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Future of Handmade Paper Industry: Sustainability & Alternative Fibers

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Abstract: *The global as well as Indian paper industry is presently facing significant constraints and challenges related to the availability, quality and cost of raw materials. Wood, the primary raw material for pulp production, is increasingly constrained due to global supply chain disruptions and prevailing geopolitical uncertainties. Moreover, the present crisis due to war in middle east has affected the supply chain of raw materials and compelled the paper industry to explore new alternative ligno-cellulosic raw materials. The extensive studies have been carried out on a wide range of alternative ligno-cellulosic raw materials abundantly available across different regions of the country for handmade paper industry. The adoption of such indigenous resources as alternative ligno-cellulosic raw materials is expected to play a crucial role in sustainability of not only handmade paper industry but also the Indian paper industry promoting green manufacturing, and environmentally responsible paper production in the future.*

Keywords: *Handmade paper industry, Alternative lignocellulosic raw material, Sustainability, Raw material crisis.*

1. Introduction

The paper production in prehistoric times relied predominantly on non-woody raw materials such as cotton rags and discarded fishnets made from hemp and Ramie. With time, paper industry depended on wood, agricultural residue and waste paper as raw material for paper making. However, one of the major challenges faced by both mill made paper and handmade paper industry is the escalating cost of raw material coupled with continuous supply. In 2024, the non-wood pulp market is estimated at USD 18.75 billion with projections to reach USD 28.9 billion by 2033 driven by growing demand for sustainable alternatives in paper production [1]. The search for environmentally sustainable and economically viable alternatives has become an important priority for researchers, policymakers, and industries worldwide. Although the Indian paper industry has exhibited a robust annual growth rate of 6–7%, [2] surpassing the global average, particularly in the packaging sector necessitates the exploration and adoption of alternative ligno-cellulosic raw materials to ensure long-term sustainability and resource security [3-6]. The handmade paper industry is one of the oldest industries based on renewable fibrous resources and traditional knowledge. Indian handmade paper sector utilizes cotton rags and other alternative ligno-cellulosic raw materials like banana, jute etc. for handmade paper making. The research and development studies have been conducted on identification and utilization of various alternative ligno-cellulosic raw materials in handmade paper sector which can be equally useful for sustainability of paper industry. According to National Horticulture Board, India is 5th largest pineapple producer globally and the cultivation is heavily concentrated in North east region (Assam, Tripura & Meghalaya as top producers) and southern states like Kerala [7]. India generates approximately 7 to 8 million tonnes pineapple leaf biomass [8]. The pineapple leaf yield approximately 6-8% of fibre [9]. According to Bamboo Research & Training Centre BRTC, India's bamboo production is approximately 14.6 million tonnes annually.

2. About the Raw Materials

Presently, the emphasis is laid on global scale to use non-woody raw materials for paper making. It is very important for the entrepreneur to know the alternative raw material which is locally/easily available. The images of soft bamboo and pineapple leaves are given in Figure 1.

3. ExperimentalMethods

The raw materials were cut in to size of about 3 cm (1-1.5 inches) long portions. The dust has removed manually from the fibres.

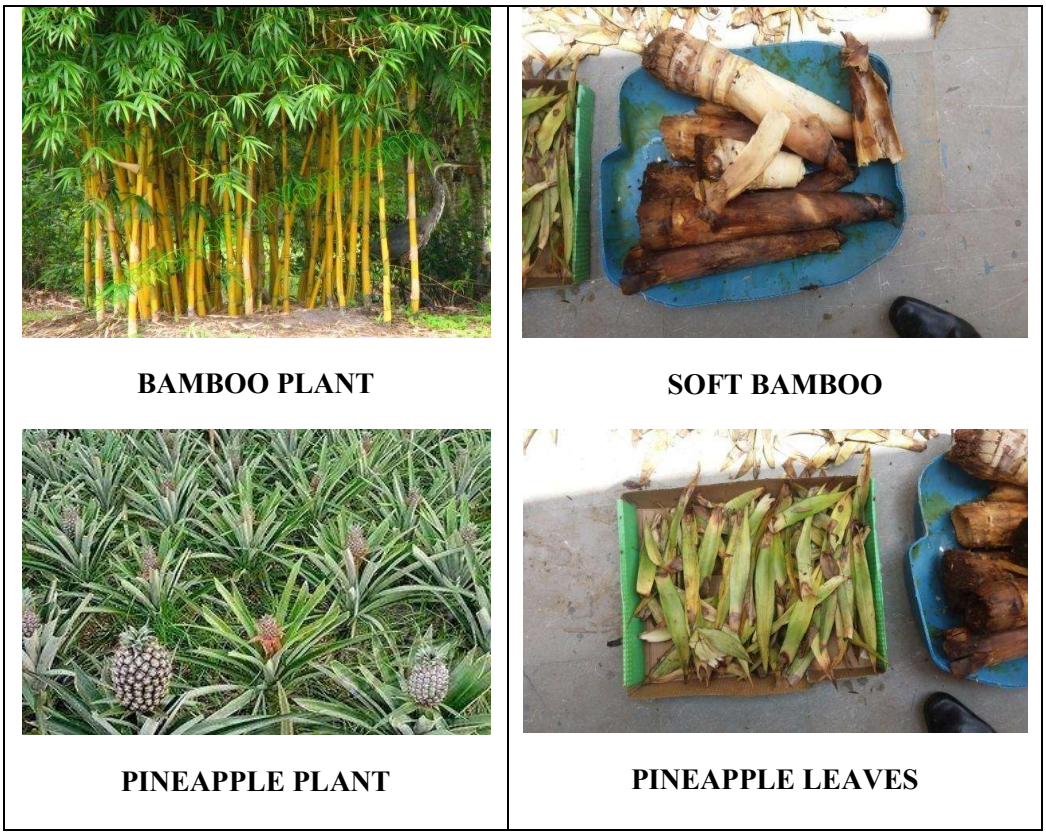

Fig.1: Bamboo plant and pineapple leaves

3.1. Proximate Chemical Composition of the Identified Fibres

The chemical composition of identified fibres viz. soft bamboo and pineapple (Table 1).

Table 1: Proximate chemical compositions of soft bamboo and pineapple fibre

Particular	Soft bamboo	Pineapple fibre
Hot water solubility,%	10.03	3.19
N/10 NaOH solubility,%	22.85	18.00
Alcohol-benzene solubility, %	29.56	14.85
Ash, %	4.19	2.25
Lignin, %	26.40	9.52
Holo-cellulose,%	70.11	84.98
α-cellulose, %	41.62	79.95

It has been observed from Table 1 that bamboo and pineapple have higher content of holo-cellulose and lower value of lignin, indicating the suitability of raw materials for handmade papermaking as well as paper industry.

3.2. Fibre Morphology

The fibre length and diameter which are considered to be important factorsfrom view point of paper making, were determined, and results recorded (Table 2).

Table 2: Length and diameter of bamboo and pineapple fibre

Common name (Scientific name)	Fibre length, mm		Fibre dia, μm	
	Avg.	Range	Avg.	Range
Bamboo (*Dendrocalamus arundinacea*)	3.00	1.5~44	14.00	07~27
Pineapple (*Ananas comosus*)	9.11	6~25	28.00	25~40

3.3. Pulping Methods

3.3.1. Alkaline pulping at boiling temperature and atmospheric pressure (APB) – Pulp yield, strength properties of pulp sheets

In this process of pulping, the identified raw materials were treated with 4%, 6% and 8% of NaOH. The pulp, black liquor and pulp sheets were evaluated following the Standard Method (Table 3).

Table 3: Yield, physical, chemical and optical strength properties of the pulp & pulp sheets (300 ml CSF)

Characteristics	Bamboo			Pineapple		
NaOH, %	4	6	8	4	6	8
Pulp yield, %	58.00	56.98	55.00	78.00	76.40	75.00
pH	08	09	11	09	10	11
RAA, gpl	0.89	1.00	1.00	0.90	1.00	1.30
TDS, %	0.87	1.10	1.30	1.05	1.05	1.04
Tensile index, Nm/g	48.11	50.00	51.00	71.000	74.60	75.00
Tear index, mN. m^2/g	1.85	2.50	3.190	3.70	4.00	4.20
Burst index, ($kPa.m^2/g$)	1.60	2.00	2.50	4.00	4.50	5.00
Double fold, No.	480	600	700	7000	7500	7600
Brightness (ISO), %	36.00	37.00	38.00	39.00	40.01	40.00

3.3.2. Alkaline peroxide pulping(APP)– Pulp yield, strength properties of pulp sheets

The alkaline peroxide pulping process is further development of the earlier pulping methods i.e. pulping at boiling temperature and atmospheric pressure, to address the problem of environment pollution and to retain eco-friendly credential of handmade paper making from the identified raw materials. In this process of pulping, the identified raw materials were treated with 4% NaOH + 2% H2O2, 6% NaOH + 2% H2O2 and 8% NaOH + 2% H2O2 at 95°C as per specified conditions. The temperature of 95°C was maintained properly to get better brightness results from hydrogen peroxide. The pulp, black liquor and pulp sheets were evaluated following the Standard Method (Table 4).

Table 4: Yield, physical, chemical and optical strength properties of the pulp & pulp sheets from alkaline peroxide pulping (APP) at 95°C (300 ml CSF)

Characteristics	Bamboo			Pineapple		
NaOH,%	4	6	8	4	6	8
H_2O_2, %	2	2	2	2	2	2
Pulp yield ,%	56.08	55.00	53.00	75.10	75.33	74.00
pH	8.5	9.1	9.56	9.1	10.4	10.60
RAA, gpl	0.70	0.95	1.10	0.90	1.00	1.20
TDS, %	0.89	1.00	1.20	0.90	1.00	1.10
Tensile index, Nm/g	50.70	52.00	53.00	74.11	75.10	77.11
Tear index, mN. m^2/g	1.89	2.60	3.40	4.00	5.90	5.40
Burst index, $kPa.m^2/g$	1.70	2.40	3.00	4.40	5.00	6.11
Double fold,No.	500	700	800	7500	7700	7700
Brightness (ISO), %	38.00	40.00	41.00	43.00	44.00	45.00

3.3.3. Alkaline sulphite pulping, (ASP)– Pulp yield, strength properties of pulp sheets

The alkaline sulphite pulping process is the further development of the earlier pulping methods i.e. pulping at 95°C temperature and pressure, to address the problem of environment pollution and to retain eco-friendly credential of handmade paper making from the identified raw materials.

In this process of pulping, the identified raw materials were treated with 4%, 6% & 8% of total chemicals (NaOH-70% + H2SO3 -30%) at 120°C as per specified conditions. The pulp, black liquor and pulp sheets were evaluated following the Standard Method (Table 5).

Table 5: Pulp yield, physical, chemical and optical strength properties of the pulp & pulp sheets from alkaline sulphite pulping (ASP) at 120°C and pressure of 1.40 kg/cm2(300 ml CSF)

Characteristics	Bamboo			Pineapple		
Total Chemical, %	4	6	8	4	6	8
NaOH,%	70	70	70	70	70	70
H_2SO_3, %	30	30	30	30	30	30
Pulp yield ,%	58.00	55.00	54.00	75.00	73.00	72.00
pH	8.5	9.5	9.50	8.5	10.5	10.00
RAA, gpl	0.60	1.00	1.04	1.00	1.10	1.30
TDS, %	0.90	1.20	1.40	0.95	1.00	1.10
Tensile Index, Nm/g	52.00	54.00	54.00	74.00	75.00	78.00
Tear Index,mN. m^2/g	2.10	2.50	3.50	4.11	5.60	5.59
Burst index, $kPa.m^2/g$	1.20	2.50	3.00	4.40	5.40	6.00
Double fold,No.	600	750	900	7500	7600	7700
Brightness (ISO), %	37.00	37.00	39.00	42.00	43.00	44.00

4. Result and Discussion

The pulp produced from pineapple fibre using 4% alkaline sulphite pulping process under optimized process conditions were found to have the tensile index of 76.10 and double fold of 7610 which is very high value compared to the hosiery pulp. The strength properties with alkaline sulphite pulping is at par with alkaline peroxide pulping process with better brightness achieved along with high strength properties with alkaline peroxide pulping. Moreover, the resultant pulp produced from bamboo & pineapple have better durability and double fold with longer fibre length (3 mm to 24 mm) and diameter (24 µm to 28 µm) could be used to produce fine quality of tissue papers in various grammages. The pineapple leaf fibre contains remarkably high alpha cellulose content and low lignin content in comparison to conventional raw material used in paper industry. This makes the resulting paper having comparatively high tear, burst, tensile strength and durability. The soft bamboo fibres are naturally long and flexible which yield paper having excellent strength, durability and smooth texture [10-13].

Conclusion

- The present work was undertaken with an objective to identify the natural fibres available as ligno-cellulosic waste fibres. Among various fibres sources, bamboo & pineapple could be identified as potential fibre source & could be obtained from the plants as stem, bast and leaf fibres. These were exploited for manufacturing of good quality paper and products particularly in NE Region.
- Studies on the chemical composition of the identified lignocellulosic raw materials were found to contain high alpha-cellulose and low lignin content supporting the suitability of these fibres for paper making. The present research work, thus, should prove to be of an immense advantage to provide an alternate and good quality fibre source available as waste bio-mass in North East & different parts of the country.
- Policy Integration:The integration of pineapple leaf fibre & soft bamboo into paper promotes circular economy practices providing sustainable income for farmers. The successful policy implementation requires targeted government and industry frameworks. The discarded pineapple leaves as raw material prevent agro-waste pollution. The Union Minister Jyotiraditya M Scindia launched Rs. 236 crore Tripura Queen Pineapple mission to encourage utilization of pineapple leaves of Tripura for making value added products.

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