Banana Fibre (*Musa sapientum*): "A Suitable Raw Material for Handmade Paper Industry via Enzymatic Refining "

Atul Kumar [1], B. P. Singh [2], R. K. Jain [3], A. K. Sharma [1]
[1]*Kumarrappa National Handmade Paper Institute, Jaipur (Rajasthan), India;*
[2] *Deenbandhu Chhotu Ram University of Science & Technology, Murthal (Haryana), India*
[3]*Central Pulp and Paper Research Institute, Saharanpur, (UP), India*

ABSTRACT

In recent past there is decline of Indian Handmade Paper in export market due to increase of cost of traditionally used good quality raw material ie hosiery waste and rags. The present paper covers the potential for availability of banana fibre and its morphological & chemical nature as well as the pulping technologies with enzymatic refining. The inherent characteristics of the banana fibre i.e. lower lignin content, higher alpha cellulose coupled with average higher fibre length and dia could prove its applicability for the manufacture of a good quality handmade paper while providing an opportunity to be used as reinforcing fibre by blending the banana fibre with the short fibres pulps like bagasse. Further, the paper also covers the studies on enzymatic refining of alkaline cooked banana pulp showed nearly 16% savings in beating / refining energy which added the benefit of use of this fibre for making handmade paper and paper products with improved strength properties.

Key words: Banana fibre, lignocellulosic, alkaline pulping, enzyme, enzymatic refining energy, blending.

I. INTRODUCTION

The Indian handmade paper industries has been placed the category of village industry and had seen significant growth in last one decade. But there is tremendous decline in export figure in last couple of years because of increasing price of traditionally used raw materials ie hosiery waste and rags so the paper makers could not able to supply the demand as per the international rate. The demand of handmade paper and paper products not only at national level but in the international arena has also been declined. As per estimates, there are nearly more than 500 handmade paper units scattered all over India producing nearly 50,000 tonnes of handmade paper and board. The Indian handmade paper industry in the recent past wherein the production of handmade paper industry has reached to a turnover of Rs 250,000 million which provides employment to about 15,000 people and most of them are situated in the rural areas [1].

Keeping view in all the scarcity of good quality lignocellulosic raw material & also with the growing trend of environmental friendliness, demand of handmade papers made out of natural fibers 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 / agro residues like Banana there by addressing the problem of environment and the issue of global warming in a right prospective [2].

Handmade paper sector is considered to be eco-friendly, utilizing non woody and waste raw materials in its manufacturing process. The durability of the paper is high with 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 have been traditionally using cotton hosiery waste as the main source of raw material, which produce paper with excellent strength characteristics.

Banana production in India is the highest, and the area under its cultivation is the second largest, among all the fruits grown in India. Banana fibres obtained from the pseudo-stem of banana plant which is a waste product from banana cultivation has not been utilized properly. The extraction of fibre from the pseudo-stem is not a common practice and most of the stem is not used for production of fibers [3]. At present, the banana fibre is considered as waste product of banana cultivation and is left to decay and rot thereby constituting pollution and waste disposal problems [4].

In recent times banana fibre is projected as a good and quite promising source of natural fibre in the future. It is extensively used in the manufacture of certain papers, particularly where high strength is required and also for decorative design items for the interiors of buildings. Banana fibres are complex in structure and are generally lignocellulosic consisting of helically wound cellulose microfibrils in amorphous matrix of lignin and hemicellulose. Banana stem pulping has been studied and with conflicting reports that showed pulping agent like caustic soda and sodium sulphite or calcium bisulphite do not produce an easily bleachable pulp [5].

Conventional method of paper making uses high amount of chemicals and energy thereby releases toxic substances that cause environmental pollution. There is an immediate need for an efficient route with less energy use of chemicals and energy and lower levels of pollution with improvement of product quality is being felt and remedies to such type of problems are now answering by application of biotechnology using appropriate enzymes for specific applications during refining as per the process requirements.

The present work aimed to study the utilization of banana fibre for paper making employing alkali ie NaOH as pulping agents to produce pulp from the natural fibre to retain its eco-friendly credentials to produce paper of high quality. The study further covers the enzymatic refining of banana pulp for reduction of refining energy.

II. MATERIALS AND METHODS

2.1. About the Cellulosic Raw Material Banana:

There are many varieties of bananas available worldwide, 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 fibre** extracted from pseudo stem of banana plant growing all along the coastal region in India viz. Maharashtra, Kerala, AP, Orissa, W.B., Assam, TN, Bihar and Karnataka. For every 30-40 Kg of banana sold, in the market there is 250 Kg of waste that needs to be got rid of. As per the estimate nearly over 1 billion tonne / year of banana stems are left to rot. Therefore, there is need to dispose of a mammoth problem in India [6].

The yield of fibre is around 2.5-3.0% of the dried weight of the pseudo stem of banana [7]. Fresh banana stem weight 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 underground rhizome, attaining height of 3 - 9.5 meters. The trunk (Pseudo stem) is formed from tightly rolled spiral leaf bases. The inflorescence appears 9-12 months of planting. The time from flowering to harvesting 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 4-5 sheaths give coarse fibres and inner - most 5 sheaths give soft fibres. The yield of fibres is about 2 - 4 % of the O.D. weight of stem. India can generate about 2 lakhs tonne of banana fibres annually which can produce nearly 1.65 lakh tonnes of handmade paper. Bearing in mind, as per estimates India produces about 50,000 – 55,000 tonnes of handmade paper using traditionally cellulosic raw materials like cotton rags and hosiery waste [2]. In the present research work the fibres from Tamilnadu state were used.

2.2. Fibre Extraction from Banana:

The ‘‘pseudo-stem’’ is a clustered, cylindrical aggregation of leaf stalk bases. Banana fibre at present is a waste product of banana cultivation and either not properly utilized or partially done so. The extraction of fibre from the pseudo stem is a common practice and much of the stem is not used for production of fibres. This is reflected from the relatively expensive price of banana fibres when compared to other natural fibres. But when we compared strength properties of it’s paper, the price may be compromised.

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

2.2.1. Manual extraction process

It involves cutting the trunk in to small pieces and scrapping them with the help of a comb like structure called scrapper.

2.2.2. Mechanical process

In this process chopped plant is passed through a simple machine called 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 are to be increased, especially in nation like in India as the fibre of the banana tree is a sustainable resource for manufacturing paper.

2.3. Chemical composition and Fibre Morphology of Banana & A Comparison with other Fibres.:

The banana fibre have important advantages such as low density, appropriate stiffness and mechanical properties and high disposability and renewability. Moreover, they are recyclable and biodegradable. Banana fibre, a ligno-cellulosic fibre, obtained from the pseudo-stem of banana plant (Musa sepientum), is a leaf fibre with relatively good mechanical properties.

The fibre of banana have complex in structure. They are generally lignocellulosic, consisting of helically wound cellulose microfibrils in amorphous matrix of lignin and hemicellulose. The cellulose content serves as a deciding factor for mechanical properties along with microfibril angle. A high cellulose content and low microfibril angle impart desirable mechanical properties for fibres. Lignin are composed of nine carbon units derived from substituted cinnamyl alcohol; that is, coumaryl, coniferyl, and syringyl alcohols [8]. Lignins are associated with the hemicelluloses and play an important role in the natural decay resistance of the lignocellulosic material. The composition of these fibres are obtained by elemental analysis, as determined [9]. Fibres are natural composite structures in which cellulose fibrils are held together by lignin and hemicellulose. The major constituents of plant fibres are lignin, cellulose, hemicellulose, and extractives. Each of these components contributes to fibre properties, which ultimately impact product properties [10].

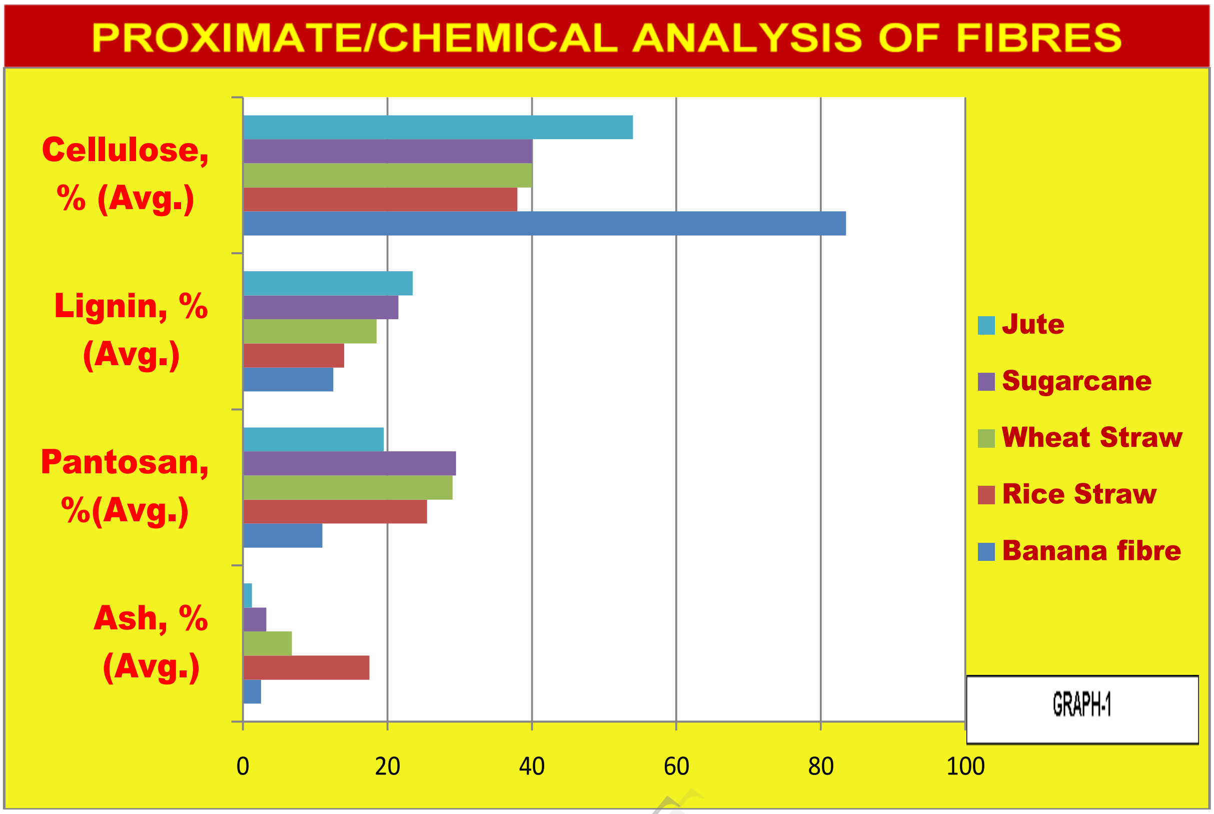
The trimmed sample of fibres were grilled in dust making machine and screened, since no diffusion limitations were observed for the particle size in preliminary studies. Samples were dried, homogenized in a single lot to avoid differences in composition among aliquots, and stored.

Characterization experiment involved the following parameters: ash (Tappi 211 om 85) alcohol-benzene extractives (Tappi 204 cm-97), cellulose (Tappi 203-om-93), Klason lignin (Tappi T 222 om-98) contents. All treatments in this study were in a completely randomized design with five replications (variation coefficient less than 5%. less than 1% for holocellulose and cellulose contents).

Table-1. Proximate / Chemical analysis of banana & it's comparison with other fibres*

Particulars	Banana fibre	Rice Straw*	Wheat Straw*	Sugarcane*	Jute*
Ash, %	2~3	15~20	4.5~9	1.5~5 0	0.5~2
Pentosan, %	10~12	23~28	26~32	27~32	18~21
Lignin, %	11~14	12~16	16~21	19~24	21~26
Cellulose,%	82~85	28~48	29~51	32~48	45~63

*(Properties of Non wood Fibers-James S. Han)



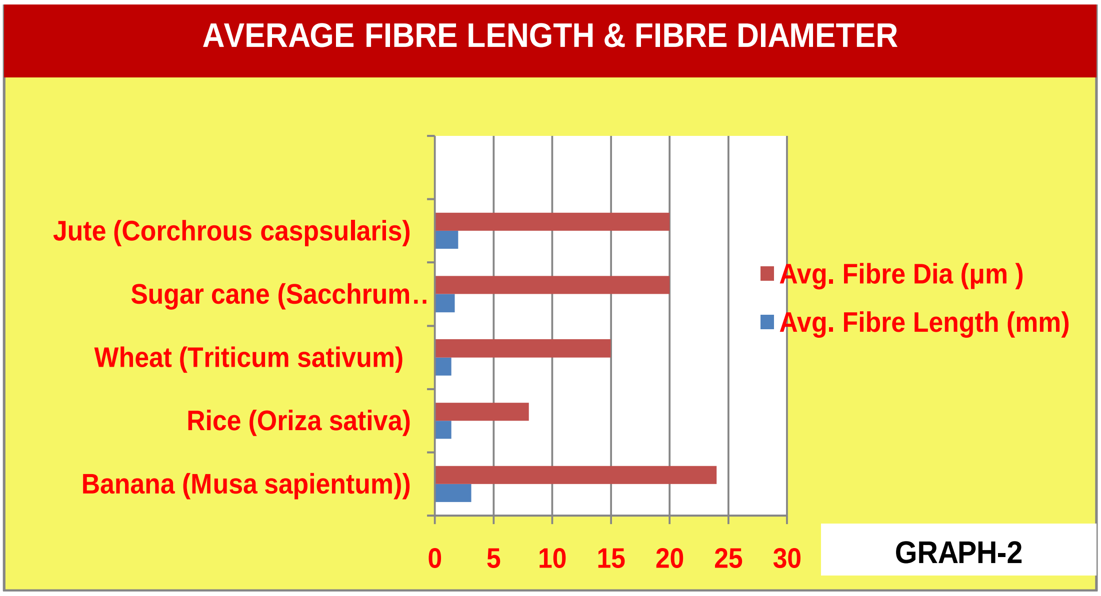
Fibre Length and Dia:

For determination of fibre length, 100 individual fibres were measured from each variety. Statistical analyses were performed using PROJECTINA Microscope and the differences among varieties were compared. The means were separated on the basis of least significant difference at 0.05 probability level.

Table-2. Length and Dia of Banana & comparison with other Fibres*:

Common name (Scientific name)	Fibre Length (mm)		Fibre Dia (µm)	
	Avg	Range	Avg	Range
Banana (*Musa sapientum*)	3.11	1.9~16	24.00	16~32
Rice* (*Oriza sativa*)	1.4	0.4~3.4	8	4~16
Wheat* (*Triticum sativum*)	1.4	0.4~3.2	15	8~34
Sugar cane* (*Sacchrum officiarum*)	1.7	0.8~2.8	20	10~34
Jute* (*Corchrous caspsularis*)	2	2~5	20	10~25

* Fibre length and fibre dia were reported by Isenberg (1967).



2.4. Pulping of the Banana Fibres:

Pulp is a fibrous material resulting from complex manufacturing processes that involve the chemical and / or mechanical treatment of various types of plant material. Today, wood provides the basis for approximately 90% of global pulp production, while the remaining 10% originates from annual plants. Pulp is one of the most abundant raw materials worldwide which is used predominantly as a major component in the manufacture of paper and paperboard, and with increasing importance also in the form of a wide variety of cellulose products in the textile, food, and pharmaceutical industries. The pulp industry is globally competitive and attractive from the standpoint of sustainability and environmental compatibility. In many ways, this industry is an ideal example of a desirable, self-sustaining industry which contributes favorably to many areas of our daily lives. Moreover, there is no doubt that it will continue to play an important role in the future. Although the existing pulp technology has its origins in the 19th century, it has still a very high potential of further innovations covering many areas of science. Knowledge of the pulping processes has been greatly extended since Pulping Processes the unsurpassed book of Sven A. Rydholm – was first published in 1965. Not only has the technology advanced and new technology emerged, but our knowledge on structure–property relationships has also deepened considerably. In context of handmade paper, cotton waste and hosiery waste being the basic raw materials for paper making in India, where pulping do not required normally but to process banana fibre Alkaline pulping process followed by enzymatic refining were conducted.

2.4.1. Alkaline Pulping Process.
2.4.2. Enzymatic Refining.

2.4.1. Alkaline Pulping Process.

Alkali treatments refers to the application of alkaline solutions. Among these, treatment with NaOH has been used for delignification of these pseudo stem ie. leaf fibre. The alkali treatment causes swelling, leading to an increase in internal surface area, a decrease in the degree of polymerization, a decrease in crystallinity, separation of structural linkages between lignin and carbohydrates, and disruption of the lignin structure. As a consequence, the lignin is dissolved from the raw material, being separated in the form of a liquor rich in phenolic compounds that represents the process effluent. The inconvenient of this technique is that it also degrades part of the hemicellulose.

After cutting the raw material banana into suitable size ie 1-1.5 inches, it was subjected to alkaline pulping method. The raw material was cooked at 100° C temperature with 8% of sodium hydroxide and cooked for three hours with the bath ratio 1:8.The conditions are depicted in Table-3[6].

Table-3. Pulping conditions of Banana fiber (Alkaline Pulping):

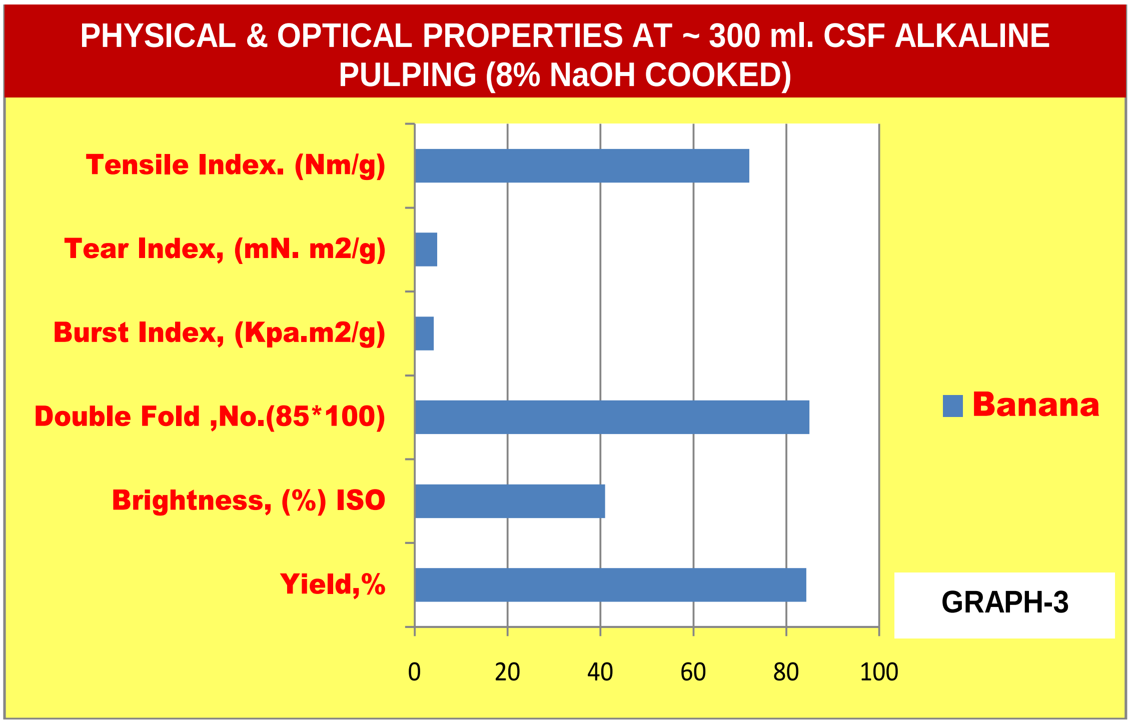
S.No.	Characteristics	Banana
1.	**Cooking conditions**	
	NaOH, %	8
	Time, Hrs	3
	Temperature °C	100
	Bath Ratio	1:8
2.	**Effluent Characteristics**	
	Residual active alkali after digestion, gpl	1.00
	BOD (Biological Oxygen Demand) **ppm**	1220
	COD (Chemical Oxygen Demand) **ppm**	6000
3.	**Pulp Yield ,%**	86.66

Strength Characteristics

After washing, the fibers were beaten in laboratory valley 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 $\pm$1ºC and 65$\pm$2 % relative humidity. After conditioning, the physical strength properties were evaluated as per the Standard Test Methods viz TAPPI, BIS, IS & ISO:2471. The results are recorded in Table-4[6].

Table-4. Physical and optical strength properties of the pulps from Alkaline Pulping Process (At ~ 300 ml freeness).

S.N.	Characteristics	Banana
	CSF, ml	**300**
1.	Tensile Index. (Nm/g)	72.03
2.	Tear Index, (mN. m^2/g)	4.86
3.	Burst Index, (Kpa.m^2/g)	4.10
4.	Double Fold ,No.	85*100
5.	Brightness, (%) ISO	41.00
6.	Yield,%	84.32



2.4.2. Enzymatic Refining.

Recently, there are several new technologies using enzymes able to modify fibres parameters, achieve desired properties, improve processing results and ecology in the area of bast fibre processing and fabric finishing. The main enzymes acting in bioprocessing process are pectinases, xylanases , laccases and cellulases. Pectinases have a leading role in the degumming of natural fibres by removing inter lamellar pectin which acts as a cementing substance between the fibres [16].

Production of release and high density papers requires high amount of refining energy. The use of cellulase / hemicellulse enzymes prior to beating/refining is proposed to modify the fibre surface and improve the fibrillation in the following mechanical treatment. Thus, less energy is needed to obtain a target refining level. In order to maintain good strength properties the use of cellulase containing enzyme mixtures requires thorough optimization.

Enzyme pretreatment of pulps

Enzyme treatment of alkaline cooked banana pulp (with 8.0% NaOH) was carried out by adding refining enzyme to the unrefined pulp after sufficient dilution & mixed properly by kneading mechanism. Enzymes in respective doses (0.03 %, 0.05% and 0.07%) were added and enzyme treatment of pulp was done using the conditions shown in Table-5. Control was run parallelly with maintaining all the conditions except the enzyme. Both the untreated and the enzymatically treated pulps were refine to obtain desired freeness values. After refining, the pulps were characterized for drainability and strength properties.

Table-5. Enzyme Pretreatment Conditions

Particulars	Control banana alkaline pulp	Enzyme treated banana alkaline pulp	Enzyme treated banana alkaline pulp	Enzyme treated banana alkaline pulp
Enzyme dose, %	-	0.1	0.1	0.1
Surfactant dose, %	-	0.03	0.05	0.07
Treatment Time,(min.)	30	60	60	60
Temperature, ^{0} C	50	50	50	50
Consistency, %	10	10	10	10
pH	8.5	8.5	8.5	8.5

Effect of Enzyme on refining energy

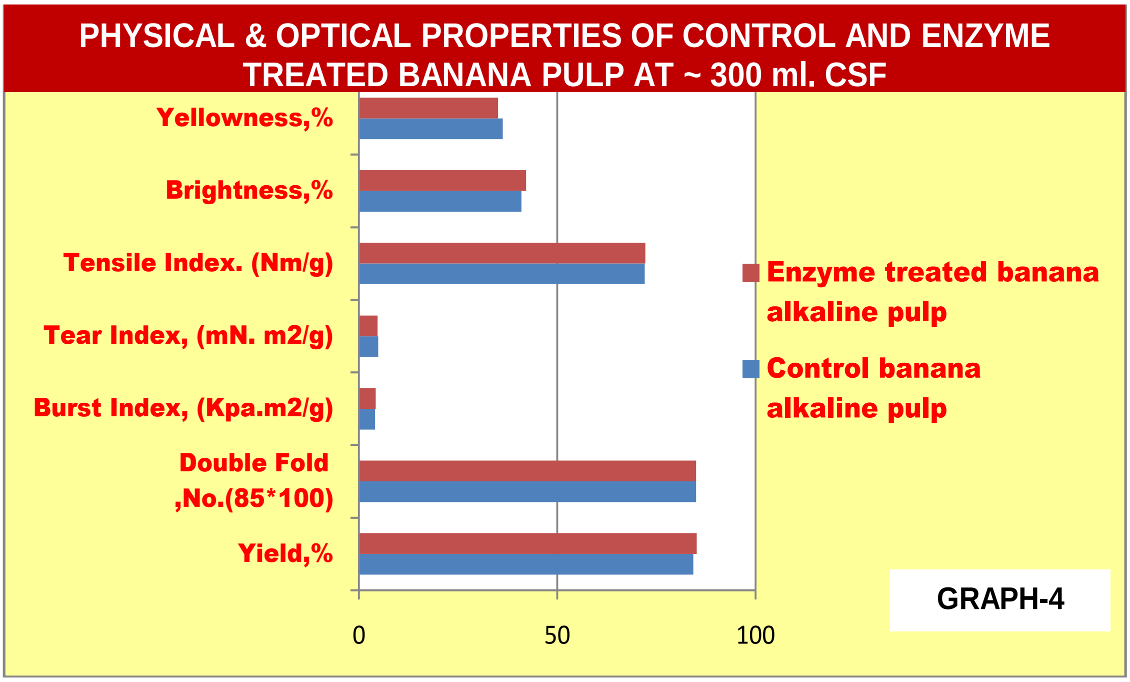
The effect of enzymatic refining can be visualized from the following table-6 and the further studies were made with the conditions of 0.1% enzyme and 0.05% surfactant dose refined pulp result.

Table-6. Effect of enzyme on pulp yield and refining energy during enzyme treatment of banana alkaline pulp

Parameter	Control banana alkaline pulp	Enzyme treated banana alkaline pulp
Yield, %	84.32	85.17
Refining energy consumed, KWH	1.50	1.25
Savings in Energy,%	-	**16.70**
Freeness ,CSF, ml	~300	~295

Table-7. Strength & Optical properties of enzyme treated and untreated (Control) alkaline banana pulps

Parameter	Control banana alkaline pulp	Enzyme treated banana alkaline pulp
Optical Properties		
Brightness , %	41.00	42.15
Yellowness,%	36.30	35.11
Strength properties		
CSF,ml	~300	~295
Tensile Index. (Nm/g)	72.03	72.21
Tear Index, (mN. m^2/g)	4.86	4.70
Burst Index, (Kpa.m^2/g)	4.10	4.25
Double Fold ,No.	8500	8500
Yield,%	84.32	85.17



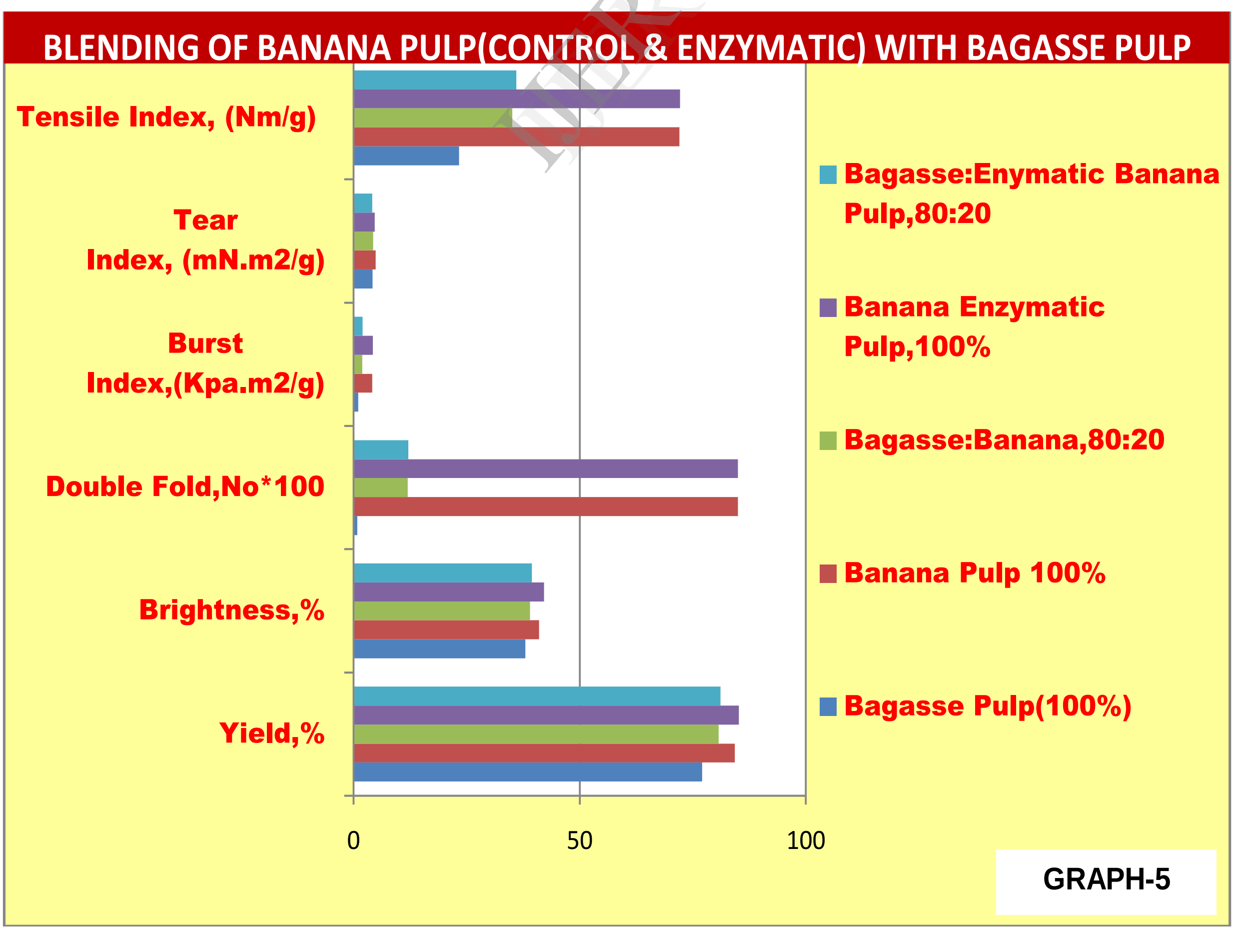
Although each treatment is more efficient to remove a specific fraction of lignocellulose, in some cases, a combination of them is required to achieve an efficient conversion of the fraction of interest. Biological or enzymatic treatments, for example, cannot be applied directly on the raw materials because lignin hinders the attack of fungi or enzymes to the material cell wall. Therefore, for the enzymatic hydrolysis of cellulose is crucial a previous hydrolysis step to promote a partial removal of lignin and hemicellulose, so that the cellulose fibers become more accessible to the enzymes attack. In addition, the best method and conditions of treatment depend greatly on the type of lignocelluloses, varying thus, with the raw material used. It is important emphasizing that the selection of a treatment method affects the cost and performance in the subsequent hydrolysis and fermentation stages. Ideal hydrolysis process should achieve high yields of fermentable reducing sugars, avoid degradation or loss of yielded sugars and the formation of inhibitors to the subsequent fermentation, and require minimal energy, chemicals and equipments.

2.5. Studies on blending of banana pulp (Alkaline Cooked & Refined pulp) with bagasse fibre pulp (8% Alkaline Cooked).

Blending of virgin pulp with short fibre pulp offers another viable option for upgrading the pulp sheet strength. Many studies have shown the strength enhancement of short fibre by adding virgin pulps (Latifah et al., 2009; Garg et al., al., 2008; Wanrosli et al., 2005; Rushdan, 2003; Aravamuthan et al., 2002; Dell & Paul, 1998; Horn et al., 1992). The major mechanism of strength improvement is probably due to increase of inter fibre bonding as a result of substitution of short fibres with active virgin fibres (Wanrosli et al., 2005). However, the strength properties of pulp blends are not simply the average of the strength properties of their component. Depending on the nature of the components and the specific property of interest, they may well be positive or negative deviations from the average (Rushdan, 2003). Strength properties of the bagasse fibre (80%) blended with banana pulp (20%) were given in table-8. There were an improvement in the strength properties of the blended pulp (80% bagasse fibre & 20% banana fibre) in respect of Tensile index, Tear index, Burst and Double fold as compared to the pulp from bagasse fibre (100%). Therefore, it could be possible to utilize the banana fibre pulp as reinforcing fibre for improving the quality of the paper being produced from bagasse fibre pulp.

Table-8. Strength Properties of Blended Pulp –Banana alkaline & Banana Enzymatic Refined Pulp with Bagasse Fibre (8% NaOH cooked for 3 hrs. at 100^0 C & at 300 ml.CSF) Pulp.

Characteristics	Bagasse fibre pulp (100%)	100% Alkaline Cooked Banana pulp	Bagasse fibre pulp + Banana pulp (80: 20)	100% Alkaline Enzymatic refined Banana pulp	Bagasee fibre pulp :Alkaline Enzymatic refined Banana pulp(80: 20)
CSF, ml	~300	~300	~300	~295	~300
Tensile Index, (Nm/g)	23.33	72.03	35.11	72.21	36.01
Tear Index, (mN. m^2/g)	4.21	4.86	4.31	4.70	4.10
Burst Index, (Kpa.m^2/g)	1.00	4.10	1.90	4.25	2.00
Double Fold , No.	82	8500	1200	8500	1210
Brightness, (%) ISO	38.00	41.00	39.00	42.15	39.41
Yield,%	77.10	84.32	80.71	85.17	81.14



III. RESULT AND DISCUSSION

3.1. The physical strength properties of the fibres of banana at 100 degree temperature showed a good strength properties that can be seen in the table (Table-4) Graph-3. Also the effluent generated is under control. The tensile and folding strengths are remarkable, also the other strength properties like tear and burst strengths are good. So the banana fibre can be used for making handmade papers by using NaOH in digester. The pulp thus produced can be used for making variety of handmade papers / paper boards, particularly specialty papers like archival tissue and water mark papers (Chhapri Papers). This method can be useful for the industry people who have the cooking utensils like digesters or even they do not have digesters simply go for open digestion.
3.2. There is an improvement of 1.00% in pulp yield of the enzyme treated banana pulp (0.1% enzyme & 0.05% surfactant) is observed when compared with the pulp yield of untreated pulp. Data is shown in table-6. Enzyme treatment resulted in to **16.70%** savings in consumption of energy during refining of enzyme treated pulp.
3.3. The strength properties of enzyme treated pulps of alkaline banana pulps were shown in table-7 &Graph-4. It has been observed that the strength properties like tensile and burst indexes of enzyme treated banana pulp were improved while the tear index is slightly decreased when compared with the strength of the untreated banana pulp. No changes were observed in double fold of the enzyme treated pulp. The brightness of the enzyme treated banana pulp showed 1.15 unit % ISO improvement and the yellowness of the pulp was reduced from 36.30 % ISO to 35.11%.
3.4. The blending studies with short fibre pulp like bagasse which were cooked with with 8% NaOH for 3 hours at 100 degree of temperature. The freeness (ie. Canadian Standard Freeness) level maintained was 300 ml. were blended with banana pulp of both enzyme treated and untreated pulp. The result depicted in Table-8 and Graph-5 clearly indicates that there is remarkable increase in tensile and double fold which enable to make paper like file covers and folders. Also there is in increase in burst which indicates that carry bags and wrapping papers can also be made.

IV. CONCLUSION

4.1. The investigation of cellulose content (82~85%), lignin (11~14%) and fibre dimensions (Average length-3.11mm, and Dia-24 μm) Table-1 & 2 and Graph-1 & 2 of the pseudo stem ie leaf fibres yielding banana plant with the use of certain indices showed that this raw material is very suitable for producing handmade paper of various grades. The same has been compared with other agro residue fibres which show the superiority of banana fibre.
4.2. Since the fibres are coming from annual plant. The variations in chemical and physical properties in a given plant might need to be controlled through agricultural practices. The yield of plant fibre as well as chemical compositions may vary from place to place. Of particular importance for pulping are fibre length, lignin content and cellulose content. The low lignin content indicates that this fibres will require very mild pulping conditions. At 8% of NaOH cooked pulp of banana fibre have good strength properties which make a suitable fibre for paper making.
4.3. The handmade paper industry with minimum effluent discharge and small size units allows a large canvas for use of bio-technological application over the big paper mills. Taking advantage of several options such as proximity to consumer or exporter centers, easy accessibility for transportation of supplies and products to various consumer centers, as well as a large employment potential, the very use of banana fibre can be a sustainable objective
4.4. As the Indian economy based on the rural economy, this production system will not only stop the wealth drain from rural to urban areas but also establish a strong industrial base for rural development with the perfect use of biomass.
4.4. The high biomass output of the fibre plants could provide large amounts of pulp, which could substitute the conventional raw materials used in India.
4.5. The another very good use of the banana pulps are as to blend it with bagasse (A short fibre Pulp). As evident from the results depicted in table 8 that the strength properties increased remarkably in many parameters. Here, it may also be recommended that this banana fibre by enzymatic route of refining, can replace imported long fibre wood pulp sheets which are being imported by big paper mills.

V. ACKNOWLEDGMENT

Authors thankfully acknowledge the technical support rendered by Shri. Dhermendra Kumar, JRF & Ms. Chetna Gupta, JRF during the experimental work. Thanks are also due to Shri. Kamal Raj Sharma, Lab. Assistant for testing of papers.

VI. REFERENCES

[1]. Strengthening of Handmade Paper industry in India (IND/90/037/A/01/37). Technical Report on Pulping of fibrous raw materials for handmade papermaking, UNDP-KVIC Project, Prepared by- Ing. Abinish Panda, Senior Consultant Pulp and Paper Industry, September,1995.

[2]. Technical Survey Report under ADB-KVIC Programme for Cluster Development of Handmade Paper in India under KRDP Programme submitted by KNHPI, Jaipur to Khadi and VI Commission, Mumbai.

[3]. Mukhopadhy,S., Fangueiro, R ., Arpaç, Y and Şentürk, U (2008) Banana fibres -Variability and Fracture Behaviour, Journal of Engineered Fibers and Fabrics, Vol.3

[4]. Saravana Bavan D and G C Mohan Kumar (2010) Potential use of natural fiber composite materials in India *Journal of Reinforced Plastics and Composites* 29: 3600 http://jrp.sagepub.com/content/29/24/3600.

[5]. Heikal, S.O (1976) Nitric acid paper pulps from banana stem. Indian Pulp and Paper 31(3): 5

[6]. The Use of Alternate Ligno-cellulosic Raw Materials Banana *(Musa sapientum)* Ankara *(Calotropis procera)* and Pineapple *(Ananas comosus)* in Handmade Paper & their Blending with Waste Paper. Atul Kumar[1],Brij Pal Singh [2],Rakesh Kumar Jain[3],and Ashwini Kumar Sharma,[1] 1: Kumarappa National Handmade Paper Institute, Sanganer, Jaipur, (Rajasthan) ,India; 2: Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Sonepat (Haryana),India; 3: Central Pulp and Paper Research Institute Saharanpur,(UP),India. Paper published in American Journal of Engineering Research (AJER) e-ISSN : 2320-0847 p-ISSN : 2320-0936 Volume-02, Issue-09, pp-171-189 www.ajer.org

[7]. Panda, A., Singh, S. N., Bhoomiah, M. and Khandekar, V. "Handmade Paper Making in India: Prospects, Possibilities and Problems," Paper-ex-1995,International Seminar on Pulp and Paper Industry, New Delhi,Pages-157-187.

[8]. Literature review of physical and chemical pretreatment processes for lignocellulosic biomass-"BIOSYNERGY" Paulien Harmsen*, Wouter Huijgen**, Laura Bermudez***, Robert Bakker**Wageningen UR Food & Biobased Research (WUR-FBR, NL) **Energy Research Centre of the Netherlands (ECN, NL) ***Abengoa Bioenergía Nuevas Tecnologías (ABNT, ES) September 2010, Report 1184

[9]. Cellulose-Prof. Dr. Dieter Klemm1, Prof. Dr. Hans-Peter Schmauder2,Prof. Dr. Thomas Heinze3, 1 Institute of Organic and Macromolecular Chemistry, Friedrich Schiller University of Jena, Humboldtstrasse 10, D-07743 Jena, Germany; Tel.: _49-3641-948-260; Fax: _49-3641-948-202; E-mail: c9kldi@uni-jena.de 2 Research Centre of Medical Technology and Biotechnology, Geranienweg 7,D-99947 Bad Langensalza, Germany; Tel.: _49-3603-833-140; Fax: _49-3603-833-150; E-mail: hpschmauder@fzmb.de 3 Bergische University of Wuppertal, FB 9, Chemistry, Gauss Strasse 20, D-42097 Wuppertal, Germany; Tel.: _49-202-439-2654; Fax: _49-202-439-2648;E-mail: theinze@uni-wuppertal.de

[10]. A Review of Literatures Related of Using Kenaf for Pulp Production (Beating, Fractionation, and Recycled Fiber)- Published by Canadian Center of Science and Education (Modern Applied Science) Vol. 4, No. 9; September 2010,by Ahmad Azizi Mossello (Corresponding author) Institute of Tropical Forestry and Forest Products, University Putra Malaysia, Malaysia Department of Desert Region Management, College of Agriculture, Shiraz university, Shiraz, Iran, Jalaluddin Harun & Paridah Md Tahir Institute of Tropical Forestry and Forest Products, University Putra Malaysia, Malaysia Hossein Resalati Faculty of Forestry and Wood Technology , Gorgan University of Agricultural and Natural Resources, Iran.

[11]. Properties of Nonwood Fibers*1James S. Han*2
*1 Part of this paper was presented as Fiber Property Comparison at the TAPPI 1998 North American Nonwood Symposium at Atanata, GA, February 17~18 Co-sponsored by USDA Forest Service and USDA Biobased Products Coordination Council.
*2 USDA Forest Service, Forest Products Laboratory, Madison, WI 53705-2398. USA

[12]. Rousu,P., P.Rousu and Antytila,2002 "Sustainable pulp production from agricultural waste" Resour.conservat.Recycling,35:85-103.

[13]. Jime'nez,L.,Ramos,E.,Rodryguez,M.J. De-la-torre and Ferrer, 2005. Optimization of pulping conditions of abaca. An alterative raw material for producing cellulose pulp. Bioresour.Technol., 96:977-983.
[14]. Omotoso , M.A and Ogunsile,B.O,2009 " Fibre and Chemical properties of some Nigerian grown *Musa* species for pulp production" Asian Journal of Materials sciences 1(1): 14-21,2009.
[15]. Goswami ,T ,Kalita, D & Rao P.G.(2008) Greaseproof paper from banana (*Musa paradisica*) pulp fibre Indian Journal of chemical Technology Vol.15,2008,pp.457-461
[16]. Nicemol Jacob, N and Prema, P (2008) Novel Process For The Simultaneous Extraction And Degumming Of Banana Fibers Under Solid-State Cultivation , Brazilian Journal of Microbiology (2008) 39:115-121
[17]. Bhardwaj, N. K., Hoang, V., & Nguyen, K. L. (2007). A comparative study of the effect of refining on physical and electrokinetic properties of various cellulosic fibres. *Bioresource technology*, 98(8), 1647-1654.
[18]. Gupta H. K., Kumar A., Agrawal, S. (2001). "Role of Handmade Paper units in improving paper quality and efficiency of recycled waste paper based mills," *IPPTA Journal* 13(4),pages-47-51
[19]. Hunter, D. *Paper Making: The History and Technique of an Ancient Craft,* Dover Publication Inc. New York.
[20]. Handbook of Paper and Board, H. Holik (Ed.) 2006, ISBN 3-527-30997-7
[21]. Handbook of Pulp- Edited by Herbert Sixta Copyright © 2006 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim ISBN: 3-527-30999-3

VII. BIOGRAPHY

Mr. Atul Kumar, M.Sc.(Chemistry),P.G.D.in Pulp and Paper, (Forest Research Institute, Dehradun, India) Scientist, having more than 17 years of experiences in the field of research and development activity of Pulp and Paper. Presently with Kumarappa National Handmade Paper Institute, Jaipur, India devoted for the revival and benefit of the handmade paper Industry in India.

Dr. Brij Pal Singh, M.Sc.(Chemistry) Ph.D. in polymer science, Professor, Department of Chemistry, D.C.R. University of Science and Technology, Murthal, Sonepat, Haryana India, have experiences of more than 30 years in area of polymer synthesis and degradation of polymers. current research interests are composite materials of technological and commercial importance.

Dr. Rakesh Kumar Jain, M.Sc.(Chemistry) Ph.D. in Pulp and Paper, Scientist-F & Head, Biotechnology & Lignin By-products at Central Pulp and Paper Research Institute, Saharanpur,UP, India, have experiences of more than 30 years in area of pulp and paper, lignin polymers. An eminent scientist who has 100 research paper published and 8 patents.

Mr. Ashwini Kumar Sharma, B.E.(Pulp and Paper), IIT Roorkee, India, Dy. Director, having more than 25 years of experiences in the field of Pulp and Paper which include paper mill experiences. Presently with Kumarappa National Handmade Paper Institute, Jaipur, India.