissue, are growing rapidly due to higher hygiene awareness, urbanization, and demand from healthcare and hospitality [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Newsprint is steadily declining as digital media reduces newspaper and magazine consumption. Pulp and paper mills are an essential part of the global economy and provide a wide variety of products for various uses. Agricultural residues and weed plant residues can cater to the growing demand for paper in the packaging sector, as well as hygiene and sanitation products, such as paper towels, toilet paper, and disposable makeup wipes, among others [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. In India, for instance, agricultural residues account for approximately 28% of the total feedstock used in the pulp and paper industry, supplied mainly from bagasse, wheat and rice straws, and cotton stalks [1, 3, 4, 7, 8, 9-26, 28-39, 57-60].

7. Indian Paper Industries: Challenges

The Indian paper industry struggles with high raw material costs, rising imports, and supply chain issues, while outdated technology, poor fiber quality, and strict environmental norms further pressure profitability and sustainability [1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. India's paper industry is facing raw material price volatility, with

wastepaper prices declining due to weak demand, while wood pulp costs have surged because of supply disruptions and geopolitical issues. Few manufacturers have implemented price hikes in 2025 to manage costs[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Wood Pulp (around 28% of input): Prices surged amid supply chain disruptions and geopolitical tensions; both domestic and global rates kept rising in Mar 2025 quarter. Agro-residues (around 20% of input): Cost-effective source (sugar cane bagasse, wheat straw) but subject to seasonal availability causing fluctuations[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Major manufacturers like BGPPL, Emami Paper Mills, and Khanna Paper Mill announced multiple price hikes in 2025 to offset rising input costs[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Rising demand for paper and packaging will continue, but raw material cost pressures and import competition are expected to shape future price trends[1, 3, 4, 7, 8, 9-26, 28-39, 57-60]. Paper is one of the most significant inventions in human civilization, which considerably advanced global cultural development[1, 3, 4, 7, 8, 9-26, 28-39, 57-60-66]. Pulping is a key step in the conversion of fibre raw materials into paper. The raw materials used in the pulping industry primarily include wood, non-wood, and recycled fibers. Although pulping methods have changed, primary raw materials, including plant and non-plant fibers, have remained the same. In recent years, traditional pulping materials have faced various restrictions, and environmental protection requirements have made the supply of wood raw materials insufficient. Therefore, finding new alternatives has emerged as a future development trend[1, 3, 4, 7, 8, 9-26, 28-39, 57-60-65].

8. Environmental Problems

High dependency on wood for the production of pulp and paper production creates major environmental problems, like global warming, greenhouse gas emissions, deforestation, and dwindling fibrous wood resources [1-8-60-66]. As a result, alternative sustainable raw material sources for pulp and paper production might be researched to address environmental concerns[1-8-66]. Non-wood fibers, such as agricultural residues, can be used to make pulp and paper more sustainably. Agricultural residues could be suitable for cellulosic fibre sources in the pulp and paper industry since they are renewable, inexpensive, and abundant[1-8-66-103]. Cotton stalks, banana stems, hemp fibers, rice straws, wheat straws, sugarcane bagasse, and corn stalks are all non-wood plant fibers currently employed as papermaking raw materials by many paper manufacturing companies. High silica content harms paper machines' efficacy and mills' chemical recovery[1-8-56-66]. Silica remaining in the pulp, and the pulp's drainage, can be hampered by its short fiber length[1-8-60-103]. This challenge necessitates the development of appropriate technology to address it on the shop floor. In developing countries, farmers commonly burn agricultural by-products in the field, due to challenges with residual management, resulting in significant air pollution and accompanying health issues[1-8-66-103]. Traditional pulp bleaching technologies involving chlorine and chlorine compounds are still used, putting an enormous burden on environmental resources. Thus, less harmful cooking and pulp bleaching techniques must be used to convert agricultural residues into pulp and paper[1-8-23-36-45-66]. Furthermore, the developed products can be converted to specialized membranes, which can be applied to a wide range of industries, ranging from water purification to medicinal uses[1-8-66]. To properly address the environmental issue, new and faster-growing technology with less chemical and water footprints must be developed [1-8-66-103].

9. Conclusion

The need for pulp and paper has risen significantly due to exponential population growth, industrialization, and urbanization. Most paper manufacturing industries use wood fibers to meet pulp and paper requirements. Wood accounts for the largest proportion of papermaking material, offering a good fiber aspect ratio, minimal miscellaneous cell content, and higher pulping yield. There are around 900 pulp and paper mills in India producing nearly 6.8 million tons of paper, paper board and newsprint out of which 5.8 million tons accounts for the paper and paper board and the remaining is newsprint. India ranks as the 15th largest paper producer globally, contributing 5 per cent to the world's paper market. The Indian paper industry primarily relies on a mix of wood/bamboo (sourced from social/agroforestry), agricultural residues, and recycled waste paper. The shortage of fibrous wood resources and increased deforestation are linked to the excessive dependence on wood for pulp and paper production. Therefore, non-wood substitutes, including corn stalks, sugarcane bagasse, wheat, and rice straw, cotton stalks, and others, may greatly alleviate the shortage of raw materials used to make pulp and paper. The Indian paper industry uses a diverse mix of fibrous raw material primarily forest based agro residues including bagasse, straw and waste paper. The environmental consequences of wood-based paper production, including greenhouse gas emissions, have accelerated the search for sustainable alternatives. Though agro residues are available in plenty, however associated problems like complexity during processing of these fibers, quality of the end product and environmental issues are the major concern to encourage use of this potentially available renewable raw material. Out of the available species, 12 have been investigated for pulp and paper production and 2 for panels (mat board). *Dendrocalamus strictus* is the most widely used species for pulp and paper, and followed by *Bambusa bambos* and *Melocanna baccifera* accounts for 83% of all bamboos used for pulping. *Ochlandra travancorica* and *Bambusa bambos* are used for mat board. The paper industry in

India could be classified into three categories according to the raw material consumed. 1. Wood based 2. Waste paper based 3. Agro based. Another significant challenge is the technological and economic feasibility of utilizing new or underutilized species for pulp and paper production. The existing pulp and paper industry infrastructure is optimized for a few well-studied species. Incorporating new species into the production cycle may require adjustments in processing techniques and equipment, which could be cost-prohibitive. Moreover, the lack of existing knowledge on the best practices for cultivating, harvesting, and processing these species adds another layer of complexity

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

- [1] Jain RK, K. Singh K, Roy TK. Indian Paper Industry Raw Material Scenario, Growth Prospects and Pathways. IPPTA J. 2007; 19:3:129- 137.
- [2] Worku LA, Bachheti A, Bachheti RK, Rodrigues Reis CE, Chandel AK. Agricultural Residues as Raw Materials for Pulp and Paper Production: Overview and Applications on Membrane Fabrication. Membranes (Basel). 2023; 14:13(2):228.
- [3] Dangi J, Malik S, Dhanias G, Laura JS, Nandal M. Potential Use of Agricultural Residues in Chemical-Free Handmade Paper Manufacturing. ORIENTAL JOURNAL OF CHEMISTRY. 2025; 41(4): 1120-1131.
- [4] Anu Kumari, Rai R. MANUFACTURING OF PAPER FROM AGRICULTURAL RESIDUE. Advanced Engineering Science. 2022;54: 867-875. ISSN: 2096-3246.
- [5] Li P, Xu Y, Yin L, Liang X, Wang R, Liu K. Development of Raw Materials and Technology for Pulping—A Brief Review. Polymers. 2023; 15: 4465.
- [6] Belyamani I, Alameri A, Soghman J. Sustainable paper production from **date palm** and reed leaves through the valorization of agricultural waste products. Next Materials. 2026; 10. 101392
- [7] Rajaram R, Ravi R. et al., WOOD PROPERTIES OF INDIGENOUS TREE SPECIES FOR PULP AND PAPER PRODUCTION. Wood and Fiber Science. 2024; 56(3): 155-172
- [8] Tripathi JG. Study of India's Paper Industry- Potential and Growth in 21st Century. INDIAN JOURNAL OF APPLIED RESEARCH. 2014; 4: 5.112-115. ISSN - 2249-555X.
- [9] Chinnaraj S, Malimuthu C. Development of micro-propagation and mini cutting protocol for fast growing Melia, Dalbergia and *Eucalyptus* clones for pulpwood and bio-energy plantations. BMC Proc. 2011; 13;5(Suppl 7):P131.
- [10] PowerPoint Presentation (brickworkratings.com). PULP AND PAPER INDUSTRY IN INDIA.
- [11] Yadav KK, Patil PB, Kumaraswamy HH, Kashyap BK. Lignolytic Microbes and Their Role in Effluent Management of Pulp and Paper Industry. In Waste to Energy: Prospects and Applications; Kashyap, B.K., Solanki, M.K., Kamboj, D.V., Pandey, A.K., Eds.; Springer Singapore: Singapore, 2020; pp. 309–350.
- [12] Gupta PK, Joshi G, Rana V, Rawat JS, Sharma A. Utilization of Pine needles for preparation of Sheets for Application as Internal Packaging Material. *Indian Forester*. 2020; 146(6): 538–543.
- [13] **Bisht AS**, Singh S, Kumar SR. . Pine Needles A Source Of Energy For Himalayan Region. International Journal of Scientific & Technology Research. 2014; 3(12):161-164.
- [14] Basu S, Malik S, Joshi G, Gupta PK, Rana V. Utilization of bio-polymeric additives for a sustainable production strategy in pulp and paper manufacturing: A comprehensive review. Carbohydrate Polymer Technologies and Applications. 2021; 2: 100050.
- [15] Malik S, Rana V, Joshi G, Gupta PK, Ashish Sharma A. Valorization of Wheat Straw for the Paper Industry: Pre-extraction of Reducing Sugars and Its Effect on Pulping and Papermaking Properties. ACS Omega. 2020; 5(47): 30704. 10.1021/acsomega.0c04883.
- [16] Gupta PK, Ajay Thakur A, Gupta S, Bala N, Rana V, Joshi G, Singh J, Rawat, Rakesh Prakash R. PINEPEAT from *Pinus roxburghii* (Chir Pine) foliage. Waste Management Bulletin. 2024; 2: 2: 140-152.

- [17] Saravanan V, Parthiban KT, Kumar P, Marimuthu P. Wood characterization studies on *Melia dubia* cav. for pulp and paper industries at different age gradation. Res J Recent Sci. 2013; 2277:2502.
- [18] Unnikrishnan B, Gurumurthy DS. Progress on genetic modifications of pulp wood tree species relevance to India—A review. Agric Rev. 2015;36(4):265-276.
- [19] Sarwar Jahan M, Sarkar M, Quaiyyum MA. Pulping of gamari roots (*Gmelina arborea*). J Indian Acad Wood Sci. 2018; 15(1):28-32.
- [20] Chavan SB, Vishnu R, Kumar N, Kumar D, Sirohi C, Handa AK. *Melia dubia* An indigenous tree species for industrial agroforestry in India. Indian Farming. 2021; 71(6):7-11.
- [21] Chowdhury Q, Ishiguri F, Iizuka K, Hiraiwa T, Matsumoto K, Takashima Y, Yoshizawa N. Wood property variation in *Acacia auriculiformis* growing in Bangladesh. Wood Fiber Sci. 2009; 41(4):359-365.
- [22] Kant P, Nautiyal R. India timber supply and demand 2010–2030. Inter Trop Timber Org, Yokohama. 2021; 49-60
- [23] Goswami M, Bhagta S, Sharma D. *Melia dubia* and its importance: A Review. Int J Eco Plant. 2020; 7(1):029-033.
- [24] Gupta S, Singh CP, Kishan-Kumar VS, Shukla S. Machining properties of *Melia dubia* wood. Maderas, Cienc Tecnol. 2019; 21(ahead):0-0.
- [25] Dhaka RK, Gunaga RP, Sinha SK, Thakur NS, Dobriyal MJ. Influence of tree height and diameter on wood basic density, cellulose and fibre characteristics in *Melia dubia* Cav. families. J Indian Acad Wood Sci. 2020; 17(2):138-144.
- [26] Kadam KL, Forrest LH, Jacobson WA. Rice straw as a lignocellulosic resource: Collection, processing, transportation, and environmental aspects. Biomass Bioenergy. 2000; 18: 369–389.
- [27] Stratton SC, Gleadow PL, Johnson AP. Pulp mill process closure: A review of global technology developments and mill experiences in the 1990s. Water Sci. Technol. 2004; 50: 183–194.
- [28] Gopal PM, Sivaram NM, Barik D. Chapter 7-Paper Industry Wastes and Energy Generation From Wastes. In Energy from Toxic Organic Waste for Heat and Power Generation; Barik, D., Ed.; Wood head Publishing: Sawston, UK, 2019; pp. 83–97.
- [29] Bajpai P. Biological Bleaching of Chemical Pulps. Crit. Rev. Biotechnol. 2004; 24: 1–58.
- [30] Abd El-Sayed ES, El-Sakhawy M, El-Sakhawy MAM. Non-wood fibers as raw material for pulp and paper industry. Nord. Pulp Pap. Res. J. 2020; 35: 215–230.
- [31] Sharma N, Tripathi SK, Bhardwaj NK. Utilization of sarkanda for making pulp and paper using elemental chlorine free and total chlorine free bleaching processes. Ind. Crops Prod. 2020; 149: 112316.
- [32] Singh SC, Murthy ZVP. Study of cellulosic fibers morphological features and their modifications using hemicelluloses. Cellulose. 2017; 24: 3119–3130.
- [33] Tripathi SK, Alam I, Bhardwaj NK. Effect of bark content in mixed hardwood chips on pulp and papermaking properties. Nord. Pulp Pap. Res. J. 2020; 35: 325–331.
- [34] Yusuf S, Syamani FA, Fatriasari W, Subyakto. Review on Bamboo Utilization as Biocomposites, Pulp and Bioenergy. IOP Conf. Ser. Earth Environ. Sci. 2018; 141: 12039.
- [35] Gupta R, Lee YY. Pretreatment of corn stover and hybrid poplar by sodium hydroxide and hydrogen peroxide. Biotechnol. Prog. 2010; 26: 1180–1186.
- [36] Nagpal R, Bhardwaj NK, Mishra OP, Mahajan R. Cleaner bio-pulping approach for the production of better strength rice straw paper. J. Clean. Prod. 2021; 318: 128539.
- [37] Bajpai P. Application of enzymes in the pulp and paper industry. Biotechnol. Prog. 1999; 15:147–157.
- [38] Kaur D, Bhardwaj NK, Lohchab RK. Effect of incorporation of ozone prior to ECF bleaching on pulp, paper and effluent quality. J. Environ. Manag. 2019; 236: 134–145.
- [39] Malik S, Rana V, Joshi G, Gupta PK, Sharma A. Valorization of Wheat Straw for the Paper Industry: Pre-extraction of Reducing Sugars and Its Effect on Pulping and Papermaking Properties. ACS Omega. 2020; 5: 30704–30715.
- [40] Santiago AS, Neto CP. Assessment of potential approaches to improve *Eucalyptus globulus* kraft pulping yield. J. Chem. Technol. Biotechnol. 2007; 82: 424–430.

- [41] Gomide JL, Fantuzzi Net, H, Regazzi AJRÁ. Analysis of wood quality criteria of eucalyptus wood for kraft pulp production. Rev. Árvore. 2010; 34: 339–344.
- [42] Pokhrel D, Viraraghavan T. Treatment of pulp and paper mill wastewater—A review. Sci. Total Environ. 2004; 333: 37–58.
- [43] Gonzalo A, Bimbela F, Sánchez J, Labidi J, Marín F, Arauzo J. Evaluation of different agricultural residues as raw materials for pulp and paper production using a semichemical process. J. Clean. Prod. 2017; 156: 184–193.
- [44] Mboowa D. A review of the traditional pulping methods and the recent improvements in the pulping processes. Biomass Convers. Biorefinery. 2021
- [45] Saeed HA, Liu Y, Chen H, Lucia L.A. Suitable approach using agricultural residues for pulp and paper manufacturing. Nord. Pulp Pap. Res. J. 2017; 32,: 674–682.
- [46] Rudi H, Resalati H, Eshkiki RB, Kermanian H. Sunflower stalk neutral sulfite semi-chemical pulp: An alternative fiber source for production of fluting paper. J. Clean. Prod. 2016; 127: 562–566.
- [47] Deykun I, Halysh V, Barbash V. Rapeseed straw as an alternative for pulping and papermaking. Cellul. Chem. Technol. 2018; 52: 833–839.
- [48] Deniz'I, Kırıcı H, Ates S. Optimisation of wheat straw *Triticum durum* kraft pulping. Ind. Crops Prod. 2004; 19:237–243.
- [49] Ferdous T, Ni Y, Quaiyyum MA, Uddin MN, Jahan MS. Non-Wood Fibers: Relationships of Fiber Properties with Pulp Properties. ACS Omega 2021; 6: 21613–21622.
- [50] Ekhuemelo DO, Tor K. Assessment of fibre characteristics and suitability of maize husk and stalk for pulp and paper production. J. Res. For. Wildl. Environ. 2013; 5, 41–49.
- [51] Tsalagkas D. et al., A Comparative Fiber Morphological Analysis of Major Agricultural Residues (Used or Investigated) as Feedstock in the Pulp and Paper Industry. BioResources. 2021; 16: 7935–7952.
- [52] Main NM. et al., Suitability of Coir Fibers as Pulp and Paper. Agric. Agric. Sci. Procedia. 2014; 2: 304–311
- [53] Yousefi H. Canola straw as a bio-waste resource for medium density fiberboard (MDF) manufacture. Waste Manag. 2009; 29: 2644–2648.
- [54] Samariha A, Khakifirooz AJB. Application of NSSC pulping to sugarcane bagasse. BioResources 2011; 6: 3313–3323.
- [55] Ogunsile BO, Oladeji TG. Utilization of banana stalk fiber as reinforcement in low density polyethylene composite. Matéria (Rio De Jan.). 2016; 21: 953–963.
- [56] Abd El-Sayed ES, El-Sakhawy M, El-Sakhawy MA.M. Non-wood fibers as raw material for pulp and paper industry. Nord. Pulp Pap. Res. J. 2020; 35: 215–230.
- [57] Ghosh UK. Short sequence environmental friendly bleaching of wheat straw pulp. J. Sci. Ind. Res. 2006; 65: 68–71. 20.
- [58] Gangwar AK, Prakash NT, Prakash R. Applicability of microbial xylanases in paper pulp bleaching: A review. BioResources 2014; 9: 3733–3754.
- [59] Walia A, Guleria S, Mehta P, Chauhan A, Parkash J. Microbial xylanases and their industrial application in pulp and paper bio-bleaching: A review. 3 Biotech. 2017; 7: 11.
- [60] Sharma N, Bhardwaj NK, Singh RBP. Environmental issues of pulp bleaching and prospects of peracetic acid pulp bleaching: A review. J. Clean. Prod. 2020; 256,:120338.
- [61] Ali M, Sreekrishnan TR. Aquatic toxicity from pulp and paper mill effluents: A review. Adv. Environ. Res. 2001; 5: 175–196.
- [62] Pan GX, Leary GJ. The bleachability of wheat straw alkaline peroxide mechanical pulp. Cellul. Chem. Technol. 2000; 34: 537–547.
- [63] Laftah WA, Wan Abdul Rahman WA. Pulping Process and the Potential of Using Non-Wood Pineapple Leaves Fiber for Pulp and Paper Production: A Review. J. Nat. Fibers. 2016; 13: 85–102.
- [64] Jiménez L, Rodríguez A, Pérez A, Moral A, Serrano L. Alternative raw materials and pulping process using clean technologies. Ind. Crops Prod. 2008; 28: 11–16.

- [65] Mazhari Mousavi SM, Hosseini SZ, Resalati H, Mahdavi S, Rasooly Garmaroody E. Papermaking potential of rapeseed straw, a new agricultural-based fiber source. J. Clean. Prod. 2013; 52: 420–424.
- [66] Zhong L, Huimei W, Lanfeng H. Pulping and Papermaking of Non-Wood Fibers. In Pulp and Paper Processing; Salim Newaz, K., Ed.; IntechOpen: Rijeka, Croatia, 2018; p. Ch. 1.
- [67] Danielewicz D. Industrial Hemp as a Potential Nonwood Source of Fibres for European Industrial-Scale Papermaking-A Review. Materials (Basel). 2023 4;16(19):6548. doi: 10.3390/ma16196548. PMID: 37834685.
- [68] Crini G. et al., Applications of hemp in textiles, paper industry, insulation and building materials, horticulture, animal nutrition, food and beverages, nutraceuticals, cosmetics and hygiene, medicine, agro-chemistry, energy production and environment: A review. Environmental Chemistry Letters. 2020; 18:1451–1476 <https://doi.org/10.1007/s10311-020-01029-2>.
- [69] **Malabadi RB**, Raghavendra S. Biobleaching of kraptp pulp with cellulase-free xylanase isolated from novel yeast strain. National seminar on role of microbes in environmental protection and rural development. October 23-25. 1998 North-Eastern-Hill-University and International society for conservation and natural. Vol-1, N0-1 page-35.
- [70] **Malabadi RB**, Raghavendra S, Vijaykumar S. Production of cellulase free xylanase from a novel yeast strain used for bio-bleaching in paper industry. Research Journal of Microbiology. 2007; 2(1):24-33.
- [71] Mahmud A, Anannya FR. Sugarcane bagasse - A source of cellulosic fiber for diverse applications. Heliyon. 2021; 7. e07771.
- [72] Ahmed S, Saeed R, Khan A. Sustainable utilization of agricultural residues for pulp and paper industry. Journal of Cleaner Production. 2019; 235: 1234-1241.
- [73] Mustapha A. Sustainable Paper Production from Sugarcane Bagasse: An Innovative Approach to Mitigate Wood Fibre Dependence and Promote Eco-friendly Alternatives. : Glob. J. Environ. Sci. Technol. 2024;12(10):144-148. ISSN: 2384-5058.
- [74] Sharma D, Agrawal S, Nagpal R, Mishra OP, Bhardwaj N, Mahajan R. Production of eco-friendly and better-quality sugarcane bagasse paper using crude xylanase and pectinase biopulping strategy. 3 Biotech. 2023;13(2):61.
- [75] Sangule OT. Preparation And Characterization Of Eco-Friendly Handmade Paper From Banana Fibers. International Journal of Creative Research Thoughts (IJCRT). 2022; 10: 461-467. ISSN: 2320-2882
- [76] Hemalatha P, Srikumar TS. Utilization of banana pseudo stem fibre in handmade paper production: A sustainable approach. International Journal of Engineering and Advanced Technology (IJEAT). 2020; 9(3): 1154–1158.
- [77] Basri NEA, Samsudin MS, Ahmad M.Z. Reusing agricultural waste for pulp and paper production: Characteristics of banana fibre. Journal of Cleaner Production. 2019; 224: 394–402.
- [78] Vigneswari S, Ramesh R, Ramachandran T. Studies on banana fiber reinforced handmade paper for eco-friendly applications. Cellulose Chemistry and Technology. 2016;50(9–10), 1059–1065.
- [79] Dutt D, Upadhyaya JS, Tyagi CH. Comparative study of various agro residues for pulp and paper making. BioResources. 2009; 4(4): 1510–1529.
- [80] Kumar S, Sharma M. Utilization of banana fiber as a sustainable raw material for paper production. Journal of Natural Fibers. 2019; 16(2): 154–164.
- [81] Singh R, Singh AK. Chemical pulping and bleaching of agricultural residues for papermaking. Bioresources, 13(4):125–9140.
- [82] Pandiselvam R et al., Development and characterization of gelatinized starch doped microcellulose paper from tender coconut (*Cocos nucifera* L) husk. Process Safety and Environmental Protection. 2024; 10.1016/j.psep.2024.02.015.
- [83] Kusriani E. et al., Synthesis of Biodegradable Tissue Paper Comprised of Cellulose Isolated from Rice Straw Waste and Chitosan: Characterizations and The Effect of Chitosan Concentrations. EVERGREEN - Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy. 2025; 12: 02. 863-872.
- [84] Chollakup R, Kongtud W, Sukatta U, Premchookiat M, Piriyaatits K, Nimitkeatkai H, Jarerat A. Eco-Friendly Rice Straw Paper Coated with Longan (*Dimocarpus longan*) Peel Extract as Bio-Based and Antibacterial Packaging. Polymers. 2021; 13: 3096.
- [85] Shi M, Ma Z, Tian Y, Zhang X, Shan H. Effects of maize straw treated with various levels of CaO and moisture on composition, structure, and digestion by in vitro gas production. Anim Biosci. 2021;34(12):1940-1950.

- [86] Parameswaran I et al., Development of Sustainable Paper, Drinking Straw and Plate Using Zea mays Husk. Research Square. 2026. DOI: <https://doi.org/10.21203/rs.3.rs-8157514/v1>.
- [87] Hailemariam, T.T., Woldeyes, B. Production and characterization of pulp and paper from flax straw. *Sci Rep.* 2024; **14**, 24300.
- [88] Tyohemba R L et al., Agricultural Waste Utilization for the Production of Paper-Bags: A Potential Substitute for Plastics Bags in Food Packaging. Nile Journal of Engineering and Applied Science. 2025; 2(2)L DOI: <https://doi.org/10.5455/NJEAS.227181>.
- [89] Johar N, Ahmad I, Dufresne A. Extraction, preparation and characterization of cellulose fibres and nanocrystals from rice husk. *Industrial Crops and Products*. 2012; 37 (1): 93 – 99.
- [90] Kadam KL, Forrest LH, Jacobson WA. Rice straw as a lignocellulosic resource: collection, processing, transportation, and environmental aspects. *Biomass and Bioenergy*. 2000; 18 (5). 369 – 389.
- [91] Kalia S, Kaith BS, Kaur I. (Eds.). Cellulose fibers: bio-and nano-polymer composites: green chemistry and technology. Springer Science & Business Media. 2011.
- [92] Singh R, Sharma A, Rana R. Non-wood fibers in the paper industry: Challenges and opportunities. *Advances in Materials Science*. 2018.
- [93] Rousu P, Rousu P, Anttila J. Sustainable pulp production from agricultural waste. *Resources, Conservation and Recycling*. 2002; 35(1-2) 85 – 103.
- [94] Çiçekler M, Özdemir A, Tutuş A. Characterization of pulp and paper properties produced from okra (*Abelmoschus esculentus*) stalks. *Drvna Industrija*. 2022; 73: 423-430.
- [95] Jain P, Gupta C. A sustainable journey of handmade paper from past to present: A review. *Probl. Sustainable Dev.* 2021; 16: 234-244.
- [96] Alam M, Rikta SY, Bahauddin KM, Hasnine T, Ibne Kamal AK. Production of eco-friendly handmade paper from wastepaper and other local biomass material. *Acad. J. Environ. Sci.* 2018; 6: 147-155.
- [97] Reddy KO, Maheswari CU, Shukla M, E. Muzenda E. Preparation, chemical composition, characterization, and properties of Napier grass paper sheets. *Sep. Sci. Technol.* 2014; 49: 1527-1534.
- [98] Arafat KMY, Nayeem J, Quadery AH, Quaiyyum MA, Jahan MS. Handmade paper from waste banana fibre. *Bangladesh J. Sci. Ind. Res.* 2018; 53: 83-88
- [99] Sottile FA. et al., Hand-made paper obtained by green procedure of cladode waste of *Opuntia ficus indica* (L.) Mill. from Sicily. *Nat. Prod. Res.* 2021; 35: 359-368.
- [100] Rajesh Y, Shivde P, Daware G, Mane V, Mawal V, S. Derle S. Synthesis of handmade craft-paper from agricultural waste. *Indian J. Chem. Technol.* 2024; 31: 546-552.
- [101] Ng GT, CK Ng. Development of natural bio-plantation waste as pulp for paper making. *Adv. Mater. Res.* 2014; 1043: 209-213.
- [102] Palwan E, Debbarma S, Chaudhuri SR. Agro-waste Valorization Through Handmade Papermaking: A Sustainable Alternative Livelihood Approach. *Trends Agric. Sci.* 2025; 4 (2): 163-169.
- [103] Vince Ryan G. et al., Converting Paper Waste And Agricultural Fibers To Salvaged Paper Products. *International Journal of Academic Multidisciplinary Research (IJAMR)*. 2025; 9:5: 119-12. ISSN: 2643-9670.