International Journal for Multidisciplinary Research (IJFMR)
E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

# Development of Eco-Friendly Handmade Paper And Paper Board From Soft Bamboo, Whole Banana & Pineapple Leaves Fibre- Available in N.E. Region of India

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**Abstract:**
The studies were carried out to established suitability of lingo-cellulosic raw materials namely Soft Bamboo (*Dendrocalamus arundinacea*), Banana (Musa Sapientum) & Pineapple (Ananas Comosus) for making pulps for handmade paper industry which are abundantly available in north eastern part of India. This should help in providing a cost effective, good quality cellulosic raw material as an alternate to cost prohibitive traditionally used cotton hosiery waste traditionally used for manufacturing good quality handmade paper & it's products. This will help in improving the cost economics & competitiveness of the Indian paper industry in the global market besides addressing the problems of environment & global warming. The Studies thus carried out provide useful information about the nature of these raw materials, suitable pulping process to produce an eco-friendly handmade paper and board & converted products. The research work provides a good quality cost effective lingo-cellulosic raw material for handmade paper industries with a possibility of replacement of the expensive and traditionally used cotton hosiery waste. The paper thus produced using environmental friendly pulping and bleaching process is characterized for its strength properties like tensile, tear, bursting, folding endurance and other parameters. Further the study will be useful in providing opportunities for employment generation and income enhancement among the rural masses as well as addressing the bio-mass dumping.

**Keywords:** Alkaline Peroxide Pulping (APP), Alkaline Sulphite Pulping (ASP), Leaf fibre

## 1. Introduction:

### 1.1. Status of Handmade Paper Industry in India:

There are around 500 units of handmade paper, paper boards & products spread all over the India. However, about 50% of these units are fully functional as on date. More than 80% of the handmade paper units exist in the form of clusters located in various regions of the country, some of them are at Kalpi, Sanganer, Kurukshetra, Mehboob Nagar and Pune etc.. Besides, issues like good quality of raw material at cost effective price, these units are facing acute problems of availability of raw materials that has resulted in closure of many of these units. Such degenerative cause has ultimately hampered the growth of the handmade paper sector.

With the growth in various sectors such as education, industry and consumable products, the per capita consumption of paper in India has increased more than double in last decade from 4 Kgs per capita to 12 Kgs per capita. However, the consumption of paper in India is still relatively low as compared to the other county like U.S., China, Japan and world average. Handmade paper production meets only less than 0.5% of the India's requirement of paper. Thus, there is a considerable scope for the handmade paper industry for abridging the said gaps by partially replacing the mill made paper with more of handmade paper and paperboard. To meet out the ever increasing demand in the country, in terms of paper and paper board, handmade paper industry can contribute significantly at least for certain special varieties of paper and paper board.

**Table:1. Raw Materials Being Utilized for Handmade Papermaking by Different Countries of the World.**

| S.No. | Name of the country | Raw Material used |
|---|---|---|
| 1. | Argentina | 100% Cattail fibre (bull rust that is not the fuzzy hard) of actual slices of fruits and vegetables and made into sheets 'Papyrus style' to create some of the most unusual and charming paper. |
| 2. | Bhutan | Lokta fibre/rags |
| 3. | Canada | 100% cotton rags |
| 4. | Chinese Paper | 100% Kozo, little bit of rice straw, Quintana fiber |
| 5. | Colombia | Cotton |
| 6. | Czech Republic | Cotton & Linen rags |
| 7. | Egypt | Genuine Papyrus |
| 8. | England | 100% cotton rags and linen |
| 9. | France | 100% cotton rags |
| 10. | Germany | 25% cotton, 75% high alpha cellulose |
| 11. | Holland | Cotton with high alpha cellulose |
| 12. | India | 100% cotton rags derived from tailor cuttings, gunny bags, sunn hemp, silk fibres, green grass, waste paper,bast and leaf fibres. |
| 13. | Italy | 100% cotton or 50% cotton and 50% high alpha cellulose |
| 14. | Japan | Kozo, Gampi, Mitsumata |
| 15. | Nepal | Daphne |
| 16. | Philippines | Abaca |
| 17. | Japan | 100% cotton or 50% cotton and 50% Eucalyptus |
| 18. | Thailand | Abaca |
| 19. | USA | Cotton rags, Linen rags, Abaca, Hemp, Silk, Sugarcane |

### 1.2. Work Plan:

The literature review reveals that even today the Handmade Paper Industries in India are basically based on traditionally used raw materials i.e. hosiery waste and cotton rags which are becoming scarce and costly day by day. Looking in to the problem the Project Proposal on "Development of Eco friendly Handmade Paper & Paper board from Bamboo, Whole Banana and Pine Apple leaves as a raw materials

available in NE Region" submitted to DST and got sanctioned. The outcome of project can solve these problems, so there is a need to explore alternate ligno-cellulosic raw materials available in NE region to find the suitability for making handmade paper.

### 1.2.1. Collection, Morphological and Physico-Chemical Characterization of the Identified Raw Materials:

The selected raw materials are available in NE region in different part of the country. The Soft Bamboo, Banana leaves fibres and Pineapple leaves fibre were collected from Bethany Society, Shillong through OKVIC, Shillong. The fibres are available in raw form. The detailed studies has been conducted on the chemical characteristics of the selected cellulosic raw materials.

**Physico-Chemical Characterization:**

- Determination of Hot Water Solubility.
- Determination of N / 10 NaOH Solubility.
- Determination of A-B (Alcohol - Benzene) Solubility.
- Determination of *alpha* Cellulose.
- Determination of Total Lignin.
- Ashes

### 1.2.2. Pulping of the Identified Raw Materials using Eco-friendly Conditions:

The Indian Handmade Industries are said to be eco-friendly in nature and it is. Keeping the concept of eco-friendliness, the selected raw materials were subjected to different methods of pulping and eco-friendly bleaching process by using mild chemicals treatment and other operating parameters. Studies will be carried out on delignification of these three ligno-Cellulosic raw materials viz Soft Bamboo, Banana leaves & Pineapple leaves by exploring different eco-friendly compatible pulping process as follows:

- Alkaline pulping at boiling temperature.
- Alkaline peroxide pulping process (APP).
- Alkaline sulphite pulping process (ASP).

### 1.2.3. Preparation of Handmade Paper Sheets from the Pulps Obtained from the Identified Raw Materials:

The soft bamboo, banana and pineapple pulped raw materials, after beating at desired freeness level i.e. CSF (Canadian Standard Freeness) subjected to handmade paper sheet making as per the standard methods.

The papers thus produced from the three identified raw materials from different pulping conditions will be evaluated for various parameters as follows:-

**Strength & Optical Properties:**

- Tensile Index, (Nm/g).
- Tear Index, (mN. $m^2$/g).
- Burst Index, (KPa. $m^2$/g).
- Double Fold, (No.)
- Brightness, (% ISO).

### 1.3. Aims and Objectives:

- The traditionally used raw materials in the Indian handmade paper Industry i.e. hosiery waste, cotton waste and linters are becoming expensive and scarce in availability, therefore, it would not be fair to think that these raw materials either be available in plenty and sustainable & cost effective to other possible fibre sources.
- The processing of the traditionally used raw materials ie hosiery waste as a raw material requires a simple beating process for the defibration / defibrillation, which requires huge quantity of energy during the beating to convert the fibre length to thickness in to an ideal ratio from the strength point of paper making. Thus, in India, the higher cost of the basic raw material and higher quantity of energy required during the process for it's conversion in to the fibre suitable for handmade paper making has been one of the major drawback and the factor responsible for closing up of the industry, thereby, adversely affect product export, employment generation etc.
- As a result of the scarcity of raw material and higher energy input in process a number of unit located in different cluster & the major hub the number of unit reduced.
- The rise in cost of traditionally used raw materials i.e. hosiery waste and cotton rags increased to double in last couple of years (Table-2) show the trends of increase in price of traditional raw material. The red colour in the year 2019 has been given to indicate that, this is the maximum price for the raw material i.e. hosiery waste fibre to run the handmade paper industries.

**Table: 2. Price of Cotton Hosiery waste from 1975 to 2023**

| Years | Rs/kg |
|---|---|
| 1975 | 10 |
| 1980 | 11 |
| 1985 | 13 |
| 1990 | 14 |
| 1995 | 15 |
| 2000 | 17 |
| 2005 | 20 |
| 2008 | 22 |
| 2009 | 34 |
| 2010 | 38 |
| 2011 | 58 |
| 2012 | 60 |
| 2013 | 61 |
| 2014 | 61 |
| 2015 | 63 |
| 2016 | 63 |
| 2017 | 65 |
| 2018 | 67 |
| 2019 | 67 |
| 2020 | 67 |
| 2021 | 70 |

| | |
|---|---|
| 2022 | 75 |
| 2023 | 80 |

- In view of the above problem faced by the handmade paper industries, the present research work aims to explore the utilization of soft bamboo, banana and pine apple which are available & cheaper source of plant fibres for handmade paper industries.

## 2. Raw Materials for Handmade Paper - Composition and Analysis of Fibres (Bamboo, Banana & Pineapple):

**Physical Properties:**

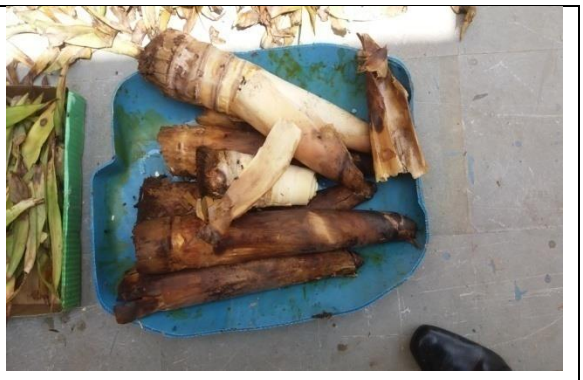
A notable physical difference between wood and non wood fibre is that non wood fibres are formed in aggregates or bundles. This is why non wood fibers like cotton and flax can be used to make rope and textile. The fibre aggregates are polymers, with a single fibre unit representing the basic building block of the polymer. Physical properties important to the understanding of non-wood fibres are fibre length and width, crystallinity, and permeability. Fibre length is the most important properties for pulping.

The raw materials namely **Bamboo (*Dendrocalamus arundinacea*), Banana (Musa Sapientum) & Pineapple (Ananas Comosus)** to establish it's suitability as cellulosic raw materials for making pulps for handmade paper industry. This should help in providing a cost effective, good quality cellulosic raw material as an alternate to cost prohibitive traditionally used cotton hosiery waste for manufacturing good quality handmade paper & its products.

This will help in improving the cost economics & competitiveness of the Indian paper industry in the global market besides addressing the problems of environment & global warming.

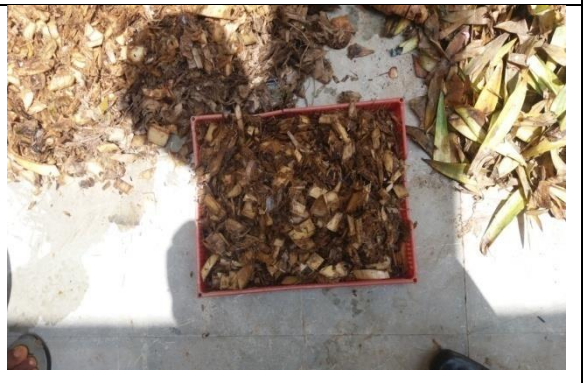
**Photograph of the raw materials and fibres structure:**

**BAMBBO PLANT**

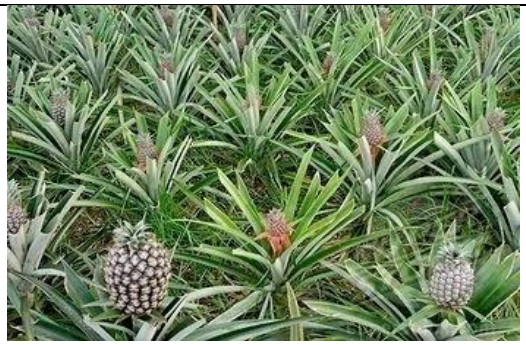


**SOFT BAMBOO**

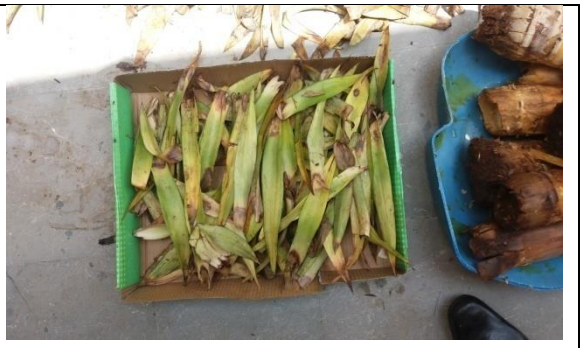
**BANANA PLANT**



**CHOPPED BANANA**



**PINEAPPLE PLANT**



**PINEAPPLE LEAVES**

**Figure: Bamboo, Banana & Pineapple Plant and their leaves.**

## 3. Experiments & Results:

### 3.1. Proximate Chemical Composition of the Identified Fibres:

The chemical composition of the identified fibres provides a useful information about suitability of the fibre source from view point of handmade paper making. It gives an assessment of the cellulosic and non-cellulosic (i.e. lignin, hemicelluloses extractives and ash contents) materials present in the raw material. The results of chemical composition of identified fibres viz. soft bamboo, banana and pineapple are shown in table-6.

**Table: 3. Proximate Chemical Compositions of Bamboo, Banana, and Pineapple Fibres:**

| Particulars | Soft Bamboo | Banana leaves | Pineapple leaves |
|---|---|---|---|
| Hot Water Solubility,% | 10.91 | 8.91 | 3.10 |
| N/10 NaOH Solubility,% | 23.01 | 20.10 | 18.90 |
| Alcohol-Benzene Solubility % | 30.04 | 25.00 | 15.00 |
| Ash, % | 4.45 | 3.80 | 2.00 |
| Lignin, % | 27.90 | 15.10 | 10.11 |
| Holocellulose,% | 69.00 | 78.00 | 85.00 |
| α-cellulose, % | 41.00 | 75.11 | 78.80 |

The extractives soluble in hot water and N/10 NaOH basically indicate the extent of carbohydrate degradation present in the fibre. The N/10 NaOH solubility accounts for the total phenolic components, tannins and other colouring substances present in the fibre. The data shown in table-3, indicating N/10 NaOH solubility i.e. 10.91%, 8.91% &3.10% for bamboo, banana & pineapple respectively which are comparatively lower than woody raw materials, indicate the better suitability of fibre for paper making.

The alcohol-benzene solubility shown in table-3, indicates that the extractives which consists of resins, fatty acids, gums, tanins etc. are lowest i.e.15.00% in case pineapple compare to banana & bamboo having 25.00% and 30.04% respectively.

The ash content which is measure of mineral salt and inorganic matter present in the fibre is on higher side in case of bamboo (4.45%), it is because of the dirt and black epidermal barks are adhered with the fibres. The pineapple fibre has lowest ash content (200%) among the identified fibres while banana has moderate ash content (3.80%), showing superiority of the pineapple fibre over the banana and bamboo.

The lignin, a polyphenolic polymer, an undesirable component in view point of handmade paper making is found to be on the lower side i.e.10.11%, 15.10% & and 27.90% in pineapple, banana & bamboo

fibres respectively as shown in table-3.

The total carbohydrate fractions of the fibre which include alkali resistantα -cellulose and other polymeric carbohydrates associated with the cellulosic portions are found to be on higher side in all the three identified raw materials. From the results shown in the table-3, it can be seen that pineapple has 85.00% of holo-cellulose followed by 78.00% & 69.00 % in case of pine apple, banana and bamboo fibres respectively.

The α – cellulose are very high in all the identified fibres. Pineapple fibre has maximum holocellulose (85.00%) and α- cellulose (78.80%) as compared to other two fibres. Banana fibre has more holocellulose (78.00%) and α- cellulose (75.11%) as compared to bamboo fibre i.e. (69.00%) holocellulose and (41.00%) α- cellulose.

From the results of proximate chemical composition of the three identified raw materials i.e. bamboo, banana and pineapple, showing the higher content of holocellulose and lower value of lignin, indicating the suitability of raw materials for handmade papermaking.

### 3.2. Fibre Morphology:

The fibre morphological studies of bamboo, banana, and pineapple were surveyed. The fibre length and diameter which, considered to be an important factor from view point of paper making, were determined, and results recorded in table-4.

**Table: 4. Length and Diameter of Bamboo, Banana and Pineapple Fibres:**

| 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 |
| Banana (*Musa sapientum*) | 3.00 | 1.8~15 | 24.00 | 16~32 |
| Pineapple (*Ananas comosus*) | 9.11 | 6~25 | 28.00 | 25~40 |

The average fibre length of Bamboo varies from 1.5 mm to 44 mm, with an average length of 3.00 mm and fibre diameter varies from 0.7 μm to 27 μm, with an average diameter of 14.00μmThe average fibre length of banana varies from 1.8 mm to 15 mm, with an average length of 3.00 mm and fibre diameter varies from 16 μm to 32 μm, with an average diameter of 24.00μm

The average fibre length of pineapple varies from 6 mm to 25 mm, with an average length of 9.11 mm and fibre diameter varies from 25μm to 40μm, with an average diameter of 28.00μm

Among the three identified fibres pineapple has the highest value followed by banana & bamboo. The values of the fibre length are better compared to the other wood / non wood based fibres used for paper making indicating the suitability of the identified fibres for making better quality handmade papers.

### 3.3. Pulping Methods:

Laboratory series Digester with six bombs each with a capacity of 2.5 litres were used for the digestion of the identified raw materials viz. bamboo, banana, and pineapple.

Chemicals used in the pulping process: Sodium hydroxide in case of alkaline pulping at boiling temperature and atmospheric pressure; Sodium Hydroxide and Hydrogen Peroxide in case of alkaline

peroxide pulping process; Sodium Hydroxide and Sodium Sulphite in case of alkaline sulphite pulping process.

Sampling:The raw materials were cut in to pieces about 3 cm (1-1.5 inches) long portions. The dust was removed by mechanical dusting process before the pulping of fibres. Before pulping the all the three raw materials were treated with following condition for the softening of the raw materials, The pulp was washed thoroughly after the treatment.

### 3.3.2. 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.

Washing: The cooked pulps after the pulping were transferred to a fine terylene cloth and the surplus black liquor is squeezed out for effluent characterizations& washed well with the fresh water. Pulp yields for the fibres were evaluated.

Pulp Evaluation: The cooked pulps were run in to laboratory valley beater to achieve the desired CSF (Canadian Standard Freeness) value i.e. 300 ml. From these beaten pulps, hand sheet on British Sheet making machine and Tissue Sheet making machine, were made as per the standard procedure and dried them.

After conditioning, the physical and optical strength properties were evaluated as per the Standard Test Methods viz TAPPI, BIS, IS & ISO:2471.The test results are shown in table-5.

**Table: 5 Pulp -Yield, Physical, chemical and Optical strength properties of the pulp & pulp sheets from alkaline pulping at boiling temperature and atmospheric pressure process (At 300 ml CSF):**

| S. N. | Characteristics | Bamboo | | | Banana | | | Pineapple | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CSF, ml | 300 | | | 300 | | | 300 | | |
| | NaOH % | 4 | 6 | 8 | 4 | 6 | 8 | 4 | 6 | 8 |
| | Pulp Yield, % | 58.98 | 57.11 | 55.56 | 76.15 | 75.00 | 73.14 | 79.61 | 77.41 | 76.11 |
| | pH | 08 | 09 | 10 | 09 | 10 | 11 | 09 | 10 | 11 |
| | RA, gpl | 0.90 | 1.10 | 1.23 | 1.10 | 1.25 | 1.50 | 1.00 | 1.19 | 1.40 |
| | TDS, % | 0.97 | 1.21 | 1.40 | 1.10 | 1.25 | 1.35 | 1.00 | 1.12 | 1.34 |
| **1** | Tensile Index (Nm/g) | 50.90 | 52.32 | 53.90 | 72.03 | 73.20 | 74.15 | 72.10 | 75.65 | 77.71 |
| **2** | Tear Index (mN. $m^2$/g) | 1.90 | 2.70 | 3.21 | 3.81 | 3.90 | 4.10 | 3.91 | 4.11 | 4.60 |
| **3** | Burst Index (Kpa.$m^2$/g) | 1.70 | 2.22 | 2.90 | 3.97 | 4.81 | 4.97 | 4.10 | 4.98 | 5.12 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **4** | Double Fold, No. | 500 | 700 | 800 | 5500 | 5600 | 6650 | 7500 | 7700 | 7800 |
| **5** | Brightness (%) ISO | 40.00 | 38.00 | 37.00 | 41.00 | 40.00 | 40.00 | 41.60 | 41.10 | 40.00 |

**Results and Discussions:**

From the results indicated in table-5, it could be observed that the pineapple fibre pulp showed highest pulp yield (79.61) at NaOH concentration of 4% with reasonable high strength properties in respect of double fold (7500), tensile index (72.10), tear index (3.91) and burst index (4.11). The pulp yield in case of identified fibres i.e. bamboo, banana and pineapple were always more than 58.98 % with 4%, 6% and 8% NaOH which could be considered a very good pulp yield from any lingo-cellulosic fibres. The inherent chemical composition of the identified fibres having lower lignin and higher cellulosic content could attributed to such high yield pulp. The data of the strength properties i.e. appreciably high double fold varying from 7800 (8% pineapple) to 800 (8% bamboo), tensile index 77.71 (8% pineapple) to 53.90 (8% bamboo), tear index 1.90 (4% bamboo) to 4.60 (8% pineapple), burst index 1.70 (4% bamboo) to 5.12 (8% pineapple) may be taken as the very good strength properties which could be reflected from the inherent fibre morphological character of these fibres i.e. the higher fibre lengths and fibre diameters.

If we compare the strength properties of pulp sheets made from the identified raw materials i.e. bamboo, banana, and pineapple, the pineapple pulp sheethas better properties over the other two. The bamboo pulp sheet has poor strength properties among the three identified raw materials while that of banana has strength properties in between other two pulp sheets.

This pulping method is suitable for such handmade paper industries which have the cooking facility like open digestion, where stationary / vomiting type digester is required for the pulping and wants to use these identified raw materials. In place of the vomiting type digester, open boiling in any big utensil could be preferred to curtail the expense of digester. During the pulping, proper bath ratio should be maintained time to time for proper cooking of the raw materials, which results in better delignification. The pulps, thus, produced can be used for making variety of handmade papers / paper boards.

### 3.3.3. Alkaline Peroxide Pulping, (APP)– Pulp - Yield, Strength Properties of Pulp Sheets:

The alkaline peroxide pulping process is the 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% H2O2and 8% NaOH + 2% H2O2, at 95°C as per specified conditions discussed. The temperature of 95°C was maintained properly to get better brightness results from hydrogen peroxide.

Pulp Evaluation: The cooked pulps were run in to laboratory valley beater to achieve the desired CSF (Canadian Standard Freeness) value i.e. 300 ml. From these beaten pulps, hand sheet on British Sheet making machine and Tissue Sheet making machine, were made as per the standard procedure and dried them.

After conditioning, the physical and optical strength properties were evaluated as per the Standard Test Methods viz TAPPI, BIS, IS &ISO: 2471.The test results are shown in table-6.

Before pulping the all the three raw materials were treated with following condition for the softening of

the raw materials, The pulp was washed thoroughly after the treatment

**Table: 6. Pulp - Yield, Physical, Chemical and Optical strength properties of the pulp & pulp sheets from alkaline peroxide pulping (APP) at 95°C temperature and pressure of 1.40 Kg/cm$^2$ process (At 300 ml CSF):**

| S. N. | Characteristics | Bamboo | | | Banana | | | Pineapple | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CSF, ml | 300 | | | 300 | | | 300 | | |
| | NaOH,% | 4 | 6 | 8 | 4 | 6 | 8 | 4 | 6 | 8 |
| | H2O2, % | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| | Pulp Yield ,% | 57.58 | 56.00 | 54.00 | 74.34 | 73.00 | 71.14 | 77.11 | 75.33 | 74.00 |
| | pH | 08 | 09 | 9.50 | 09 | 10 | 10 | 09 | 10 | 10.50 |
| | RA, gpl | 0.80 | 1.00 | 1.20 | 1.00 | 1.15 | 1.40 | 1.00 | 1.11 | 1.30 |
| | TDS, % | 0.91 | 1.11 | 1.31 | 1.00 | 1.19 | 1.31 | 0.96 | 1.10 | 1.30 |
| **1** | Tensile Index, (Nm/g) | 52.76 | 54.55 | 56.00 | 74.00 | 75.25 | 76.10 | 76.00 | 77.20 | 79.22 |
| **2** | Tear Index (mN. m$^2$/g) | 2.00 | 2.80 | 3.60 | 3.90 | 4.80 | 4.98 | 4.11 | 5.60 | 5.90 |
| **3** | Burst Index, (Kpa.m$^2$/g) | 1.80 | 2.50 | 3.10 | 4.17 | 5.00 | 5.97 | 4.50 | 5.58 | 6.22 |
| **4** | Double Fold ,No. | 600 | 800 | 900 | 5700 | 5800 | 6800 | 7600 | 7750 | 7850 |
| **5** | Brightness (%) ISO | 42.00 | 41.00 | 40.00 | 45.00 | 46.00 | 47.00 | 46.00 | 45.10 | 44.00 |

**Results and Discussions:**

The result of pulp yields and strength properties using APP process for bamboo, banana, and pineapple fibres at various process conditions i.e. 4%, 6% & 8%, with 2% H2O2 at a temperature 95°Cand maintaining bath ratio of 1:8 for 3 Hrs are shown in table-6.

From the results indicated in table-4, it could be observed that the pulp yields are higher for pineapple with 4% alkali i.e. 77.11% followed by 74.34% for banana & 54.00% for bamboo. The strength properties for all three fibres with different pulping condition of caustic i.e. 4%, 6% and 8% were quite good in respect of all the parameter such as tensile index from 52.76 (4% bamboo), to 79.22 (8% pineapple), double fold value 600 (4% bamboo) to 7850 (8% pineapple). The strength properties like tear index and burst index were also quite high. The above strength properties indicate that all the identified three fibres could be utilized for manufacturing of high value added paper including the

security, currency papers and could be a substitute or a source for its blending for the cotton hosiery fibre, which is being conventionally used for the security and currency papers.

The digester was used for the pulping of identified lignocellulosic raw materials which results better delignification. It is recommended to use digester and temperature should be maintained at 95ºC during the digestion to avoid the evaporation and decomposition of hydrogen peroxide.

If we compare the strength properties among the identified raw materials i.e. bamboo, banana, and pineapple, the pineapple fibre has better properties over the other two. The bamboo fibre has poor strength properties among the three identified raw materials while banana has burst and brightness properties at par with pineapple fibre.

Thus, this pulping method is very much suitable for such industries where the cooking facility like rotary spherical digester is used provided the industry is willing to use the identified fibrous raw materials.

**3.3.4. 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 120°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% Total Chemical (NaOH-70% + H2SO3 -30% ), 6% Total Chemical (NaOH-70% + H2SO3 -30% ) & 8% Total Chemical (NaOH-70% + H2SO3 -30% ) 120°C as per specified conditions discussed. The temperature of 120°C was maintained properly to get better results from sodium sulphite.

Pulp Evaluation: The cooked pulps were run in to laboratory valley beater to achieve the desired CSF (Canadian Standard Freeness) value i.e. 300 ml. From these beaten pulps, hand sheet on British Sheet making machine and Tissue Sheet making machine, were made as per the standard procedure and dried them.

After conditioning, the physical and optical strength properties were evaluated as per the Standard Test Methods viz TAPPI, BIS, IS &ISO: 2471.The test results are shown in table-7.

Before pulping the all the three raw materials were treated with following condition for the softening of the raw materials. The pulp was washed thoroughly after the treatment

**Table: 7. Pulp - Yield, Physical, Chemical and Optical strength properties of the pulp & pulp sheets from alkaline sulphite pulping (ASP) at 120°C temperature and pressure of 1.40 Kg/cm$^2$ pressure (At 300 ml CSF):**

| S. N. | Characteristics | Bamboo | | | Banana | | | Pineapple | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | CSF, ml | 300 | | | 300 | | | 300 | | |
| | Total Chemical% | 4 | 6 | 8 | 4 | 6 | 8 | 4 | 6 | 8 |
| | NaOH,% | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |
| | H2SO3, % | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 | 30 |
| | Pulp Yield ,% | 58.55 | 56.78 | 54.10 | 74.00 | 72.00 | 70.11 | 76.89 | 74.83 | 73.00 |
| | pH | 09 | 09 | 9.55 | 09 | 10.10 | 10.10 | 09 | 10.21 | 10.50 |
| | RA, gpl | 0.70 | 1.10 | 1.24 | 1.10 | 1.20 | 1.45 | 1.10 | 1.20 | 1.42 |
| | TDS, % | 0.93 | 1.14 | 1.51 | 1.12 | 1.21 | 1.35 | 0.98 | 1.11 | 1.13 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | Tensile Index, (Nm/g) | 53.12 | 55.57 | 56.76 | 74.50 | 76.05 | 76.98 | 76.10 | 77.98 | 80.00 |
| **2** | Tear Index (mN. $m^2$/g) | 2.10 | 2.86 | 3.70 | 3.97 | 4.89 | 5.00 | 4.22 | 5.78 | 6.00 |
| **3** | Burst Index, (Kpa.$m^2$/g) | 1.81 | 2.55 | 3.14 | 4.67 | 5.10 | 6.00 | 4.58 | 5.98 | 6.50 |
| **4** | Double Fold ,No. | 610 | 825 | 910 | 5740 | 5850 | 6820 | 7610 | 7770 | 7880 |
| **5** | Brightness (%) ISO | 40.00 | 38.00 | 38.00 | 44.00 | 45.00 | 46.00 | 45.00 | 45.00 | 44.00 |

**Results and Discussions:**

The result of pulp yields and strength properties using ASP process for bamboo, banana, and pineapple fibres at various process conditions i.e. 4%, 6% & 8% of total chemical with ratio of 70:30 at a temperature 120°C and maintaining bath ratio of 1:8 for 3 Hrs are shown in table-7.

From the results indicated in table-10, it could be observed that the pulp yields are higher for pineapple with 4% total chemical i.e. 76.89% followed by 74.00% for banana & 58.55% for bamboo. The strength properties for all three fibres with different pulping condition of total chemical i.e. 4%, 6% and 8% were quite good in respect of all the parameter such as tensile index from 53.12 (4% bamboo), to 73.00 (8% pineapple), double fold value 610 (4% bamboo) to 7880 (8% pineapple). The strength properties like tear index and burst index were also quite high. The above strength properties indicate that all the identified three fibres could be utilized for manufacturing of high value added paper and could be a substitute or a source for its blending for the cotton hosiery fibre, which is being conventionally used for the security and currency papers.

The digester was used for the pulping of identified lignocellulosic raw materials which results better delignification. It is recommended to use digester and temperature should be maintained at 120ºC during the digestion to get better effect.

If we compare the strength properties among the identified raw materials i.e. bamboo, banana, and pineapple, the pineapple fibre has better properties over the other two. The bamboo fibre has poor strength properties among the three identified raw materials while banana has burst and brightness properties at par with pineapple fibre.

Thus, this pulping method is very much suitable for such industries where the cooking facility like rotary spherical digester is used provided the industry is willing to use the identified fibrous raw materials.

## 5. Conclusion & Summary:

**Handmade Paper from the Identified Alternate Lignocellulosic Raw Materials viz. Bamboo, Banana and Pineapple Fibres:**

- Conventionally, the raw materials used most commonly in handmade industry are the off cut of the textile industry i.e. hosiery waste in white colour as well as in mixed colors, cotton rags, off cut from HMPI, and recycled secondary fibres but the availability of these raw materials for handmade paper industry is becoming scarce and very expensive. As a matter of fact, the existence of handmade paper industry has become difficult and more than 50% of the units have been closed. This has resulted in decreased production and adversely affected on the exports & domestic market besides decreased opportunities for employment generation. Looking into the problem of availability of

cellulosic raw material for handmade paper industry and to make the raw material available at cheaper and affordable price. There is an urgent need to identify alternate source of locally and an easily pulpable raw materials, which could be made available for handmade paper industry at cheaper price.

- The present work thus was undertaken with an objective to identify the natural fibres available as ligno-cellulosic waste fibres. Among various fibres sources, Bamboo, Banana & Pineapple could be identified as potential fibre source & could be obtained from their plants as stem, bast and leaf fibres. These were exploited for manufacturing of good quality handmade paper and products particularly in NE Region.
- Studies on the fibre morphology and chemical nature of identified raw materials indicated their suitability for manufacturing of high quality handmade paper and paper products. While comparing the chemical composition with conventionally used cotton hosiery waste, all the three identified lignocellulosic raw materials were found to contain around 80% of α-cellulose contents, lower content of lignin (less than 8%), which are considered to be one of the important parameter for their suitability for handmade paper making. Further, the fibre lengths and diameters were found to be appreciably higher (length more than 3 mm and dia more than 24 μm) in all the identified fibres which were comparable or higher than the conventionally used cotton hosiery waste. Thus, the preliminary studies on Physico-chemical and morphological characteristics supported the suitability of these fibre for handmade paper making.
- Due to the inherent chemical nature of the identified ligno-cellulosic raw materials viz. Bamboo, Banana and Pineapple required use of milder doses of NaOH, hydrogen peroxide and Sodium sulphite to delignify or dissolve lignin and bleaching of the cellulose rich pulp to make it suitable for handmade papermaking. Thus, the efforts were made to make the delignification and / or bleaching process an ecofriendly process (APP) to retain ecofriendly credentials.
- The present research work focused on using eco-friendly pulping and bleaching process, viz. Alkaline Pulping, Alkaline Peroxide Pulping & Alkaline Sulphite Pulping processes using milder conditions in respect of use of chemicals, temperature during the pulping and bleaching of the identified lingo-cellulosic raw materials to produce pulps, suitable for handmade papermaking.
- Similarly, the pulp produced from bamboo, banana and pineapple using 8% alkaline peroxide pulping process under optimized pulping conditions produce the pulp of very high strength properties having high tensile index value and double fold number.
- Lignocellulosic raw materials may be used to produce a wide range of products ranging from very inexpensive, low performance paper / paper board, to expensive, high performance paper / paper board. The wide distribution, renewability, and recyclability of these lingo-cellulosic raw materials can expand the market for low-cost paper / paper products. The pulping technology thus used, can be well suited to handmade paper makers to manufacture variety of paper / paper boards with excellent strength properties.
- Paper products having complex shapes can also be produced from these fibrous materials produces flexible fibre pulp. Within certain limits, any size, shape, thickness, and density is possible.
- 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 N.E. & different part of the country. This will help not only in providing a cheaper source of raw materials for the very survival of the

sick units, which are at the verge of closure, but also address the problem of environmental problem which otherwise is caused due to dumping of these ligno-cellulosic mass as a waste.

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