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Exploring Alternate Fibrous Raw Materials in Southern India: Oil Palm EFB fiber, Coir Husk and Areca Nut Husk for Pulp, Paper and Board Making

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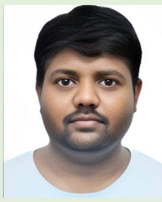

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Abstract: *The increasing pressure on forest resources and the growing emphasis on sustainable manufacturing have intensified interest in non-wood lignocellulosic residues for pulp and paper production. Empty Fruit Bunch (EFB), an abundant by-product of the palm oil industry, has emerged as a potential alternative raw material due to its wide availability and acceptable fibre characteristics. After the removal of fruits from Fresh Fruit Bunches (FFB), EFB remains as a solid lignocellulosic residue. EFB constitutes approximately 20–22% of the weight of Fresh Fruit Bunches, and for every ton of crude palm oil produced, about 1.0–1.2 ton of EFB is generated.*

In addition to EFB fibre, coir husk and areca nut husk are two other promising agro-residual resources that can be utilized for pulp and paper production. In India, the southern states of Andhra Pradesh, Telangana, Tamil Nadu, and Karnataka have abundant availability of EFB fibre, coir husk, and areca nut husk; however, their papermaking potential remains largely underexplored.

The present communication provides an overview of recent developments in the pulping and bleaching of these three raw materials for paper and paperboard applications. Chemical and Chemi-thermomechanical pulping (CTMP) processes for these materials are discussed with respect to pulp yield, delignification efficiency, and fibre quality. Attention is given to the challenges associated with high ash and silica content in EFB fibre, coir husk, and areca nut husk. Process modifications adopted to overcome these limitations are also discussed. The substantial potential of EFB, areca nut husk, and coir husk pulps for partial substitution of wood-based pulps is highlighted, and future research directions for cleaner processing and industrial-scale implementation are identified in this paper.

Keywords: *EFB fibre, Coir husk,Areca nut husk, kraft pulping, Chemi-mechanical Pulping.*

Introduction

Paper demand in India is growing steadily at about 6–7% every year. This growth is driven by increasing literacy, expansion of organized retail, growth in e-commerce, rising healthcare needs, eco-friendly packaging, and overall economic development. At present, paper consumption in India is quite low compared to the rest of the world. The average Indian consumes about 16 kg of paper per year, while the global average is around 57 kg, and in developed countries it exceeds 200 kg. However, packaging paper and paperboard are the fastest-growing segments of the industry. Demand is rising due to better packaging requirements for FMCG products, pharmaceuticals, textiles, ready-to-eat foods, and the ban on single-use plastics. Writing and printing paper demand is supported by government focus on education, literacy, and quality stationery.

Agroforestry is a major strength of India's paper industry. More than 90% of the wood used by paper mills comes from trees grown by farmers under industry-supported plantation programs. Around 5 lakh farmers are involved in growing these trees, covering about 1.2 million hectares across the country. This has helped generate rural employment, increase farmer income, improve green cover, and support carbon sequestration.

Despite these efforts, raw material scarcity remains a major challenge. India is a fibre-deficient country. About 75% of paper produced in India uses recycled fibre, but fresh fibre from wood and agro-residues is still essential because recycled fibre loses strength after repeated use.

Overall, the Indian paper industry has strong growth potential, deep rural linkages, and environmental benefits. With the right policy support and raw material availability, it can become more competitive globally, reduce imports, support farmers, create jobs, and contribute significantly to India's goal of self-reliance and sustainable development. [1-3]

Considering these facts, the present study focuses on evaluating alternative fibre sources that are abundantly available in the southern part of India and can contribute to meeting the growing demand for cellulosic fibres for different grades of pulp and paper. Empty Fruit Bunch (EFB) fibre, coir fibre, and areca nut husk are three such potential raw materials that can be converted into pulp, paper, paperboard, and other value-added products, rather than being disposed of through incineration. Their utilization in pulp, paper, and board production also supports the principles of a circular economy by promoting efficient resource use and sustainable end-of-life management.

EFB fibre

As a promising feedstock for pulp and paper industry, oil palm empty fruit bunch (EFB) has emerged as a raw material among various non-wood biomass. EFB has been collected as a by-product of palm oil industry in huge quantity, especially in countries across Southeast Asia, Africa, and parts of South Asia. It has been found that one tonne of fresh fruit yields around 0.22 tons of EFB. EFB is now available as raw fibre material for making paper-based products due to the growth of the oil palm sector. EFB is a lignocellulosic substance made mostly of cellulose, hemicellulose, and lignin. Prior research indicated that the cellulose percentage in EFB was estimated to be around 30–50%, with hemicellulose and lignin amounts ranging from 15–35% and 20–30%, respectively [6]. However, lignin from EFB has yet to be separated, and its structural characteristics remain undefined. EFB has high ash and silica content, heterogeneous fibre morphology, and recalcitrant lignin structure pose significant challenges during pulping and chemical recovery. Over the past two decades, extensive research has been conducted on chemical, chemo-mechanical, and organosolv pulping of EFB to improve delignification efficiency and pulp quality while minimizing environmental impact.

Empty Fruit Bunches (EFB) are the fibrous residues left after the removal of palm fruits from fresh fruit bunches during palm oil processing. It is versatile in nature and can be processed into fibres, pellets, or briquettes, or alternatively used as mulch, compost, boiler fuel, and in various industrial applications such as composite materials, mattresses, and erosion-control mats.

In India, EFB production is closely linked to the country's relatively small but gradually expanding oil palm cultivation and processing sector. Oil palm plantations are mainly concentrated in states such as Andhra Pradesh, Telangana, and Kerala, with further development being promoted under the National Mission on Edible Oils – Oil Palm. As palm cultivation increases, EFB generation is expected to rise correspondingly over time. At present, Oil Palm India Ltd., a government joint-venture enterprise, reports the generation of approximately 8,000 metric ton of EFB annually from its mill operations, indicating that local availability exists, although on a modest scale. In general on Annual basis availability of EFB fibre is 0.6-0.9 million tons per year.

Currently, EFB is generated only in locations where palm oil processing facilities are operational. Unlike major palm oil–producing countries such as Malaysia and Indonesia, India's overall EFB output remains limited due to comparatively low domestic crude palm oil production. As a result, India does not yet have a well-developed or structured industrial supply chain for EFB fibre similar to that in Southeast Asia. Consequently, industries requiring processed EFB fibre for manufacturing, composites, or other applications often depend on imports from larger producing countries or on small and localized domestic sources.

The availability of EFB fibre is further influenced by its competing uses. Palm oil mills frequently utilize EFB internally for purposes such as biomass energy generation, composting, mulching, or soil conditioning, rather than selling it in the open market. EFB-derived materials are also used for biofuel applications, organic soil amendments, natural fibre reinforcement, mattresses, erosion-control products, and emerging bioproducts and composites, although large-scale industrial extraction and processing of EFB fibre in India is still limited. Because of this on-site utilization, free-market availability of EFB fibre is restricted unless it is specifically processed, baled, or marketed by third-party operators.

Sourcing EFB fibre in India typically involves direct engagement with palm oil mills or cooperatives, particularly in Andhra Pradesh, Telangana, and Kerala, which generate EFB and may be willing to sell it in raw or partially processed form. Another viable route is participation in industrial tenders or auctions, such as those periodically issued by Oil Palm India Ltd. for the sale of EFB or fibre, which can provide recurring supply opportunities. In cases where domestic availability is insufficient, many Indian users opt to import processed EFB fibre, pellets, or related products from Southeast Asian suppliers through established B2B trade channels. [4-6]

Coir fibre/husk

Coir fibre, obtained from coconut husk, is abundantly available in India, particularly in states such as Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh. Despite this wide availability, it remains largely underutilized in papermaking and is predominantly consumed in traditional applications such as mats, ropes, and other coir-based products.

From a fibre perspective, coir is characterized by a fibre length ranging from 1-6 mm, making it very coarse in nature. It contains a very high lignin content of about 40–45% and comparatively low cellulose content of around 35–40%. The fibres are highly stiff and elastic, which adversely affects fibre bonding during papermaking.

Due to these characteristics, coir fibre is difficult to pulp using conventional pulping methods. However, it can be processed using modified approaches such as soda–AQ pulping with a high alkali charge or steam explosion followed by chemical pulping. Bleaching of coir pulp is challenging and requires intensive chemical consumption because of its high lignin content and poor bleachability.

In papermaking, coir pulp exhibits very high tear strength but suffers from poor inter-fibre bonding, resulting in low tensile strength and a rough paper surface. Consequently, its applications are largely limited to specialty and niche products such as specialty packaging, industrial boards, handmade papers, molded products, and as a minor component in composite pulp blends, typically up to 20%. The availability of coir husk in India is 8-9 million ton per year while coir fibre is ~0.8 million tons per year

The major challenges associated with coir fibre utilization include high chemical consumption, low pulp yield, dark pulp colour, and poor bleaching response. Overall, coir fibre shows moderate potential for papermaking, primarily confined to niche and specialty applications rather than large-scale conventional paper production. [7-11]

Areca nut husk

Areca nut shell fibre, also referred to as areca nut husk or shell fibre, is a by-product generated during areca nut processing and is mainly available in states such as Karnataka, Kerala, Assam, and other North-Eastern regions of India. At present, this material is largely underutilized and is often wasted or burned, despite its potential value as a fibrous raw material for papermaking. In India Areca nut husk availability is 0.6-1.3 million tons per year.

In terms of fibre characteristics, areca nut shell fibre has a fibre length in the range of 0.8 to 1.5 mm. It contains a moderate level of cellulose, approximately 45–50%, with lignin content of about 20–25%. The fibre is relatively clean and contains low silica, which is advantageous for chemical recovery and equipment life in pulp mills.

From a pulping and papermaking perspective, areca nut shell fibre is suitable for conventional chemical pulping processes such as soda or soda-AQ pulping, as well as Kraft pulping under mild operating conditions. Its bleachability is better than that of coir fibre and is comparable to other agro-residues, allowing the production of pulp with acceptable brightness. Paper made from this fibre exhibits good tensile strength, moderate tear strength and satisfactory optical properties after bleaching.

Owing to these properties, areca nut shell fibre pulp can be utilized in blended form for writing and printing papers, packaging papers, paperboard, and specialty handmade paper products. However, certain challenges remain, including efficient collection and preprocessing of the raw material, limited experience at large industrial scale, and the need for standardization of fibre preparation and processing parameters to ensure consistent pulp quality. [12-13]

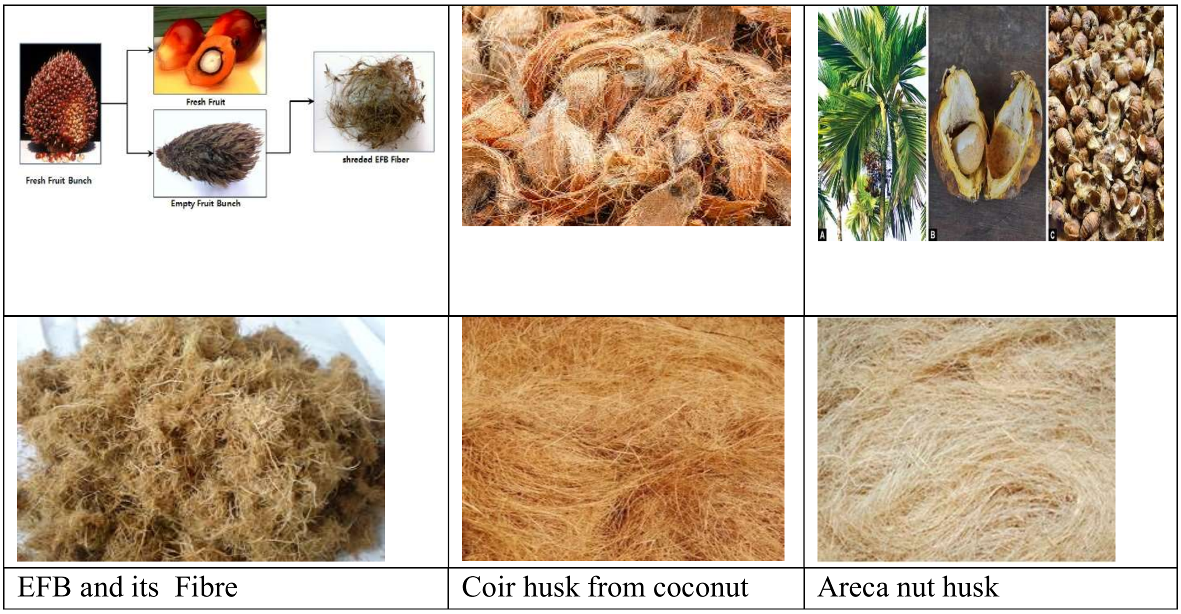

Fig. 1 The EFB, Coir husk and Areca nut husk Fibre

Findings of work carried out at CPPRI Saharanpur

The research activities were carried out on several alternate fibrous raw materials during past few years. EFB, Coir husk and Areca nut husk are a few of these. The fig 1 is showing the source of EFB,coir and areca nut fibres.

Table 1: Proximate Chemical Analysis of Different Cellulosic Raw Materials

S. No.	Parameter	Unit	EFB Fibre	Coir husk as such	Coir husk (wet cleaned)	Areca nut husk	Wheat straw	Eucalyptus
1	Cold water solubility	%	5.84	8.0	7.0	6.8	8.01	1.11
2	Hot water solubility	%	8.73	11.0	10.1	10.1	11.20	4.26
3	1/10 N NaOH solubility	%	30.0	22.0	20.0	29.9	36.5	16.0
4	Alcohol benzene solubility	%	8.32	2.90	3.5	4.0	3.50	3.90
5	Ash content	%	5.86	4.32	3.50	8.49	4.84	0.32
6	Acid insoluble lignin content	%	22.7	31.8	32.0	30.50	15.0	31.0
7	Holo cellulose	%	75.1	71.2	72.5	63.80	68.2	71.1
8	Pentosan Content	%	23.2	12.8	13.0		22.2	18.0

The chemical composition of the selected fibrous raw materials EFB fibre, coir husk (as such and wet cleaned), areca nut husk, wheat straw, and eucalyptus was evaluated to understand their suitability for pulp and paper production. The results clearly highlight the differences between non-wood fibres and conventional raw materials as depicted in Table 1.

Water solubility, both cold and hot, is an indicator of the presence of low-molecular-weight extractives, sugars, and other soluble components. Coir husk and wheat straw showed the highest cold and hot water solubility values, indicating a higher proportion of water-soluble materials that may contribute to yield loss during pulping. EFB fibre and areca nut husk exhibited moderate water solubility, while eucalyptus showed very low value, reflecting its cleaner nature and better suitability for chemical pulping.

1/10 N NaOH solubility, which reflects the presence of degraded cellulose, hemicelluloses, and other alkali-soluble components, was highest for wheat straw (36.5%) and EFB fibre (30.0%), followed closely by areca nut husk (29.9%). These high values suggest higher chemical consumption and lower pulp yield during alkaline pulping. In contrast, eucalyptus showed the lowest alkali solubility (16.0%), indicating better fibre stability. Wet cleaning of coir husk reduced alkali solubility from 22.0% to 20.0%, demonstrating the benefit of preprocessing in removing easily soluble components.

Alcohol–benzene solubility, which represents the content of waxes, fats, resins, and other extractives, was highest in EFB fibre (8.32%), suggesting the presence of significant non-polar extractives that may interfere with pulping and bleaching operations. Other agro-residues and eucalyptus showed relatively lower and comparable values, indicating fewer extractive-related processing challenges.

Ash content, an important parameter affecting chemical recovery and equipment scaling, was significantly higher in areca nut husk (8.49%) and EFB fibre (5.86%) compared to eucalyptus (0.32%). Wet cleaning of coir husk reduced ash content from 4.32% to 3.50%, again highlighting the effectiveness of preprocessing.

Acid-insoluble lignin content was highest in coir husk (both as such and wet cleaned) and eucalyptus, reflecting their more rigid and lignin-rich structure. Areca nut husk also showed high lignin content (30.5%). In contrast, EFB fibre and wheat straw had comparatively lower lignin contents, suggesting easier delignification and potentially milder pulping conditions.

Holocellulose content, which represents the total carbohydrate fraction and is directly related to pulp yield potential, was highest for EFB fibre (75.1%), followed by coir husk and eucalyptus. Areca nut husk showed the lowest holocellulose content (63.8%), indicating comparatively lower pulp yield potential. These results suggest that EFB fibre has good potential as a pulp raw material from a carbohydrate perspective. Pentosan content, representing hemicelluloses, was highest in EFB fibre (23.2%) and wheat straw (22.2%), indicating better fibre flexibility and bonding potential in paper. Coir husk showed low pentosan content, which may contribute to poorer fibre bonding and lower paper strength properties.

Overall, the results indicate that EFB fibre and areca nut husk show promising characteristics as alternative non-wood raw materials for pulp and paper production, though they require appropriate preprocessing to manage extractives and ash. Coir husk, despite high lignin content and lower pentosan levels, may be more suitable for niche applications or blended pulps. Wheat straw exhibits good carbohydrate content but high alkali solubility, suggesting careful control of pulping conditions. Eucalyptus, as expected, demonstrates the most balanced and favorable chemical composition, serving as a benchmark for comparison with alternative fibre sources.

The Pulping of EFB Fibre, Coir husk and Areca nut husk

Table 2: Result of Kraft Pulping of EFB Fibre, Coir Husk and Areca Nut Husk

Sr. No	Parameters	Unit	EFB fibre	Coir husk	Areca nut husk
1.	Active alkali charge , % (as Na_2O)	%	14	22	16
2.	Bath ratio	-	1:5	1:6	1:6
3.	Sulphidty	%	20	20	20
4.	Unscreened pulp yield	%	45.6	44.2	48.3
5.	Rejects content	%	0.2	0.2	0.3
6.	Screened pulp yield	%	45.4	44.0	48.0
7.	Pulp kappa number	-	17.5	20	21.0
8.	Unbleached pulp brightness	% (ISO)	26.8	24.0	23.0
9.	Pulp viscosity	cm^3/g	675	450	480
	Black liquor characteristics				
10.	pH	%	11.3	12	12.5
11.	Total solids	%w/w	14.3	13.8	14.2
12.	RAA as Na_2O	g/l	3.5	4.1	4.2

Cooking conditions

Ambient to 100ºC	30 min
100ºC to 165ºC/160ºC	90 min
At 165 ºC	90 min

The table 2 presents a comparative evaluation of Kraft pulping performance of three non-wood fibrous raw materials, namely EFB fibre, coir husk, and areca nut husk, under controlled laboratory conditions. The analysis focuses on pulping parameters, pulp yield and quality, and black liquor characteristics to assess their suitability for pulp and paper production.

The active alkali charge required for pulping varied significantly among the raw materials. Coir husk required the highest alkali charge (22% as Na_2O), indicating its higher lignin content and resistance to delignification. Areca nut husk required a moderate alkali charge (16%), while EFB fibre could be effectively pulped at a lower alkali charge of 14%, suggesting comparatively easier delignification. The bath ratio was maintained at 1:5 for EFB fibre and 1:6 for coir and areca nut husks, ensuring adequate liquor penetration. Sulphidity was kept constant at 20% for all three materials, enabling a fair comparison of pulping behavior.

The unscreened pulp yield ranged from 44.2% to 48.3%. Areca nut husk gave the highest unscreened yield (48.3%), followed by EFB fibre (45.6%) and coir husk (44.2%). Rejects content was low for all three materials, indicating efficient fibre separation and cooking. Coir husk and EFB fibre showed minimal rejects (0.2%), while areca nut husk showed slightly higher rejects (0.3%). After screening, the screened pulp yield followed a similar trend, with areca nut husk yielding the highest screened pulp (48.0%), EFB fibre giving 45.4%, and coir husk the lowest at 44.0%.

The kappa number, which reflects residual lignin content, was lowest for EFB fibre (17.5), indicating more effective delignification under the given conditions. Coir husk and areca nut husk exhibited higher kappa numbers of 20 and 21.0, respectively, suggesting comparatively higher residual lignin and the need for more severe pulping or bleaching. Correspondingly, the unbleached pulp brightness was highest for EFB fibre (26.8% ISO), followed by coir husk (24.0% ISO) and areca nut husk (23.0% ISO).

Pulp viscosity, an indicator of cellulose chain integrity and pulp strength potential, was significantly higher for EFB fibre (675 cm^3/g), suggesting better preservation of cellulose during pulping. Coir husk showed the lowest viscosity (450 cm^3/g), indicating greater cellulose degradation due to higher alkali charge and harsher cooking conditions. Areca nut husk exhibited moderate viscosity (480 cm^3/g), falling between EFB fibre and coir husk.

The black liquor pH values were strongly alkaline for all three raw materials, as expected in Kraft pulping. Areca nut husk produced the highest pH (12.5), followed by coir husk (12.0) and EFB fibre (11.3), reflecting differences in alkali consumption during cooking. Total solids content of black liquor was comparable across the materials, ranging from 13.8 to 14.3 g/L, indicating similar levels of dissolved organic and inorganic matter. The residual active alkali (RAA) was lowest for EFB fibre (3.5 g/L as Na_2O), suggesting more effective alkali utilization, whereas coir husk and areca nut husk showed higher residual alkali values, indicating incomplete alkali consumption and potentially lower delignification efficiency.

Overall Assessment

Among the three materials studied, EFB fibre demonstrated the most favorable pulping performance, requiring the lowest alkali charge, yielding pulp with lower kappa number, higher brightness, and significantly higher viscosity. Areca nut husk showed the highest pulp yield but required moderate alkali charge and resulted in higher kappa number and lower brightness. Coir husk, although processable, demanded the highest alkali charge and resulted in lower pulp viscosity, indicating harsher pulping conditions and greater cellulose degradation. These results suggest that EFB fibre is a promising alternative non-wood raw material for Kraft pulp production, while areca nut husk and coir husk may be better suited for blended pulps or specific paper and board grades after process optimization.

Table 3: Physical Strength Properties of Unbleached Pulp

S. No.	Properties	Unbleached EFB fibre pulp	Coir husk	Areca nut husk	Unbleached Eucalyptus pulp
1	Freeness, ml CSF	390	340	390	330
2	Burst index (kPa.m^2/g)	2.82	2.28	2.17	3.30
4	Tear index (mN.m^2/g)	8.28	6.86	7.82	5.29
5	Tensile index (N m/g)	46.2	35.33	33.32	55.62

The physical strength properties of unbleached pulps derived from EFB fibre, coir husk, areca nut husk, and eucalyptus were evaluated and compared (Table 3). The freeness values indicate that EFB and areca nut husk pulps (390 ml CSF) exhibit relatively higher drainage rates than coir husk (340 ml CSF) and are comparable to eucalyptus pulp (330 ml CSF), suggesting acceptable beatability characteristics for papermaking.

In terms of strength properties, unbleached eucalyptus pulp showed the highest burst index (3.30 kPa·m²/g) and tensile index (55.62 N·m/g), reflecting its well-known superior fibre bonding ability. Among the non-wood fibres, EFB pulp demonstrated comparatively better strength performance with a burst index of 2.82 kPa·m²/g and tensile index of 46.2 N·m/g, indicating good inter-fibre bonding and load-bearing capacity. Coir husk and areca nut husk pulps exhibited lower burst and tensile indices, which may be attributed to their coarser fibre morphology and lower bonding potential.

High yield Pulping of Areca Nut Husk for Board Making

However, the tear index results reveal a contrasting trend. EFB pulp showed the highest tear index (8.28 mN·m²/g), followed by areca nut husk (7.82 mN·m²/g) and coir husk (6.86 mN·m²/g), while eucalyptus pulp recorded the lowest tear index (5.29 mN·m²/g). This indicates that non-wood fibres, particularly EFB and areca nut husk, possess longer or coarser fibres that contribute positively to tear resistance.

Overall, the results suggest that EFB fibre pulp exhibits a balanced combination of strength properties, with tear strength superior to eucalyptus and tensile and burst strengths reasonably close to hardwood pulp. Coir husk and areca nut husk pulps, although lower in bonding-related properties, show potential for use in blends with wood pulps or for products where higher tear strength is desirable. These findings support the suitability of EFB fibre as a promising alternative non-wood raw material for pulp and paper applications.

Table 4. Chemi-mechanical Pulping of Areca Nut Husk

S. No.	Parameters	Unit			
1	O.D. weight of areca husk	gm	200	200	200
2	NaOH	%	3	2	4
3	Na_2SO_3	%	-	3	4
4	Bath ratio				
5	Temperature	^{0}C	140		
6	Time (min)		90		
7	Refining gap	µm	25,15,6		
8	Beating	min			
9	Freeness	ml (CSF)	400	410	390
10	Unscreened Pulp Yield	%	67.8	69.56	75.0

Table 5. Physical Strength Properties of CMP Pulp from Areca Nut Husk

	Physical strength properties	CSF	GSM	Burst strength (kPa)	Tensile strength (N / m)	Tear index (mN)
1	3% NaOH	400	230	0.25	5.05	2.00
2	2% NaOH, 3% Na_2SO_3	410	240	0.28	5.25	1.80
3	4% NaOH, 4% Na_2SO_3	390	230	0.70	10.70	4.20

The high yield pulp physical strength properties at Freeness values ranged from 390–410 ml CSF, indicating comparable drainage characteristics across all samples. The pulp treated with 2% NaOH + 3% Na_2SO_3 showed the highest freeness (410 ml CSF), suggesting slightly faster drainage, while the 4% NaOH + 4% Na_2SO_3 treatment resulted in marginally lower freeness (390 ml CSF), likely due to increased fibre swelling and fibrillation caused by higher chemical charge (Table 4).

GSM values were similar (230–240 g/m²), indicating that differences in strength properties are primarily due to chemical treatment rather than sheet formation or basis weight variation. A clear improvement in strength properties was observed with increasing severity of chemical treatment. The 3% NaOH treatment resulted in very low burst strength (0.25 kPa), tensile strength (5.05 N/m), and tear index (2.00 mN), indicating insufficient delignification and poor fibre bonding. The addition of sodium sulphite in the 2% NaOH + 3% Na_2SO_3 system led to a slight improvement in burst (0.28 kPa) and tensile strength (5.25 N/m), although tear index marginally decreased, suggesting limited fibre development.(Table 5)

The most significant improvement was achieved with 4% NaOH + 4% Na_2SO_3, where burst strength increased sharply to 0.70 kPa, tensile strength to 10.70

N/m, and tear index to 4.20 mN. This indicates enhanced delignification, better fibre flexibility, improved inter-fibre bonding, and more effective fibre liberation under higher alkali–sulphite conditions.

Economic viability of the Utilization of EFB fibre, Coir husk and Areca nut husk

Due to limited availability the supply of these fibres for large paper units is difficult. The limited supply may support the existing unit. The small units up to 10 tpd are viable and a feasibility possibility is projected below:

Establishment of a 10 TPD Chemi-Mechanical Pulp (CMP) plant based on agro-residues such as EFB fibre, coir husk, areca nut husk, and other lignocellulosic biomass presents a technically viable and economically attractive opportunity, particularly under decentralized or cluster-based industrial models. CMP technology involves mild chemical pretreatment of fibrous raw materials followed by intensive mechanical refining, enabling high pulp yields in the range of 80–90%, significantly higher than conventional chemical pulping processes. This high yield advantage reduces raw material consumption per ton of pulp and enhances overall fibre resource efficiency, which is critical in the Indian context of wood fibre scarcity.

At a capacity of 10 TPD, the plant would produce approximately 3,000 tonnes of pulp annually, assuming 300 operating days. The raw material requirement would range between 12–15 tonnes per day depending on fibre type and yield characteristics. Agro-residues such as EFB and areca husk are particularly suitable due to their moderate lignin content and favorable refining response, while coir husk, though more lignified, can still be processed effectively for high-bulk packaging and molded fibre applications.

From a capital investment perspective, CMP plants offer a relatively low entry barrier compared to chemical pulp mills, primarily due to the absence of large-scale chemical recovery systems. The estimated capital cost for a 10 TPD CMP facility is in the range of ₹11–14 crore, including raw material preparation, impregnation systems, high-consistency refiners, screening equipment, utilities, and effluent treatment infrastructure. Land requirement is modest (2–3 acres), making such plants suitable for rural or semi-industrial locations near biomass sources.

Operating costs are driven mainly by power consumption, as mechanical refining constitutes the most energy-intensive stage. Specific energy consumption typically ranges from 900–1,200 kWh per ton of pulp. Total operating cost is estimated at ₹24,000–25,000 per ton of pulp, including raw material, power, labor, chemicals, maintenance, and overheads. Despite higher energy usage, chemical consumption remains low (1–3%), balancing overall cost structure.

Revenue realization depends on end-use markets. CMP pulp from agro-residues is well suited for corrugating medium, duplex board furnish, thermoformed packaging, and molded fibre products. Average pulp realization is estimated at ₹35,000–40,000 per ton, with higher values achievable in molded product segments. At this price level, the plant can generate annual revenues of ₹10–11 crore, yielding EBITDA (Earnings Before Interest, Taxes, Depreciation, and Amortization) margins of 25–30%.

Financial analysis indicates a payback period of approximately 3.5–4 years and an internal rate of return (IRR) in the range of 20–24%, provided plant load factor exceeds 80% and raw material supply remains stable. Break-even capacity is estimated at ~60%, indicating moderate risk resilience for small-scale investors.

From an environmental standpoint, CMP technology offers advantages such as lower effluent toxicity, minimal sulphur emissions, and reduced chemical discharge compared to Kraft pulping. Additionally, utilization of agro-residues contributes to waste valorization, reduction in open burning, and lowering of carbon footprint relative to wood-based pulp production.

In conclusion, a 10 TPD CMP plant represents a feasible and scalable model for decentralized fibre resource utilization in India. Its techno-economic viability is strongest when integrated with packaging board mills or molded fibre product units and when located within close proximity to agro-residue generation clusters. With rising demand for sustainable packaging materials, such small-scale CMP facilities hold significant potential for supporting circular bio-economy development while strengthening raw material security for the pulp and paper sector.

Conclusions

The present study clearly demonstrates that alternative non-wood fibrous raw materials such as EFB fibre, areca nut husk, and coir husk have significant potential to partially bridge India's growing fibre deficit in the pulp and paper industry. Among the materials evaluated, EFB fibre emerged as the most promising option, showing favourable chemical composition, higher holocellulose and pentosan content, lower lignin compared to coir, and better pulping response under Kraft conditions. EFB required the lowest active alkali charge, produced pulp with lower kappa number, higher brightness, and superior viscosity, indicating efficient delignification and good cellulose preservation. Its pulp also exhibited a balanced combination of strength properties, with particularly high tear strength and acceptable tensile and burst indices, comparable to hardwood pulp.

Areca nut husk demonstrated good pulp yield, moderate chemical requirements, relatively low silica content, and acceptable strength properties, making it suitable for blended pulps in writing, printing, packaging, and paperboard grades. Although its brightness and tensile properties were lower than eucalyptus, its overall performance indicates good potential after process optimization and proper raw material handling.

Coir husk, despite its abundant availability, high tear strength, and niche product potential, showed limitations due to high lignin content, high alkali requirement, lower pulp viscosity, and poor fibre bonding characteristics. These constraints restrict its use mainly to specialty papers, boards, molded products, and low-percentage blends rather than large-scale conventional paper production.

CMP pulping supports the high yield pulp production and overcomes issues related to silica and plant size. The CMP pulp can very well use for board making and other pulp based molded packaging items after blending of chemical pulp and sizing chemicals.

Overall, the results confirm that EFB fibre and areca nut husk are technically viable supplementary raw materials, while coir husk is better suited for selective and value-added applications. Their utilization can support circular economy principles, reduce open burning and waste disposal, lower dependence on imported pulp, and strengthen rural and agro-industrial linkages, thereby contributing to the long-term sustainability and self-reliance of the Indian paper industry.

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