The Use of Banana *(Musa sapientum)* and Ankara *(Calotropis procera)* in the Handmade Paper Industries

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The Indian handmade paper industry faces problems including the escalating cost of raw materials and an export market affected by global recession. In addition, capital costs are increasing. Good quality cellulosic raw materials are essential to the paper industry. A number of ligno-cellulosic raw materials are available including bast from leaves, weeds and wild grasses which may be used by the industry in India, but yet is not widely available to each and every part of the handmade paper industry in India. Banana (*Musa sapientum*) and ankara (*Calotropis procera*) fibres may be suitable in making handmade paper and paperboard. Chemical analysis of banana and ankara materials shows very high cellulose, low lignin and ash. By using alkaline peroxide and alkaline sulphite processing a variety of papers like archival tissue *etc.* can be developed. Blending them with some short-fibre pulps further make them suitable for the production of good quality handmade paper and archival board with affordable cost. These also could be converted into quality products like bond paper, card sheets and fancy and decorative items.

Keywords: Bast fibres; Leaf fibre; Alkaline peroxide pulping (APP); Alkaline sulphite pulping(ASP);TAPPI

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INTRODUCTION

The invention of handmade paper manufacturing dates back to China in 105 A.D. when T'sai Luin, an imperial guard prepared a paper for the emperor that was made from mulberry and other barks, fishnets, hemp and rags. However, Indians are reportedly credited to have used paper made from cellulosic fibres even during the 3rd century B.C. Prior to this period, palm leaves were used for writing in India. "Papyrus" from the bank of Nile River in Egypt was the medium of communication in Egypt and is from where the word "Paper" is derived.

Scenario in India

The Indian handmade paper industry has been identified as a village industry that has seen significant growth in the last decade because of an increasing demand for handmade paper and paper products not only at national level but also in the international arena. An estimated 500 handmade paper units are scattered all over India producing nearly 50,000 tonnes of handmade paper and board. The Indian handmade paper industry had grown remarkably in the recent past. The production of the handmade paper industry has reached a turnover of Rs 250,000 million. Due to increased literacy, industrialization and modernization, the per capita consumption of the paper and paperboard has increased from 4.5 kg in the year 2000 to nearly 9.0 kg in the recent past. This industry provides employment to about 15,000 people, most of them situated in the rural areas.

With the growing trend of environmental friendliness, demand of handmade papers made out of natural fibres is rising. Moreover, the rising cost of traditionally used cellulosic raw materials like cotton rags and hosiery waste, being used in handmade papermaking is also forcing the industry to search for additional cellulosic raw materials for production of handmade paper and board which are available as waste biomass in different parts of the world. This should help in providing more opportunities for cost effective, locally available lignocellulosic raw materials and agro residues like banana, ankara, pineapple, *etc.* thereby addressing the problem of environment and the issue of global warming.

The handmade paper sector is considered to be eco-friendly, utilizing non-woody and waste raw materials in its manufacturing process. The durability of the handmade paper is high with an exclusive look and texture. The paper is available in a saga of rich varieties, designs, shapes and colors. Most of the handmade paper units in India traditionally use cotton hosiery waste as the main source of raw material, which produces paper with excellent strength characteristics.

Share in the Export Market

China is holding the maximum share of 27% in the export of handmade paper and paper products while India is at the number 2 position with a share of 24%. Thailand and the Philippines are the next competitors in handmade paper and paper products export.

Table 1. Export of Handmade Paper in the World

Country	Export in RS Crores	Percentage share
India	366	24
Philippines	127	8
Nepal	15	1
China	411	27
Others	435	28
Total	1546	
	341.07 million US $	

Source: Report on “Market research in Indian Handmade Paper Industry” by M/S Sycom Projects Consultants Pvt. Ltd. New Delhi.

Banana as a Cellulosic Raw Material

There are many varieties of bananas available worldwide, but only the cultivated and the edible banana are of economic importance. The edible clones are *Musa sapientum* (dessert banana) and *Musa paradisiaca* (culinary type). It belongs to the genus *Musa* of the family *Musaceae*, which has two genera *Musa* and *Ensete*. There are different varieties of banana differing in size, colour, and taste.

Banana fibre are leaf fibres extracted from the pseudo stem of banana plant growing all along the coastal region in India, viz Maharastra, Kerala, AP, Orissa, W.B., Assam, TN, Bihar and Karnataka. For every 30–40 kg of banana sold in the market, 250 kg of waste is produced. Thus, over 1 billion tonnes per year of banana stems are left to rot. Therefore, India needs to eliminate this wasteful practice.

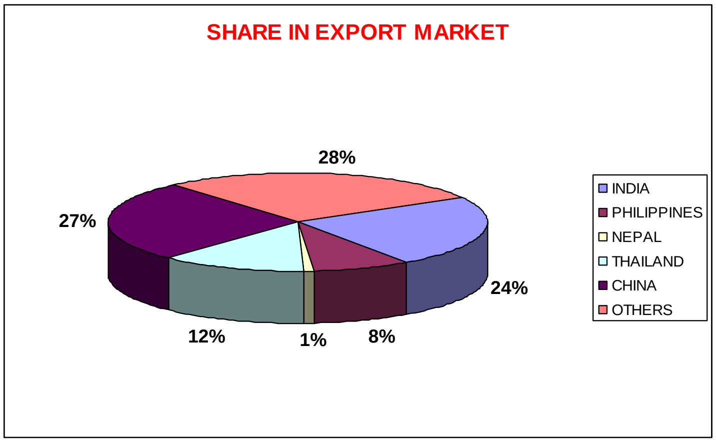

Figure 1. Percentage share of countries in export

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The yield of fibre is around 2.5–3.0% of the dried weight of the pseudo stem of banana. Fresh banana stem weighs around 25 kg with a moisture content of around 95%. India has over 500,000 acres of land under banana cultivation. It is a perennial herb with an underground rhizome, attaining a height of 3–9.5 meters. The trunk, or pseudo stem is formed from tightly rolled spiral leaf bases. The inflorescence appears 9–12 months after planting. The time from flowering to harvest takes about 3 months. After harvesting the fruits, the plants are cut for extraction of fibres. Both stems and ribs contain good fibres. Normally there are 25 sheaths in one stem. The outer 4 to 5 sheaths give coarse fibres and the innermost 5 sheaths give soft fibres. The yield of fibres is about 2 to 4 % of the outer diameter weight of stem. India can generate about 2 lakhs tonnes of banana fibres annually, which can produce nearly 1.65 lakh tonnes of handmade paper. India produces an estimated amount of 30,000–35,000 tonnes of handmade paper using traditional cellulosic raw materials like cotton rags and hosiery waste.

Fibre extraction

There are two ways of extracting fibre, manual extraction and mechanical extraction.

Manual extraction process

Manual extraction involves cutting the trunk into small pieces and scraping them with the help of a comb-like structure called a scraper.

Mechanical extraction process

In the mechanical process, the chopped plant is passed through a simple machine called a Raspador or banana fibre extractor. The yield of fibre is almost 10 times more by mechanical extraction; however, the quality of the fibre is inferior. The trend of using banana fibre to manufacture handmade paper should be increased, especially in a nation like in India where the fibre of the banana tree is a sustainable resource

Ankara as a Cellulosic Raw Material

Ankara is calcareous plant that grows in sandy soil belonging to the genus *Caltropis*. The genus consists of about 6 species that are shrubs or small trees distributed in tropical and subtropical countries of Africa and Asia. It is available in Haryana, Punjab, Gujarat, Bihar and Rajasthan and widely available in Northwest India. Rajasthan is in the area of Bikaner, Jodhpur, Pali, Jhunjhunu, Jaisalmer and Barmer. Three of the species occur in India and two of them are of economic importance namely, *C. giganta and C. procera*. Both plants yield latex containing gutta-percha like caoutchouc and contain a cardiac poison. It is a weed and yields strong fibres.

Fibre extraction

The fibres are extracted after retting (a microbial process that breaks the chemical bonds holding the stem together and thereby allowing separation of the bast fibres from the woody core). The bark is taken out by hammering or stamping. The epidermal green layer, the mucilage and the pithy stems are thus separated. The bast fibres of ankara are strong and semi-white and consist of 2% of the outer diameter weight of the stem. The fibres of ankara, also called Aak, are very strong in terms of physical strength properties.

Figure 2. Banana and ankara plants and their fibres.

EXPERIMENTAL

Alkaline Pulping Processes

After cutting the raw materials into suitable size, the material was subjected to alkaline pulping. The raw materials were cooked at 100 °C with 8%, 10% and 12% sodium hydroxide for three hours with alkali dosages (i.e. NaOH) with a bath ratio of 1:8.

Table 2. Pulping Conditions of Banana and Ankara fibres (Alkaline Pulping)

No.	Characteristics	Banana			Ankara		
1.	Cooking conditions						
	Experiment number	I	II	III	IV	V	VI
	NaOH (%)	8	10	12	8	10	12
	Time (Hrs)	3	3	3	3	3	3
	Temperature (° C)	100	100	100	100	100	100
	Bath Ratio	1:8	1:8	1:8	1:8	1:8	1:8
2.	Effluent Characteristics						
	BOD (Biological Oxygen Demand) (ppm)	1220	1380	1500	1300	1450	1730
	COD (Chemical Oxygen Demand) (ppm)	6000	7700	8100	7000	8100	8700
3.	Pulp Yield (%)	86.66	85.21	84.42	76.65	75.11	74.12

Strength Characteristics

After washing, the fibres were beaten in a Valley laboratory beater. The pulps were beaten up to ~300 mL CSF (Canadian Standard Freeness) and laboratory sheets of 60 GSM were formed in hand sheet former. The sheets were conditioned for 24 hours at 27±1 ºC and 65±2% relative humidity. After conditioning, the physical strength properties were evaluated according to the Standard Test Methods, TAPPI, BIS, IS and ISO:2471. The results are recorded in Table 7.

Alkaline Peroxide Pulping Process

Pretreatment with chelating agent

Plant materials may contain metal ions like iron, manganese *etc.*, which may interact with hydrogen peroxide and form complexes affecting the brightness and permanence of paper. Therefore, to avoid the interference of metallic ions, pretreatment of the raw material with the chelating agent, EDTA (Ethylene diamine tetra acetic acid disodium salt) was carried out. The following conditions were applied: EDTA: 0.05 %, pH: 4 to 5 for 30 minutes at room temperature.

After chelation, the raw materials were treated with de-mineralized water. After washing, the raw material was cooked with different doses of chemicals. Materials were pulped with the alkaline peroxide process (APP) under the conditions recorded in Table 3.

Table 3. Pulping Conditions of Banana and Ankara Fibres (Alkaline Peroxide Pulping)

No.	Characteristics	Banana			Ankara		
1.	Cooking conditions						
	Experiment	VII	VIII	IX	X	XI	XII
	NaOH (%)	8	10	12	8	10	12
	Hydrogen Peroxide (%)	2	2	2	2	2	2
	Time (Hrs)	3	3	3	3	3	3
	Temperature (° C)	95	95	95	95	95	95
	Bath ratio	1:8	1:8	1:8	1:8	1:8	1:8
2.	Effluent Characteristics						
	BOD (Biological Oxygen Demand), ppm	1800	2000	2300	2300	2400	2600
	COD (Chemical Oxygen Demand), ppm	7000	8000	8800	8000	8700	9000
3.	Pulp Yield (%)	80.20	78.89	75.11	75.00	74.10	73.11

Strength Characteristics

Evaluation of strength characteristics of hand sheets of the above pulp were carried out as described in the procedure discussed earlier. The results are recorded in Table 8a. The strength properties of tissue papers in different grammage developed from the experiment number VII and X are recorded in Table 8b.

Alkaline Sulphite Pulping Process

Laboratory experiments on pulping of raw materials were carried out with an alkaline sulphite pulping process as described in the following procedure. The conditions are recorded in Table 4.

Table 4. Pulping Conditions of Banana and Ankara Fibres (Alkaline Sulphite Pulping).

No.		Banana			Ankara		
1.	Cooking conditions	XIII	XIV	XV	XVI	XVII	XVIII
	Total Chemical	8%	10%	12%	8%	10%	12%
	NaOH	70%	70%	70%	70%	70%	70%
	Sodium Sulphite	30%	30%	30%	30%	30%	30%
	Time (Hrs)	3	3	3	3	3	3
	Temperature (° C)	120	120	120	120	120	120
	Bath ratio	1:8	1:8	1:8	1:8	1:8	1:8
2.	Black liquor analysis						
	Residual active alkali after digestion, (g/l)	0.72	1.29	1.73	1.02	1.47	1.98
	BOD (Biological Oxygen Demand) (ppm)	2300	2350	2500	2400	2500	2700
	COD (Chemical Oxygen Demand) (ppm)	8000	8500	9100	8700	8900	9100
3.	Yield (%)	79.50	78.51	74.80	74.10	73.00	71.51

Strength Characteristics

Evaluation of strength characteristics of handsheets of the above pulp were carried out with the procedure discussed earlier**.** The results are recorded in Table 9a.

Bleaching Studies

The unbleached pulp obtained by alkaline sulphite pulping of the two raw materials with 8% alkaline sulphite process (Experiments-XIII and XVI) were bleached with 2% hydrogen peroxide under following conditions.

Hydrogen Peroxide	2%
Sodium Hydroxide	1%
EDTA	0.15%
Consistency	8–9%
Temperature	60–70° *C*
Time	1 hr

The bleached pulp obtained as above and the bleaching effluent were characterized for strength characteristics (Table 9b) and pollution loads in terms of chemical oxygen demand (COD) and biological oxygen demand (BOD). The spent pulping liquor obtained after the alkaline sulphite pulping and washing the unbleached pulp were mixed and evaporated to a solids concentration of 30% w/w for its application in various industries.

Table 5. Effluent Characteristics of Banana and Ankara Fibres (8% Alkaline Sulphite Pulping) after the Bleaching.

Characteristics	Banana	Ankara
Effluent Characteristics	XIII	XVI
BOD (Biological Oxygen Demand), ppm	60	80
COD (Chemical Oxygen Demand), ppm	640	800
Pulp Yield, %	79.00	73.50

Strength Characteristics

Evaluation of strength characteristics of handsheets of the above pulp were carried out with the procedure discussed earlier in the report. The results are recorded in Table 9b.

Pilot Plant Trials

To confirm the laboratory results, pilot-plant experiments were carried out by pulping the raw materials using the 8% alkaline sulphite process with 70% sodium hydroxide and 30% sodium sulphite. The unbleached pulp produced in the plant was also blended with different percentages of cotton hosiery waste pulp. Results are recorded in Table 10.

RESULTS AND DISCUSSION

Morphological and Chemical Analysis of Banana and Ankara Fibre

Table 6. Chemical Composition and fibre morphology of Banana and Ankara

Physical Parameters	Banana	Ankara
Ash,%	2.45	4.10
Lignin,%	11.90	11.10
Holo-Cellulose,%	84.11	89.50
Alpha-Cellulose%	82.00	79.00
Fibre Length, mm	3.00	9.00

The chemical and fibre morphological characteristics of the bleached alkaline sulphite pulp are shown in Table 6. It is clearly evident that banana fibre and ankara fibre possessed appreciably higher fibre length, *i.e.* 3.00 mm and 9.00 mm, respectively as compared to the other raw materials like bagasse and wheat straw which have fibre lengths of 1.30 mm and 1.50 mm, respectively. The higher fibre length in both the fibrous raw materials may be advantageous, thereby, providing an opportunity for the blending of these fibrous pulps in various proportions, depending on the desired end- products. This will help not only in addressing the issue of raw material scarcity but also help in reducing the cost of the handmade paper.

The chemical analysis as indicated in Table 6, showed lower lignin content in both banana and ankara fibres *i.e.* 11.90% and 11.10%, respectively and higher holocellulose and alpha-cellulose contents compared to agro residues and woody raw materials making them suitable for producing high-grade handmade paper.

Strength and optical properties of pulps from banana and ankara employing the three pulping processes

The results of the pulp produced from the three different pulping processes are shown in Tables 7, 8a, 8b, 9a, and 9b.

Table 7. Physical and Optical strength Properties of the Pulp from Alkaline Pulping Process (At ~ 300 ml freeness).

S.No.	Characteristics	Banana			Ankara		
	CSF*, mL	300			300		
		I	II	III	IV	V	VI
1.	Tensile Index (Nm/g)	64.03	65.65	67,71	71.00	71.89	72.80
2.	Tear Index (mN. m^2/g)	4.06	4.70	5.00	4.80	4.82	4.98
3.	Burst Index (Kpa.m^2/g)	4.10	4.98	5.12	3.80	4.01	4.51
4.	Double Fold ,No.	8500	8600	8650	5500	5550	5600
5.	Brightness (%) ISO	41.00	40.00	40.00	36.00	35.00	35.00

*Canadian Standard Freeness

Table 8a. Physical Strength and Optical Properties of the Pulp from Alkaline Peroxide Pulping Process (At ~ 300 ml freeness).

S.No.	Characteristics	Banana			Ankara		
	CSF*, mL	~300			~300		
		VII	VIII	IX	X	XI	XII
1.	Tensile Index (Nm/g)	85.50	86.10	86.65	80.31	81.11	82.10
2.	Tear Index (mN. m^2/g)	5.05	5.45	6.71	6.20	6.50	6.89
3.	Burst Index (Kpa.m^2/g)	8.20	8.51	8.80	6.26	6.51	7.12
4.	Double Fold ,No.	10,000	10,110	10,600	17,900	18,000	18,550
5.	Brightness (%) ISO	48.00	46.50	45.00	38.00	37.00	36.00

*Canadian Standard Freeness

Alkaline Pulping Process

Utilization of banana and ankara pulp for manufacturing of tissue paper and its application in archival use

The pulp thus produced from APP of banana and ankara (Experiments VII and X) was further explored for making tissue paper (11 GSM) and other grammage paper (25 and 40 GSM). The results of the strength properties and age of the banana and ankara papers are shown in Table. 8b.

Table 8b. Physical and Optical Strength Properties of Different GSM Tissue Papers Developed from Fibres at ~300 ml Freeness

S. No.	Characteristics	Banana			Ankara		
		VII			X		
	GSM	~11	~25	~40	~11	~25	~40
1.	Tensile Index (Nm/g)	52.76	60.00	65,12	32.50	35.97	40.12
2.	Tear Index (mN. m^2/g)	4.64	6.10	7.71	2.72	8.00	8.70
3.	Burst Index (Kpa.m^2/g)	2.46	3.87	4.00	3.25	2.70	3.90
4.	Double Fold ,No.	250	600	1000	17	651	1100
5.	Brightness (%) ISO	48.00	48.50	48.50	46.00	47.60	48.00
6.	Age, Years (Average)	-	650	-	-	452	-

From the results shown in Table. 8b, it was observed that the tissue paper produced from banana possessed reasonably high strength properties, double fold number (250) and high age (650 years) making it suitable for archival application for preservation of old manuscripts.

The other paper of higher GSM (25 and 40) produced from banana and ankara, because of their specific peculiar texture coupled with the other features including higher age and very high strength properties made it suitable for high-end applications and value-added hand craft products viz. lamp shades, greeting cards specialty stationary items and other gift items *etc.*

Table 9a. Physical Strength and Optical Properties of the Pulp from Alkaline Sulphite Pulping Process (At ~ 300 ml Freeness).

S. No.	Characteristics	Banana			Ankara		
	CSF	300			300		
	Experiment	XIII	XIV	XV	XVI	XVII	XVIII
1.	Tensile Index (Nm/g)	84.91	85.30	85.90	79.01	80.51	81.30
2.	Tear Index (mN. m^2/g)	4.35	5.15	6.00	5.90	6.51	6.78
3.	Burst Index (Kpa.m^2/g)	7.90	8.50	8.70	5.70	6.50	7.10
4.	Double Fold ,No.	9,100	10,100	10,700	16,000	18,210	18,800
5.	Brightness (%) ISO	39.00	38.49	38,00	38.12	38.00	37.77

Table 9b. Physical Strength and Optical Properties of Bleached Pulp from Alkaline Sulphite Pulping followed by Peroxide Bleaching (~300 ml freeness)

S. No.	Characteristics	Banana	Ankara
	Experiment	XIII	XVI
1.	Tensile Index (Nm/g)	84.98	79.50
2.	Tear Index (mN. m^2/g)	4.45	5.97
3.	Burst Index (Kpa.m^2/g)	7.98	5.90
4.	Double Fold ,No.	9,120	16,040
5.	Brightness (%) ISO	48.60	44.11

The bleached pulp of 8% treated pulp showed an increase in strength properties with a remarkable increase in the brightness of the pulp.

From the results shown in Tables 8a, 8b, 9a and 9b, it was observed that the strength and optical properties of the pulp produced from alkaline peroxide pulping and alkaline sulphite pulping process followed by peroxide bleaching were superior with respect to tensile index, tear index, burst index and double fold number. The pulp exhibited a reasonable brightness value wherein it was possible to achieve a brightness of 48.60% ISO and 44.11% ISO in the case of banana and ankara pulp produced from alkaline sulphite pulping followed by peroxide bleaching, which was higher compared to other pulping processes.

Pilot Plant Trials

In order to create confidence among the entrepreneurs of the handmade paper industry, studies were scaled up to pilot scale (25–50 kg capacity) using alkaline sulphite pulping for banana and ankara fibre as raw materials. Blending of the banana and ankara pulps was also conducted in order to see the synergy of the two pulps with conventionally used hosiery waste. The aim was to replace at a level of 50% of the cotton hosiery pulp with 50% banana and ankara. Results of the blending studies are shown in Table 10.

Table 10. Blending studies of Banana and Ankara (8% Alkaline Sulphite Pulping) with 50% Hosiery Waste.

Physical Parameters	Banana 100%	Banana, 50%+ Hosiery, 50%	Ankara 100%	Ankara, 50% + Hosiery, 50%	Hosiery-100%
CSF mL.	300	300	300	300	300
Tensile Index (Nm/g)	84.91	65.56	80.51	56.34	47.56
Tear Index (mN. m^2/g)	4.35	9.11	6.51	8.23	17.61
Burst Index, (KPa.m^2/g)	7.90	10.11	6.50	9.08	12.43
Folding Endurance No.	9,100	5000	18,210	11000	1400
Brightness, % ISO	39.00	50.14	38.12	48.65	73.00

From the results, it is clearly evident that the tensile strength and double folds were increased remarkably in both the cases. More than a 5-fold increase in folding endurance indicated the advantage of exploring these fibres for high-end products like currency and security paper *etc*. However, the conditions for pulping and bleaching may be optimized further for utilization in high-end products.

CONCLUSIONS

1. High cellulose and low lignin content of both banana and ankara make them suitable and potential raw materials for handmade paper making and other varieties for high end application *i.e.* archival application for preservation of manuscripts and currency/security paper, and value-added handicraft items.
2. Exploration of these renewable lingo-cellulosic raw materials for manufacturing of handmade paper and other high-end specialty papers should help the problem of raw material scarcity.
3. Promotion and utilization of these renewable lingo-cellulosic raw materials available in huge quantities in the Asian /African countries which otherwise are being dumped as a waste biomass, should address the problem of environmental pollution and global warming besides and help to generate opportunities for employment and women empowerment.
4. The results of high yield and strength were observed by APP process in VII and X batches.
5. Bleaching of alkaline sulphite pulp by using 2% hydrogen peroxide gave appreciable advantage with respect to the brightness and strength characteristics in addition to improvement in the environmental status due to lower pollution load in the effluent discharged in the recipient stream.
6. The advantage of using alkaline sulphite pulping process is that the black liquor generated by this process can be used by the adhesive industry.
7. It is recommended to go with a lower amount of chemicals to avoid effluent loads on the environment and also gives sufficient strength properties.
8. After successful pilot plant trials, blending studies indicated that the pulps can be used to make good quality of archival tissue/board paper, bond papers, pulp sheets, card sheets, archival box papers, file covers, tote bags, coated paper, marble paper, business cards *etc*.

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