Biotechnological Application of Enzymes for making Paper Pulp from Green Jute/Kenaf (the whole plant)

PROJECT COMPLETION REPORT (PCR)

FC/RAS/00/153

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CONTENTS

Glossary

AOX	-	Absorbable Organic Halide
APMP	-	Alkaline-Peroxide-Mechanical-Pulping
APXP	-	Alkaline-Peroxide-Extruder-Pulping
BOD	-	Biological Oxygen Demand
C	-	Chlorination (Cl_2)
CEH	-	Chlorine-Alkali-Hypochlorite
COD	-	Chemical Oxygen Demand
CTMP	-	Chemi-Thermo-Mechanical-Pulping
D	-	Chlorine dioxide bleaching (D)
DED	-	Chlorine dioxide-alkali-chlorine dioxide
E	-	Alkaline extraction (NaOH)
E_0	-	Alkaline extraction reinforced with oxygen
ECF	-	Elemental Chlorine Free
H	-	Hypochlorite bleaching (Na or Ca)
L	-	Laccase (enzyme)
LE	-	Laccase followed by alkali
OCEH	-	Oxygen-chlorine-alkali-hypochlorite
ODED	-	Oxygen chlorine dioxide-alkali-chlorine dioxide
OXECH	-	Oxygen-xylanase-alkali-chlorine-hypochlorite
OXEDED	-	Oxygen-xylanase-alkali-chlorine dioxide-alkali-chlorine dioxide
P	-	Hydrogen peroxide bleaching
RMP	-	Refiner Mechanical Pulping
TCF	-	Total Chlorine Free
TMP	-	Thermo Mechanical Pulp
X	-	Xylanase (enzyme)
XCEH	-	Xylanase-chlorine-alkali-hypochlorite

XDED	-	Xylanase-chlorine dioxide-alkali-chlorine dioxide
XE	-	Xylanase followed by alkali
XECEH	-	Xylanase-chlorine-alkali-chlorine dioxide-alkali-cholrine dioxide
XEDED	-	Xylanase-alkali-chlorine dioxide-alkali-chlorine dioxide
XRP	-	Extruder-Refiner-Pulp
Z	-	Ozone bleaching

BIOTECHNOLOGICAL APPLICATION OF ENZYMES FOR MAKING PAPER PULP FROM GREEN JUTE/KENAF (WHOLE PLANT)

Executive Summary

Production of jute/kenaf in Asia

Annual world production of jute, kenaf and allied fibers is around 3 million MT. About 90% of the world production originates in Bangladesh, China, India and Thailand. In addition to fiber 1.6 million MT of leaves and 8.00 million MT of sticks are also produced amounting to total biomass production of 12.6 million MT. Jute and Kenaf provide livelihood for millions of growers, industrial workers and traders in the region.

Traditional uses of jute

Jute is traditionally manufactured into final products by methods involving spinning and weaving. Compared to technologies adopted for other fibers and textile industries, jute production and processing techniques have remained very much unchanged. The traditional jute products' markets such as packaging materials for agricultural products (including sacks, bags, carpet backing cloth, packaging for fertilizers, cement and chemicals) are being eroded by synthetic substitutes. As a result, diversification of the uses of jute has been the main thrust of efforts aiming at identifying new major market outlets. One alternative to which a great deal of attention has been given is the possible utilization of jute and kenaf in pulp and paper production. Extensive research at various institutes and pulp and paper mills indicates that most conventional pulping and bleaching techniques are suitable for jute and/or kenaf pulping.

Consumption of paper in selected jute/kenaf producing countries

The demand for paper and paperboard has increased sharply in Bangladesh, China, India and Thailand. The per capita consumption of paper and paperboard in the region is such that there is an urgent need to develop new sources of fibers raw material for pulp and paper production.

Background

There has been recently a renewed worldwide interest for annual plants including jute and kenaf, as a raw material for pulp and paper. The stem of jute and kenaf consists of two fibrous components, both of which are suitable for producing paper and paperboard products. The bark fiber is about 2.5 mm in length and constitutes 25 to 35% by weight of the stem. The shorter core fiber is about 0.6 mm in length and constitutes 60-65% by weight of the stem. Both are suitable for quality papermaking. The bark is similar to softwood fibers while the core fiber has strength properties similar to that of hard wood fibers. In Bangladesh, the Bangladesh Chemical Industries Corporation (BCIC) is the major user of fibrous raw material in the country and use bamboo, wood and bagasse as raw materials for the production of pulp and paper.

The Project

The project described in this report was initiated in January 2001 and terminated in May 2004.

Funding Agency

The common Fund for Commodities (CFC) provided the major part of the funding for the implementation of the project with co-financing from the governments of France and Bangladesh.

Development Objective

To assess the technical and economic feasibility and environmental sustainability of biotechnological processing of jute and kenaf for the commercial production of high quality pulp and paper.

Participating Institutes

The project involved collaboration of the Agro-technology & Food Innovations (A&F), The Netherlands, Centre Technique du Papier (CTP), France, the Central Pulp and Paper Research Institute (CPPRI), India, the Institute of Bast Fiber Crops (IBFC) and Yuanjiang Mills, China, the Bangladesh Chemical Industries Corporation (BCIC) and Bangladesh Jute Research Institute (BJRI), Bangladesh.

Optimization of pulping

The conditions of pulping in laboratory scale have been optimized through the use of two main chemical processes (Soda-AQ and Kraft) to produce bleachable grade pulp of Kappa number 20, which is considered to be suitable for good quality paper. Good quality pulp was produced with yield in the range of 46%-48%.

Biopulping results

- Application of biotechnology in the chemical process reduces the Kappa number by 20%.
- Desired Kappa numbers can also be obtained by reducing the alkali charge by approx 9% in Soda-AQ-pulping.
- Cooking time can be reduced from 120 minutes to 60 minutes in the Kraft process and from 90 minutes to 60 minutes in the Soda-AQ process. As a result, mill throughput can be considerably increased.
- Physical properties of paper (burst, tear and tensile index) can be improved significantly (20-40%) in biopulping process thus obtaining a better quality paper.

Bleaching results

- Bleaching was conducted with the conventional bleaching sequences CEH- (Chlorine alkali hypochlorite), ECF (Elemental Chlorine Free)-Chlorine dioxide-alkali chlorine dioxide and TCF (Total Chlorine Free) sequences with and without enzyme.
- The target brightness of 80% ISO was achieved in most of the sequences.

The use of enzyme (xylanase) in the bleaching sequences reduces the chlorine requirement by 15%. Chlorine can be reduced by 30% if xylanase treatment is followed by alkali and by 40-45% if it is used in conjunction with oxygen.

Storing and Black Liquor Management

The results of the project show that jute black liquor is suitable for evaporation to high solid concentration and for further processing in the recovery boiler. It has high carbon content (38.1%), high calorie value (3438 cals/gram), low viscosity at high solid concentration and very low concentration of non-process elements concentrations. This makes it suitable for chemical recovery operations.

Whole jute is relatively free of fungal contamination if stored after drying at moisture contents below of 15%. In case of fungal attack, a number of fungicides are effective.

Pilot Scale and Commercial Trial

Optimization of pulping was followed by a large scale (14 MT) and a commercial trial (80 MT). In Bangladesh, whole jute plants were chipped using the available mill chipper after necessary adjustment. After the production of pulp, bleached paper was produced using the conventional sequence of bleaching (40-42 MT) in the existing paper machine. The quality of the resulting paper was found suitable for wrapping and different grades of writing paper. The physical properties of the unbleached and writing paper were superior to paper made from bamboo and tropical wood. These results were corroborated by a pilot scale trial conducted in India using chemical processing.

The original planned commercial scale trial for the production of chemical pulp from kenaf could not be performed as planned. Therefore it has not been possible to compare the pulp characteristics of jute and kenaf against each other. The inability to conduct such comparative study regarding the yield, cost and physical properties of paper from jute vis-à-vis kenaf is a shortcoming that needs to be addressed in the future. However, it is expected that jute can produce better pulp than kenaf, because the fiber (bark) to stick ratio is 1:2, whereas fiber (bark) to stick ratio of kenaf is around 1:3. Ultimate fiber length of bark of both kenaf and jute is around 2 mm whereas that of core is less than 1 mm. Moreover, the price of whole kenaf in Bangladesh/India is comparatively less. Therefore, it is perhaps a preferable raw material in terms of raw materials for the paper industry.

TMP process results

- The resulting pulp had weak mechanical properties. However, the pulp bleaching led to 70% ISO brightness with 5% hydrogen peroxide charge.

- A chelation stage was necessary prior to the bleaching stage. Furthermore, three commercial enzymes were tested prior to the bleaching stage with little effect.

APMP process results

- Pulps were obtained with different chemical charges resulting in pulp of mechanical properties suitable for newsprint papers. The brightness target of 60-65% ISO was achieved.
- The best chemical charge was 3% sodium hydroxide and 1% hydrogen peroxide for the impregnation stage and 3% hydrogen peroxide and 1.5% sodium hydroxide applied at the bleaching stage. These chemical charges can only be slightly reduced.
- The yield of mechanical pulping was 80%. This paper is suitable for newsprint.

High yield pulping experiments using extruder and refiner and as well as mechanical pulping trials by APMP process showed that refiner pulping of jute is superior to extruder pulping in terms of energy consumption, mechanical performance and structural performance of pulp and paper. On the other hand, extruder pulping of jute is superior to mechanical pulping in terms of opacity. Fungal pre-treatment of jute in the refiner mechanical pulping can reduce energy consumption by approximately 20-25% with improvement in strength properties and brightness.

APMP pulp was shown to be much stronger and brighter than thermo-mechanical pulp and can be used for newsprint paper. The yield of pulp was around 80% and the brightness 60-65% ISO.

Economic pre-feasibility study

The study concluded that:

1. The sale of fine paper from chemical pulp and newsprint paper from mechanical pulp in the Bangladesh domestic market is the best option if it is supported by government through reduction or exemption of import taxes for chemicals and/or financial assistance on VAT, Corporate Tax, etc. The construction of Pulp Mill in the EPZ may constitute such government assistance.

2. Production of paper and pulp from kenaf under the current conditions prevailing in India seems to be the most attractive commercial option.

3. A more detailed feasibility study is necessary in order to validate the numerous assumptions that were made in the study (e.g. prices of raw materials, inland freight, interest rate, local tax and sales prices for pulp and paper, etc.) assumptions, and also include costs of cultivation, the logistics of storing the raw materials as well as market demand.

PROJECT COMPLETION REPORT (PCR)
BIOTECHNOLOGICAL APPLICATION OF ENZYMES FOR MAKING PAPER PULP FROM GREEN JUTE/KENAF (THE WHOLE PLANT)

I. Project Summary

1.1 ***Project Title:*** Biotechnological Application of Enzymes for Making Paper Pulp from Green Jute/Kenaf (The Whole Plant)

1.2 ***Number:*** FC/RAS/001/153

1.3 ***Project Executing Agency (PEA):*** United Nations Industrial Development Organization (UNIDO)

1.4 ***Location:*** Bangladesh, China, India, France and the Netherlands

1.5 ***Starting Date:*** 01.01.2001

1.6 ***Completion Date:*** 31.05.2004

1.7 ***Financing:***

Total Project Cost: US$ 1,493,260

CFC Financing (Grant): US$ 888,260

Co-financing by other donors: Government of France US$ 110,000 European Commission and Government of Bangladesh US$200,000

Counterpart contribution from participating countries/institutes: US$295,000

The details of the counterpart contributions from participating institutes are:

International Jute Study Group (IJSG)	US$ 10,000
Bangladesh Jute Research Institute (BJRI), Bangladesh	US$ 30,000
Bangladesh Chemical Industries Corporation (BCIC), Bangladesh	US$ 70,000
Institute of Bast Fiber Crops (IBFC), Yuanjiang (Hunan), China	US$ 20,000
Centre Technique du Papier (CTP), France	US$ 50,000
Central Pulp and Paper Research Institute (CPPRI), India	US$ 55,000
Agrotechnology & Food Innovations (A&F), The Netherlands	US$ 60, 000
	Total US$ 295,000

II. Background and Context in which the Project was Conceived

Conventional jute and kenaf products are now facing severe competition due to the emergence of synthetic substitutes. The diversification of jute/kenaf uses is very much of an imperative for the survival of the jute/kenaf industry. Demand for pulp and paper has increased significantly in the jute/kenaf growing countries, while their limited forest resources are further dwindling. The substitution of conventional raw material for pulp and paper by jute and/or kenaf would be both timely and beneficial to the rural economy and the environment.

Jute fiber is traditionally manufactured into final products through methods involving spinning and weaving. Compared to technologies adopted for other fibers and textile industries, jute production and processing techniques have remained very much unchanged. The traditional jute products' markets such as packaging materials for agricultural products (including sacks, bags, carpet backing cloth, packaging for fertilizers, cement and chemicals) are being eroded by the use of products based on synthetic substitutes. Diversification of the uses of jute by identifying major new market outlets is therefore essential to fend off further decline of the jute sector. One alternative to which a great deal of attention had been given in the recent past is the possible utilization of jute and/or kenaf in pulp and paper production. Extensive research at various institutes and pulp and paper mills indicates that most conventional pulping techniques are suitable for jute/kenaf pulping.

Annual world production of jute and allied bast fiber (kenaf) is around 3 million tons (**Table 1**). In addition to fiber, 6.5 million tons of sticks are also produced. Therefore, subject to meeting several technical and economic criteria, surplus jute/kenaf production can be directed for the paper industry.

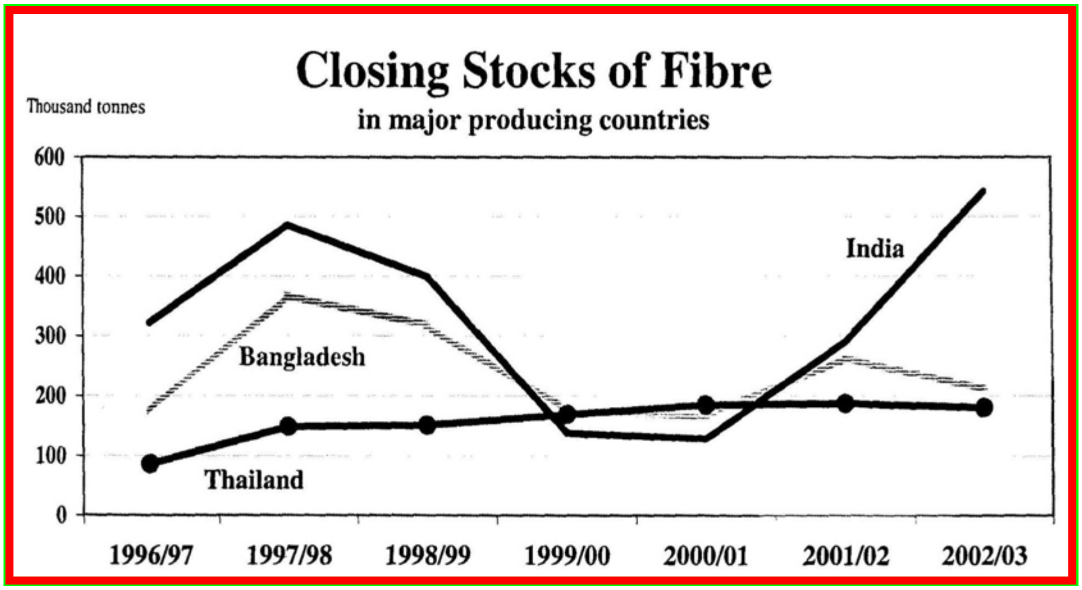
Table 1: World Production of Jute and Kenaf

Country	Area '000 ha	Jute ('000 MT)		Kenaf ('000 MT)	
		Fiber	Stick	Fiber	Stick
World	-	2,612.7	5,225.4	433.7	1,301
Bangladesh	426	777	1,554	--	--
India	1070	1,778	3,556	202	606
China	56	--	--	130	390
Thailand	19	--	--	30	90
Nepal	11	16	32	--	--

Source: *FAO, jute, kenaf and allied fibers June 2003. CCP: JU/HF/ST/2003/1.

**Calculated from Dempsey James, M. Fiber Crops, 1975. A University of Florida Book

The statistics of the last five years of closing stocks of fiber in major producing countries, like, Bangladesh and India show that fiber is available at the end of each season. This surplus jute can, in theory, be used for the pulp and paper industry.



Source: FAO - CCP: JU/HF/ST/2003/1.

The project specifically aims at developing biotechnological processes, which would be applicable in processing of jute into pulp and paper products, i.e. biopulping for the pretreatment of the raw material and enzyme-aided bleaching for achieving reduction in chemical and/or energy consumption. These processes are virtually unpracticed in the pulp and paper industry in the developing world albeit the fact that the use of biotechnology in the sector has been reported to have significant economic and environmental advantages[1]. Of the process stages studied and developed, the application of enzymes in bleaching are already being used in several mills worldwide (producing 500-1000 tons of pulp/day), whereas the biopulping technology has so far only been tested in pilot trials in quite large scale (about 50 tons/day)[2].

[1] Dr. G.M.Scott, Dr. M. Akhter and Dr. T.K.Kirk, "An update on Biopulping Commercialization", TAPPI 2000 Pulping/Process & Product Quality Conference, Nov. 5-8, 2000, Boston, USA.

[2] Dr. Liisa Viikari, "Enzymes in the Pulp and Paper Industry", TAPPI 2000 Pulping/Process & Product Quality Conference, Nov. 5-8, 2000, Boston, USA.

One of the main objectives of the project is the identification of the most promising biotechnological processes by comparing them against the standard chemical and mechanical pulp manufacturing processes employed by the industry and assessing their applicability in the context of opportunities and capacities of jute-producing countries in the developing world.

Conventional pulping is the process by which wood is transformed into a fibrous mass. Existing commercial processes are generally classified as mechanical, chemical or combined (chemical and mechanical).

Chemical pulping

Chemical pulping accounts for 75% of the world pulp production of which 90% is produced by the dominant Kraft process. The objective of chemical pulping is to degrade and remove all of the lignin thus leaving behind most of the cellulose and hemicullose in the form of intact fibers. In practice chemical pulping methods are successful in removing most of the lignin; they also degrade certain amount of hemicelluloses and cellulose so that the yield of pulp is low compared to mechanical pulping, usually between 40 and 50% of the original raw materials. In chemical pulping, the wood chips are cooked with the appropriate chemicals at elevated temperature and pressure. The two principal methods are alkaline kraft process and the acidic sulphite process. The kraft process is dominant because of advantages in chemical recovery and pulp strength.

Mechanical pulping

Until recently, the most common method of mechanical pulping was the ground wood processes where a block of wood is pressed lengthwise against a grinding stone. This has been superseded by what is known as the Refiner Mechanical Pulping (RMP). This process involves shredding and grinding chips of woods between the rotating disk of the refiner. RMP has undergone substantial development in the past few years. New installations now employ thermal (and/or chemical) pre-softening of the chips to modify both the energy requirements and pulp properties. For example, Thermo Mechanical Pulp (**TMP**) is usually much stronger than RMP and contains very little screen reject material. Mechanical pulping processes have the advantage of converting up to 95% of the dry weight of the wood into pulp, but they require substantial amounts of energy to accomplish this. However, mechanical pulps form opaque paper with good printing properties but the sheet is weaker than chemical pulps and discolours easily on exposure to light because of the high lignin content.

Traditionally, newsprint-quality paper has been produced by mixing 75% ground wood and 25% chemical pulp although more recently the percentage of chemical pulp has been further reduced. In industrialised countries newsprint-quality paper is nowadays made out of combinations between TMP and recycled paper. At present, several mills produce newsprint-quality paper consisting of 100% recycled material.

TMP processes have been augmented by the addition of sodium sulphite, in a process, called chemi-thermo-mechanical pulping (CTMP), or by addition of NaOH instead of sodium sulphite. These latter pulps are called alkaline-thermo-mechanical pulps (ATMP).

The latest development is to replace sulphite by alkali and peroxide, which is more environments friendly. This process is known as alkaline-peroxide-mechanical-pulping (APMP). Mechanical pulping has the disadvantage of being capital and energy intensive and yields paper of lesser strength. These disadvantages limit the use of mechanical pulping in some grades of paper only. Increasing environmental awareness has made it necessary to investigate methods for reducing the amount of energy, sulphur and chlorine containing compounds. This has led to the development of biopulping and biobleaching.

Biopulping

Biopulping is defined as the treatment of wood or other lingocellulosic material with natural lignin-modifying/degrading fungi prior to pulping. Pre-treatment of chips reduce the energy requirement (in mechanical pulping), chemical requirement and cooking time (in chemical processes) and improve the handsheet physical properties.

Research work and mill trials until now have been focused on the application of enzymes for the pulping and bleaching of wood. The application of enzymes has shown encouraging results regarding their efficiency vis-à-vis other traditional bleaching techniques. Biobleaching allows substantial savings in overall chemical costs and reduces chlorinated organic materials in pulp and effluents thus providing an attractive alternative to conventional processes.

The application of biotechnological methods on wood has been shown to reduce energy consumption by 20 to 30% and improve the burst and tear indices. Application for bio-technological methods on wood in the chemical process of pulping[3] and bleaching has also been reported to reduce chemical consumption and cooking time. Reduction of chemical consumption would have positive impact on the environment by minimizing the levels of Absorbable Organic Halide (**AOX**) and chlorides in the bleaching plant effluents. On the other hand, enzymes could effect selective changes in pulp and paper properties, which would provide market advantages and benefits to the pulp and paper industry[4].

Jute and kenaf, being annual crop, could be used as a raw material to substitute hard and softwood (e.g. bamboo, bagasse etc.) for making pulp and paper. Green jute and kenaf are known to have higher content of pentosans (xylans) than hardwoods and softwoods. The use of enzymes such as xylanases has been shown to improve bleaching by facilitating the reaction of the bleaching chemicals with lignin. Studies also demonstrated that the treatment with enzymes is more efficient in terms of reduction of chemical requirements and emissions for hardwood than for softwood pulps. As green jute has more pentosans (20% to 25%) than hardwoods (12% to 18%), it is reasonable to expect that the results of enzyme treatment of green jute or green jute pulp would be at least as good as or better than those obtained with hardwoods.

As early as 1994/1995 BCIC conducted commercial production trials of pulp from green jute plant in four paper mills. During these trials a number of problems were encountered relating to chipping and storing of green jute and deterioration of the quality of the pulp.

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[3] Paper Age February, 1991

[4] Lew Christov, "Potential of some hydrolyzing and oxidative enzymes for pulp and paper production and modification" , TAPPI 2000 Pulping/Process & Product Quality Conference, Nov. 5-8, 2000, Boston, USA

Whole kenaf pulping has been conducted in Thailand and China and studies on the production of Chemo-Thermo-Mechanical Pulp (CTMP) from whole kenaf conducted in the USA and Canada have demonstrated that exceptionally high quality pulp can be produced at a production cost lower than that of the typical pine thermo-mechanical pulp[5]. Studies on the production of newsprint paper have been carried out in India and the properties of the sheets were comparable to commercial newsprint[6].

Jute pulping through the application of biotechnological methods, if proven economically and technically feasible, will open up a potentially large market which might absorb not only the existing surplus production of jute in the producing countries, but may also require additional production capacities to meet growing demand of jute fiber with wider implications for the farming and working populations in terms of generating additional job opportunities and incomes.

The broad objective of the project was, therefore, to develop biotechnological applications of enzymes for the large-scale production of pulp with a view to opening up new market outlet for jute while, at the same time, reducing the production costs through energy savings and the polluting effects of chemical effluents.

The Key Commodity Issues Addressed and their Relevance to the Strategy of the Sponsoring International Commodity Body (ICB):

The sponsoring ICB recognizes the importance of promoting alternative uses of jute in view of the shrinking market share in the traditional jute products sectors in order to maintain and/or enhance the income of poor farming populations, generate additional job opportunities through the generation of demand for the oversupply of fibers, and substitute the sharply increasing imports of pulp by pulp produced from domestic resources.

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[5] Jon G. Udell, “General feasibility study: keaf newsprint system”, American National Publication Association, University of Wisconsin, USA, September 1980.

[6] Dr. A. Panda, « Need for technological improvements in processing of jute and kenaf fiber for pulp and paper making”, National Consultant, UNDP, CPPRI, India

Development Objective

To assess the technical and economic feasibility and environmental sustainability of biotechnological processing of jute and kenaf for the commercial production of high-quality pulp and paper.

Specific Project Objectives and Expected Outputs:

Objective - 1: To identify and collect micro-organisms and processes currently being used in different pulp and paper mills and select suitable ones for jute biopulping

Expected Output:

- Comparative study to identify suitable micro-organisms and processes for jute biopulping.
- Collection of micro-organisms used for biopulping of wood.
- Selection of micro-organisms for biopulping and biobleaching of jute.
- Selection of microbial strains that will mostly satisfy the overall objective of the project.

Objective - 2: Determination of optimal biopulping and biobleaching conditions

Expected Output:

- Procedures for the production of enzymes and their application in preparing handsheets.
- Optimisation of pulping in chemical and mechanical processes.
- Reduction of chemical and energy inputs in the chemical and mechanical pulping through the application of bioprocesses.
- Reduction of toxic chemical effluents by biobleaching.

Objective - 3: To manage the black liquor produced during pulping and effluents generated during bleaching and identify suitable methods for green jute storage

Expected Output:

- Reduction of discharges of hazardous chemical effluents.
- Identification of appropriate storage conditions for green jute/kenaf.

Objective - 4: Large-scale trial application of enzymes

Expected Output:

- Pilot and commercial scale trial of chemical pulping to produce unbleached and bleached paper.
- Writing paper of brightness above 80% ISO.
- Pilot scale trial of mechanical pulping for the production of newsprint grade paper with brightness above 60% ISO.
- Preliminary assessment of the techno-economic viability of the developed bioprocesses.

Objective - 5: Dissemination of results and completion of the project

Expected Output:

- Draft project completion report (PCR)

Targeted Beneficiaries and Extent of Benefits

Bioprocesses are expected to generate new opportunities for the jute industry thus sustaining demand for raw jute/kenaf and stabilizing prices with concomitant increase of farmers' income. The paper and pulp industry is expected to benefit from the reduction of costs and application of environmentally sustainable processes.

The primary beneficiaries of this project will be the main jute/kenaf producing countries. In particular the project will benefit marginal and small farmers of rural communities involved in jute/kenaf production and utilization. Potentially, a larger number of countries would also derive benefits from technology transfer emanating from the project.

Project –Budget

The total fund allocation for the project was US$ 1,493,260 of which the Common Fund for Commodities contributed US$ 888,260. The Governments of France and Bangladesh contributed US$110,000 and US$ 200,000 respectively. The participating institutions made in-kind contributions worth US$ 295,000.

Management and Implementation Arrangements

The Consultative Committee of CFC, at its 20th Meeting held from July 28 to August 1, 1997, reviewed the project proposal on "biotechnological application of enzymes for making paper pulp from green jute/kenaf (the whole plant)" and recommended it for approval. The Common Fund for Commodities (CFC), the International Jute Organization (now IJSG) and the United Nations Industrial Development Organization (UNIDO) signed an implementation agreement in 1999. UNIDO was assigned as the Project Executing Agency, hereinafter referred to as **PEA**. The International Jute Study Group, Bangladesh, (IJSG), was assigned as the supervisory body. A Project Leader was appointed from January 2001 to supervise the overall technical activities of the project in consultation with the PEA.

The project involved collaboration of the following parties:

Bangladesh Chemical Industries Corporation (BCIC)
Institute of Bast Fiber Crops, China, (IBFC)
Central Pulp and Paper Research Institute, India, (CPPRI)
Centre Technique du Papier, France, (CTP)
Agrotechnology & Food Innovations, The Netherlands, (A&F)

III. Project Implementation and Results Achieved

1. Project Implementation

Preparation, efficiency and effectiveness of project implementation including project management

The project was formally initiated in January 2001 through the signing of Memoranda of understanding between the PEA and the five parties specifying the terms of reference for the specific activities to be undertaken by each party. These are summarized in the table below.

No.	Activities	Institutes
A	Identification of microorganisms and inventory of processes currently used in pulp and paper mills and selection of suitable strains for jute biopulping.	BCIC
B	Comparative studies of different microorganisms used in various pulp and paper mills in Europe, USA, and Canada.	BCIC
C	Optimization of pulping in chemical process.	BCIC, CPPRI, CTP & IBFC
D	Biopulping in chemical and mechanical process.	BCIC, CPPRI, A&F and IBFC
E	Bleaching with and without enzyme in various sequences.	BCIC, CPPRI, CTP, A&F and IBFC
F	Management of black liquor and effluent management.	CPPRI and A&F
G	Storing of green jute/kenaf	IBFC
H	Pilot scale trial (chemical/mechanical)	A&F, CTP and CPPRI
I	Large-scale trial.	BCIC

Some adjustments of the above work plan was deemed necessary as a result of project exigencies in accordance with the decision of the mid-term review meeting, which was held in December 2002. Prior to the mid-term review meeting an independent reviewer was appointed by CFC, in 2002, to review progress and recommend actions. The work plan for 2003 was thus amended taking into account the recommendations of the independent reviewer and the exigencies of the project. Accordingly, it was decided that activities for 2003 would involve:

Mechanical Pulping

Mechanical pulping for newsprint grade pulp out of whole jute would be through the Alkaline Peroxide Mechanical Pulping (APMP) the latter being optimized and fine tuned by CTP and A&F.

Chemical Pulping

Commercial trials would be conducted in Karnaphuli Paper Mills Limited (KPM) (using whole jute) and in IBFC (using whole kenaf), while pilot scale trials would be conducted at CPPRI.

Biobleaching

BCIC under the supervision of the PL would conduct bleaching trials with various commercial and developed enzymes at CTP. These trials should be replicated at KPM, CPPRI and IBFC.

2. Project Results

OBJECTIVE 1:

To identify and collect micro-organisms and processes currently being used in different pulp and paper mills and select suitable ones for jute biopulping.

Target

- Inventory of processes currently being used in research institutes and paper mills.
- Isolation and collection of suitable microorganisms for biopulping.

Results Achieved

- Microorganisms suitable for biopulping were identified (**Annex–2, Appendix–F & G**).
- Nine (9) strains were selected for biopulping out of twelve (12) strains that were isolated (in Bangladesh and India) and collected (from USA and Europe) strains.

- 3 strains were selected for the production of xylanase for biobleaching. The experimental procedure is shown in **Annex–2, Appendix–A**.

OBJECTIVE 2:

Determination of optimal biopulping and biobleaching conditions

Target

A. To produce bleachable grade pulp of Kappa No. 20 (considered to be suitable for good quality pulp) by two chemical processes. (Soda-AQ and Kraft process).
Assigned Institutes: IJSG/BCIC, CPPRI, CTP and IBFC (Kenaf)

B. Application of biopulping in chemical/mechanical processes to reduce chemical requirements, cooking time and energy.
Assigned Institutes: IJSG/BCIC, A&F, CPPRI and IBFC

C. To achieve brightness of 80% ISO while reducing the chemical requirements in various bleaching sequences by the application of commercial and locally isolated enzymes.
Assigned Institutes: BCIC, CPPRI, CTP and IBFC

D. To achieve brightness above 60% ISO suitable for newsprint paper in the mechanical pulping with and without commercial enzyme.
Assigned Institutes: A&F and CTP

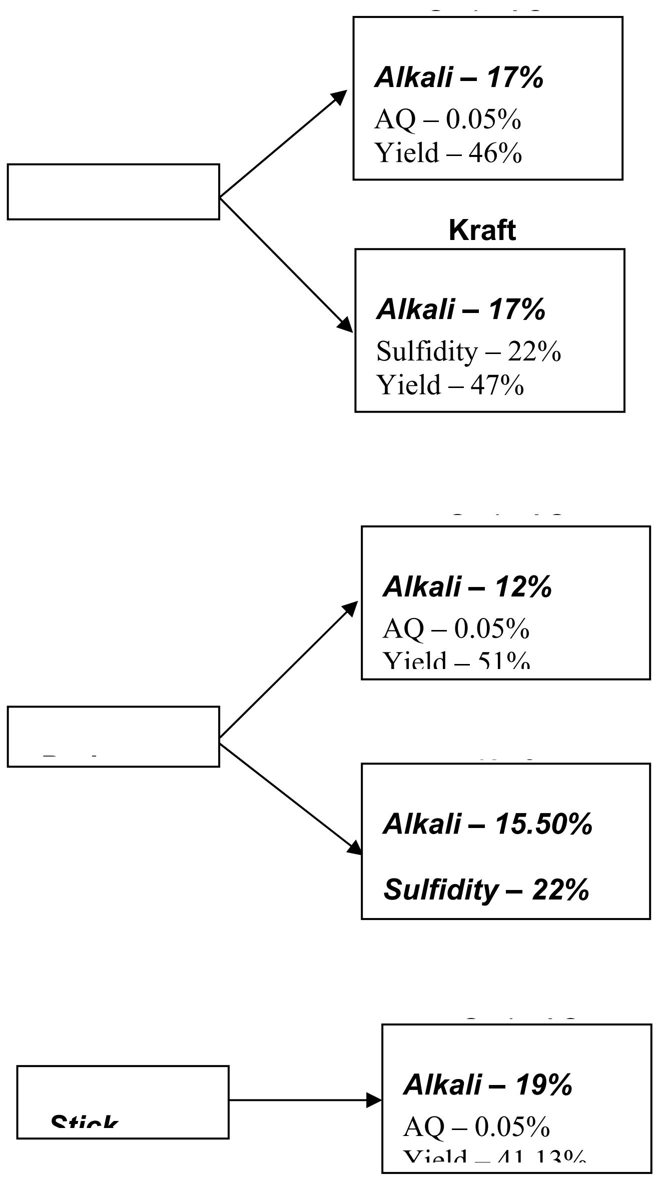
Results Achieved

A. Optimisation of Pulping

A number of experiments were conducted at Karnaphuli Paper mills, BCIC (Bangladesh Chemical Industries Corporation), CTP (Centre Technique du Papier), CPPRI (Central Pulp and Paper Research Institute) and IBFC (Institute of Bast Fiber Crops) to produce pulp with Kappa No. 20 in order to optimise the conditions of pulping, by varying the liquor ratio with jute chips in the Soda-AQ process and the requirements of alkali in both the Soda and Kraft processes.

Bangladesh Chemical Industries Corporation (BCIC): Alkali as Na_2O

BCIC optimized the pulping conditions in both Soda-AQ and Kraft process using whole jute, bark and stick. The results below show that it is possible to obtain the desired Kappa No. 20 in both Soda-AQ and Kraft processes.

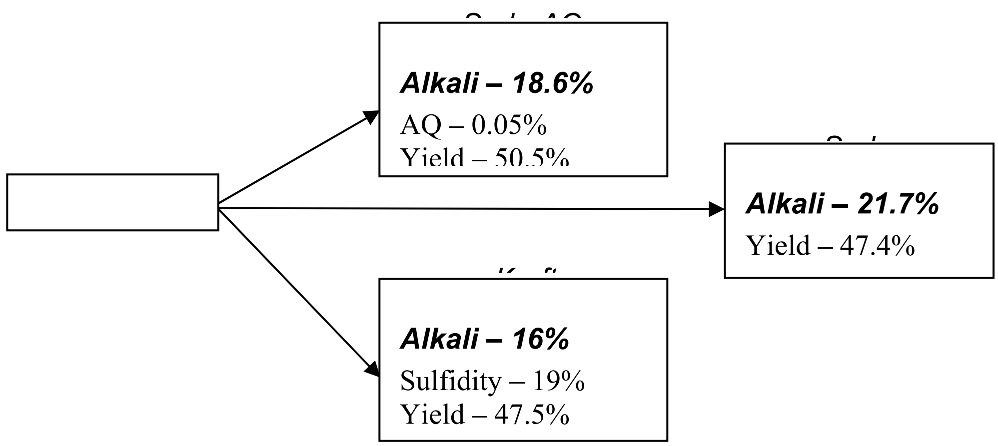


- Cooking temperature for both Soda-AQ and Kraft processes – 170°C.
- Cooking time for Soda-AQ process – 90 Minutes and for Kraft process – 120 Minutes.

The experimental details are shown in **Annex 2 – Appendix–B**

<u>Central Pulp and Paper Research Institute (CPPRI): Alkali as Na_2O</u>

CPPRI optimized the conditions of pulping in Soda, Soda-AQ and Kraft processes. In Soda-AQ process bleachable grade pulp of Kappa No. 18.4 was obtained. Similarly bleachable grade pulp of Kappa No. 20 was obtained in Kraft process using 16% alkali (Na_2O) and 19% sulfidity. The conditions for the optimization of pulping using whole Jute in Soda-AQ, Soda and Kraft processes are shown below.

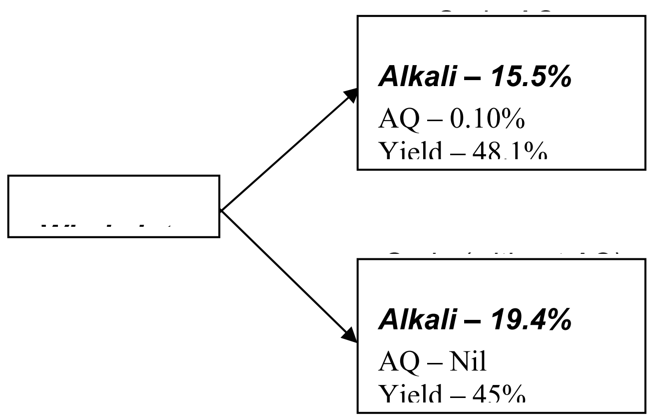


- Cooking temperature for both Soda-AQ and Kraft processes – 165°C.
- Cooking time for Soda-AQ and Kraft processes – 90 Minutes.

(Ref.: Annex 3 – table 8, 9 and page 10)

<u>Centre Technique du Papier (CTP), France: Alkali as Na_2O</u>

CTP optimized the pulping conditions in Soda-AQ and Soda (without AQ) process. The results given below show that higher yield (3% more) and lower Kappa number were achieved with the Soda-AQ processed as compared to the Soda process**.**

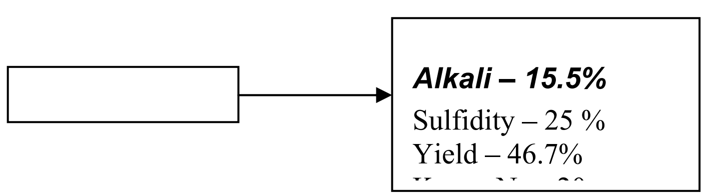


- Cooking temperature for both Soda-AQ and Soda (without AQ) processes – 170°C.
- Cooking time for both Soda-AQ and Soda (without AQ) processes – 120 Minutes

(Ref.: Annex 4 – table 1)

<u>Institute of Bast Fiber Crops (IBFC): Alkali as Na_2O</u>

IBFC also optimized the pulping conditions in the Kraft process using whole Kenaf. The results achieved from the optimization of pulping at IBFC is as under:



- Cooking temperature for Kraft process – 170°C.
- Cooking time for Kraft process – 55 Minutes

(Ref.: Annex 5)

The results of the pulping optimization-experiments are summarized in **Table 2** below.

Table 2: Summarized results of the optimization of chemical pulping

Stages	Soda-AQ				Kraft			
	Na_2O (%)	AQ (%)	Yield (%)	Kappa No.	Na_2O (%)	Sulfidity	Yield (%)	Kappa No.
BCIC – Whole Jute	17	0.05	46	20.5	17	22	47	20.0
BCIC- Bark	12	0.05	51	18.60	15.50	22	52.49	24.58
BCIC- Core	19	0.05	41.13	20.80	-	-	-	-
CPPRI – Whole Jute	18.6	0.05	50.5	18.4	16	19	47.5	20.7
CTP – Whole Jute	15.5	0.10	48	18.3	-	-	-	-
IBFC – Whole Kenaf	-	-	-	-	15.5	25	46.7	20

Soda AQ process: optimization of cooking conditions

- 170^0C for 90 minutes (BCIC)
- 165^0C for 90 minutes (CPPRI)
- 170^0C for 120 minutes (CTP)

Kraft process: optimization of cooking conditions

- 170^0C for 120 minutes (BCIC)
- 165^0C for 90 minutes (CPPRI and BCIC)
- 170^0C for 55 minutes (IBFC and BCIC)

B. *Biopulping Experiments*

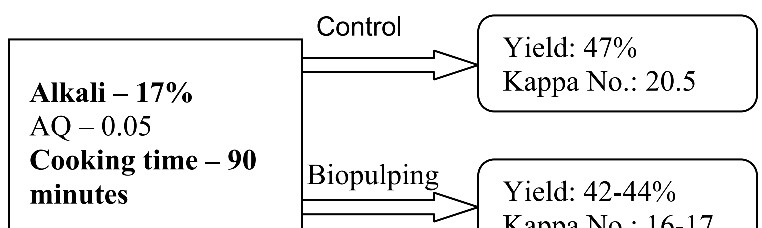
Biopulping experiments were conducted in conjunction with both chemical and mechanical processes. The findings of the experiments are summarized below.

Biopulping in conjunction with the chemical process
Experiments conducted at BCIC and CPPRI

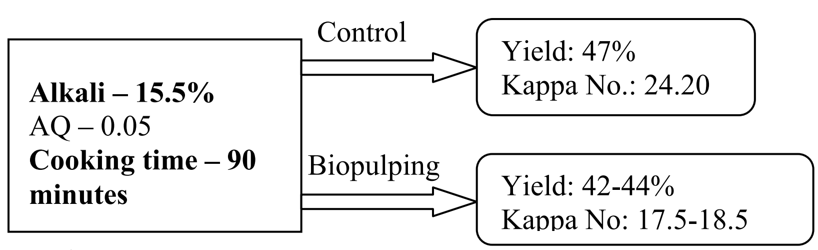
With the optimum conditions obtained at Karnaphuli Paper Mills Ltd., 61 biopulping experiments were conducted for bleachable grade pulp of Kappa No. 20 using 4 strains of *P. chrysosporium*, 2 strains of *C. subvermispora*, one strain of *F. lignosus* and 2 strains of ST (two unidentified microbial strains from CPPRI) in conjunction with both the Soda-AQ and Kraft processes.

In the Soda-AQ process, both the amount of alkali and cooking time were varied; while in the Kraft process only the cooking time was varied. Out of the nine strains, *F. lignosus* and *C. subvermispora* were found to be suitable for biopulping in both the Soda-AQ and Kraft processes.

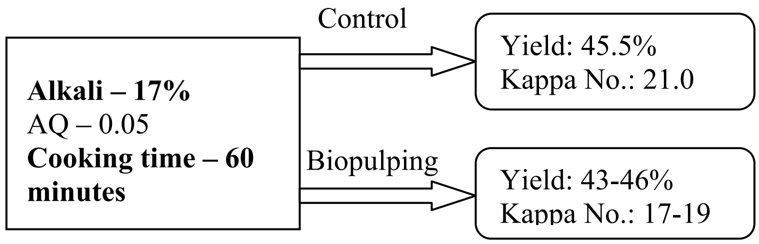
The average optimized results of the two strains in the biopulping process as well as the results of the control process are shown in the following diagram.



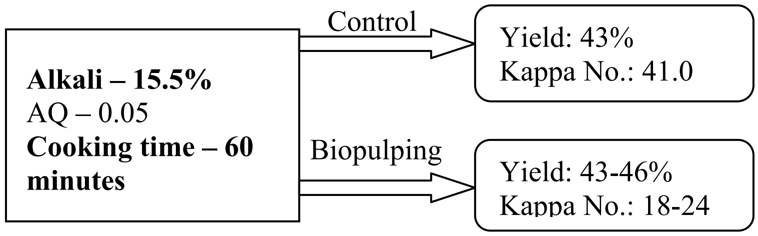
Soda-AQ Process



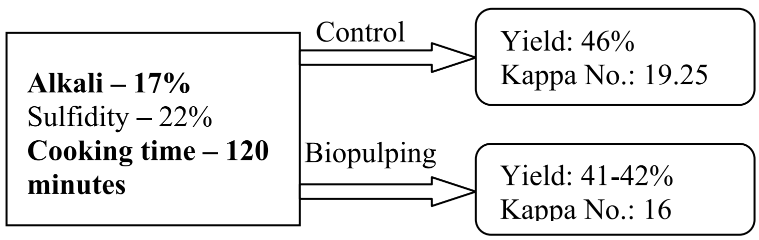
Soda-AQ Process



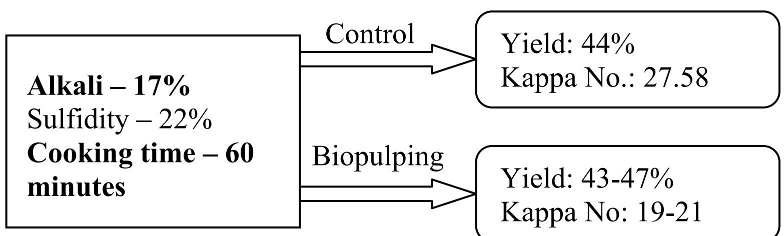
Soda-AQ Process



Soda-AQ Process



Kraft Process



Kraft Process

The results of the biopulping process can be summarized as:

- The Kappa number can be reduced by approximately 20% at the same cooking condition in both the Soda-AQ and Kraft processes. ***(Source: Annex-2, Table 15, 17 and 20).***
- The desired Kappa number (20) can also be obtained by reducing the alkali charge by 9%.
- Cooking cycles can be increased facilitating more throughputs in the existing mills.

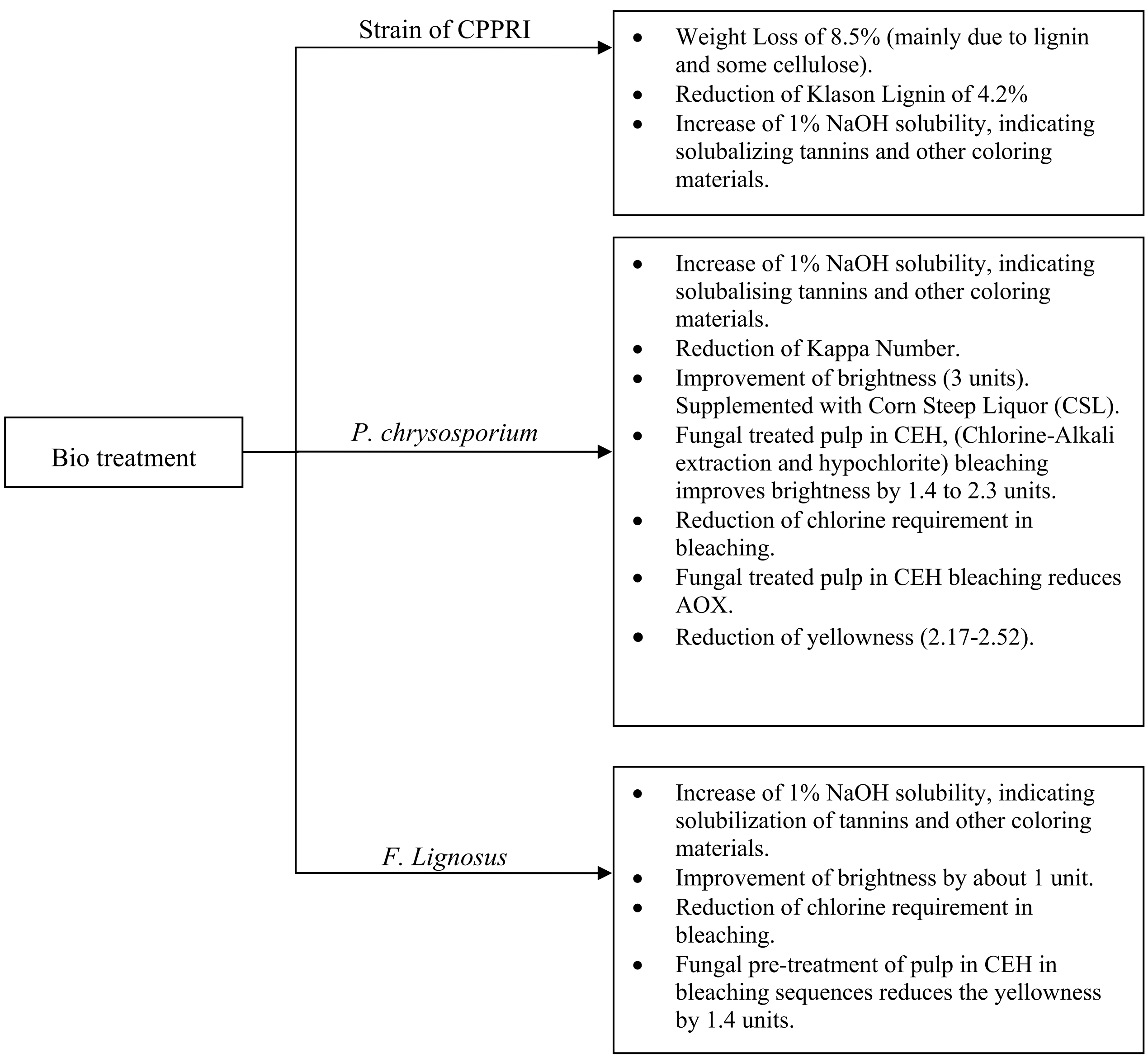
- The physical properties of paper (burst, tear and tensile indices) can be improved significantly (20-40%).

The details on the experimental procedure are shown in ***Annex 2, Appendix-C***.

<u>CPPRI</u>:

Biopulping experiment were conducted at CPPRI on whole jute using CPPRI – 1 and screened strains of IJSG, ***Phanerochaete chrysosporium*** **(PC)** and ***F. lignosus*** **(FL)**.

The figure below summarizes the experiment results:

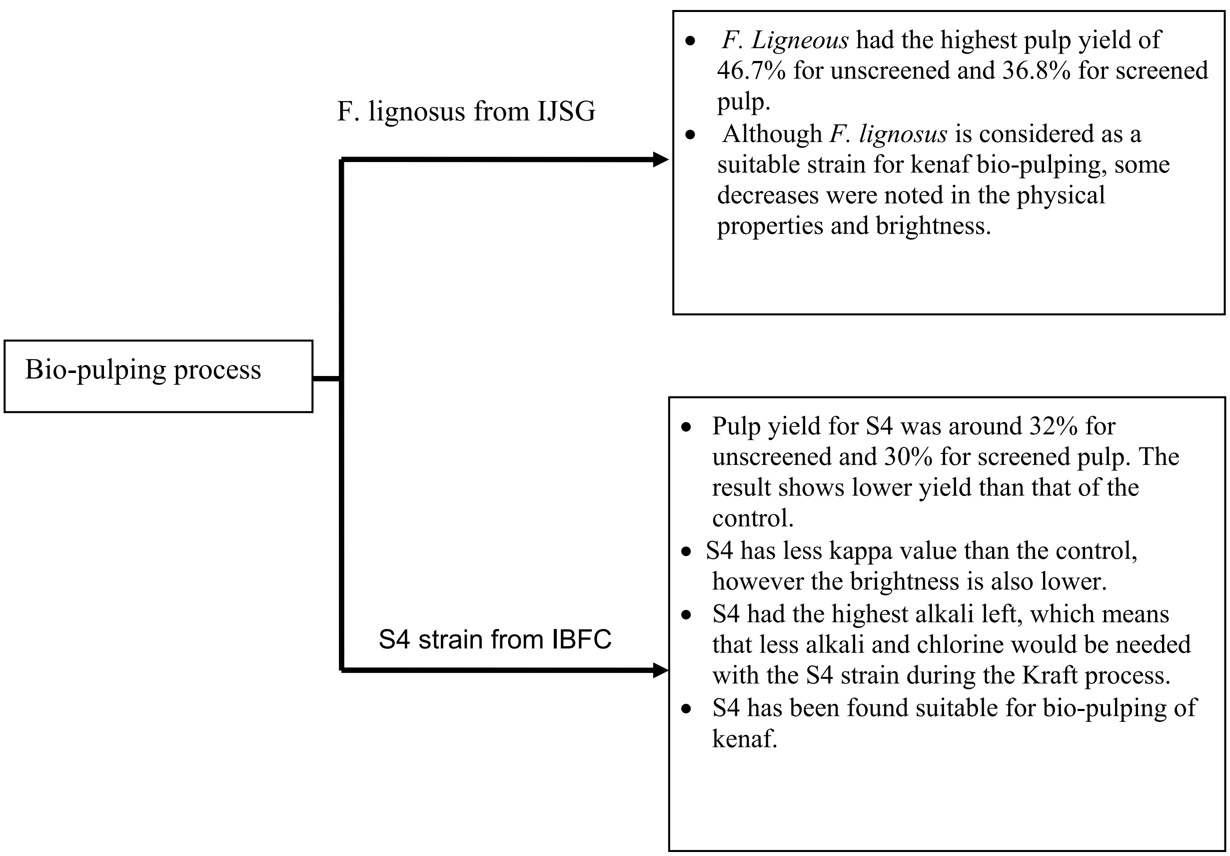


(Ref.: Annex 3 – table 10, 11, 12, 13, 14, and 15)

***IBFC*:**

IBFC found 2 microbial strains, S4 (isolated by IBFC) and *F. lignosus* (collected from IJSG), suitable for biopulping of kenaf. The treated kenaf was found more suitable for mechanical pulping than the untreated controls.

There has been some difficulty in quantifying conclusively the effect of different strains during the biopulping process. Essentially, each enzyme responded differently to different treatments. The overall qualitative conclusions are summarized in the figure below.



(Ref.: Annex 5 – Figure 6, 7 and 8)

Biopulping in conjunction with the mechanical process

Experiments conducted by A&F

The F. lignosus strain supplied by the project leader was used. The findings on the effect of incubation time and the F. lignosus pre-treatment on simulated (PFI-mill) Refiner Mechanical Pulp (RMP) of green jute are summarized in the following.

- Pre-treatment of simulated RMP green jute pulp with F. lignosus results in 10 to 20% savings in energy at the same level of pulp strength properties or beating degree and a 1 to 3% ISO higher brightness.
- Treatment with *P. chrysosporium* leads to higher strength properties than with *F. lignosus* at equal beating degree.
- Incubation time of the fungus of 12 to 14 days has greater effect on the beating degree and strength properties as compared to incubation time of 10 days with no decline of the pulp quality. Losses due to fungal treatment are about 12.3%. These losses may be due to the degradation of lignin and cellulose.

(Ref.: Annex 1:page-62 and 64)

In a further study, simulated Alkaline Peroxide Mechanical Pulps (APMP) produced in a PFI mill and pre-treated with the fungus *F. lignosus* showed no statistically significant differences between treated and untreated pulp . However, additional small-scale experiments with more homogeneous size distribution and a further reduction of jute to smaller pieces results in significant differences. Size reduction followed by an additional coarse refining step in 12 inch refiner leads to more uniform dimensions of the shortened jute, a more homogenous mixture of jute bast and core, 2.7% higher brightness and an easier running of the PFI-mill. In this refining stage 100 kWh per ton was used. The results of the experiments are highlighted below:

- The simulated APMP-process consumes about 25% less energy and results in better paper properties than the RMP process, whereas the fungal treatment saves at least an additional 5%.
- The losses caused by the consecutive treatments are 16.4 % for the untreated and 21.7% for the fungal-treated green jute. The difference between treated and

untreated jute is much smaller than with the RMP process. Apparently most of the mass that is degraded by fungi is also removed by bleaching. This means that the main part of the losses caused by the fungal treatment is also removed in the bleaching step.

- The alkaline peroxide treatment raises the brightness of both the treated and untreated pulp to a level of 60 to 65% ISO. No clear effect of the treatment on the brightness could be measured above this level.

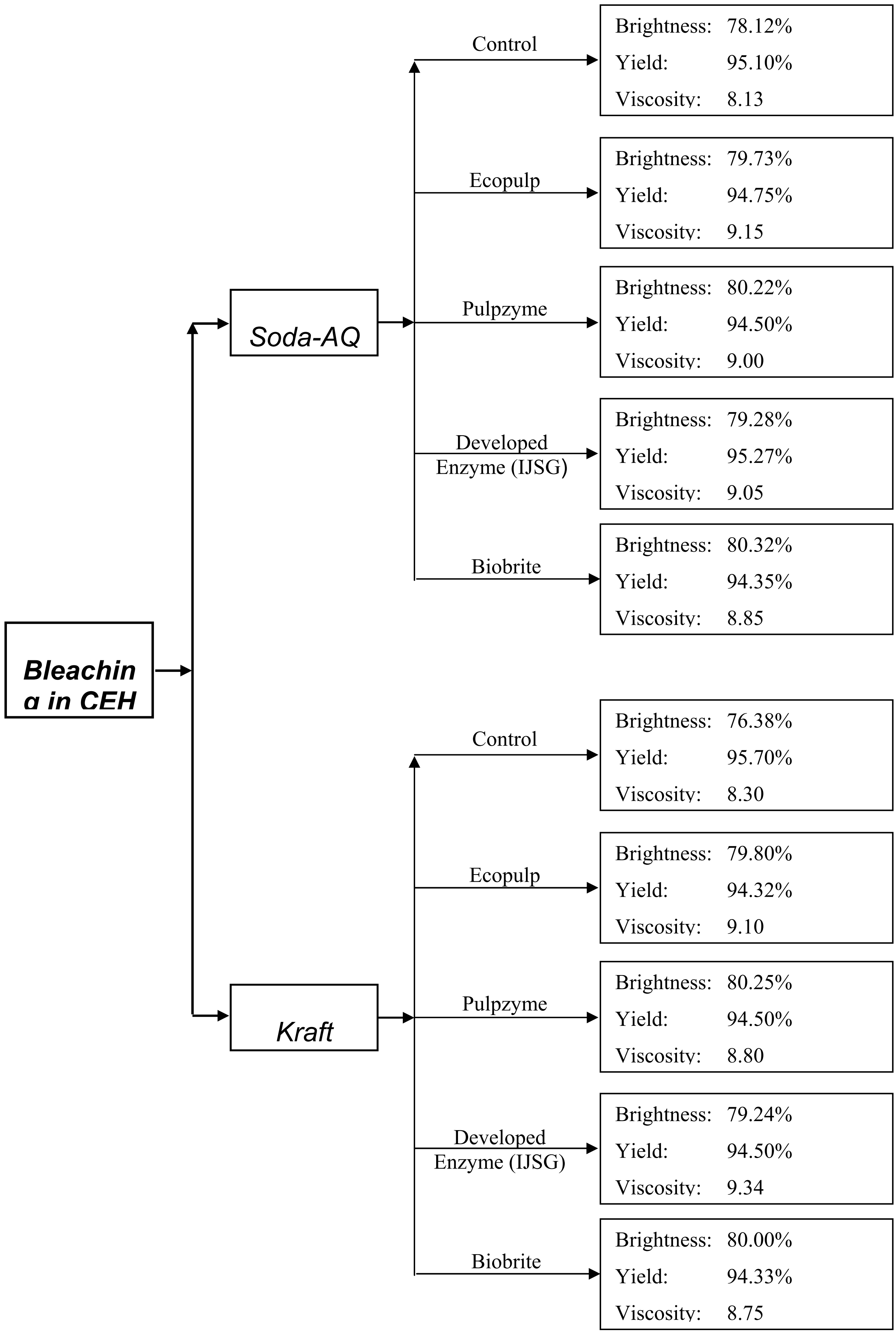
  (Ref.: Annex 1: page-71-74)

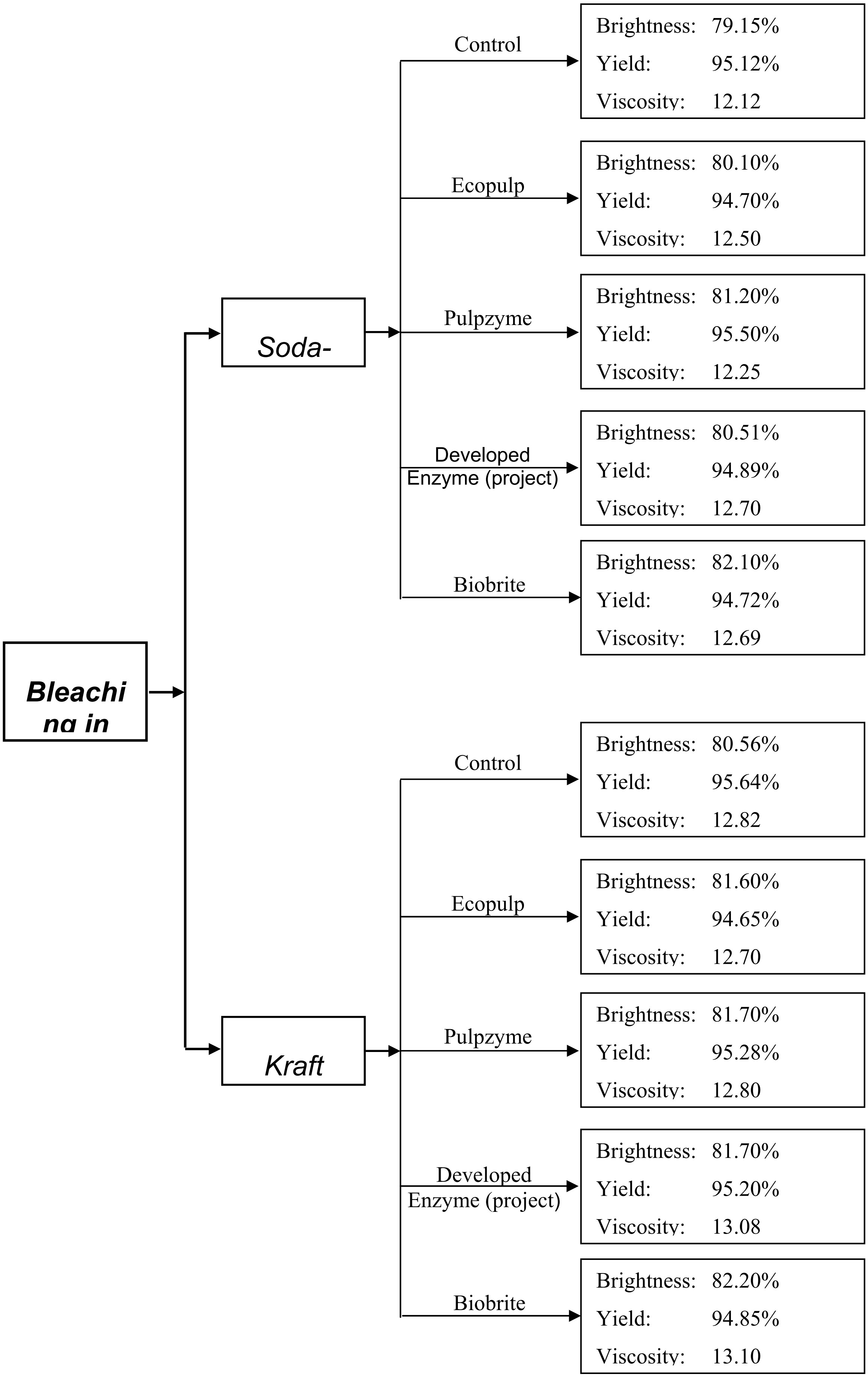
C. Bleaching Experiments:

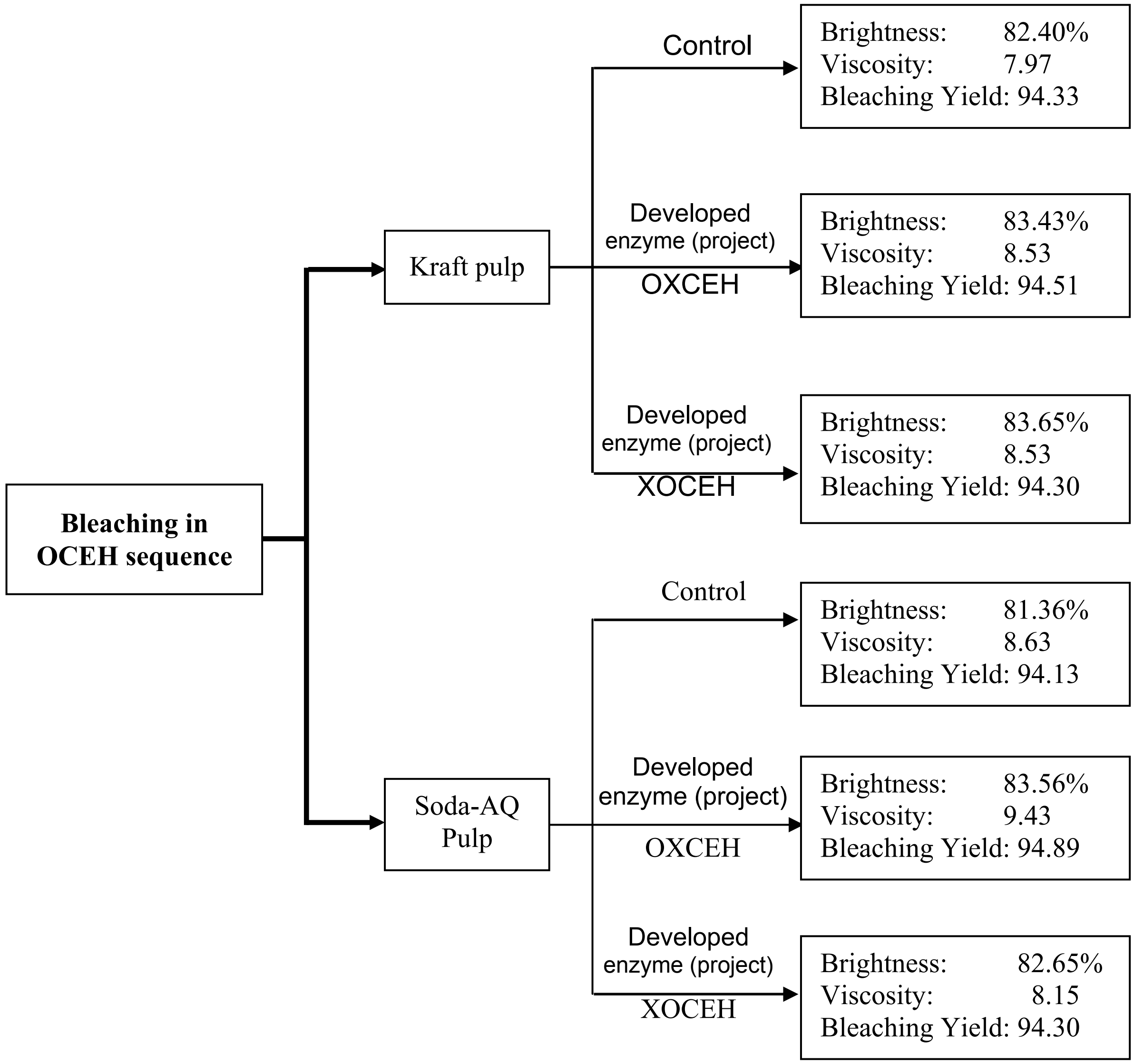
<u>BCIC:</u>

Bleaching experiments were conducted in conventional Chlorine-Alkali-Hypochlorite (CEH), Elemental Chlorine Free (ECF), Chlorine dioxide-alkali-chlorine dioxide (DED) and Oxygen-Chlorine-Alkali-Hypochlorite (OCEH) sequences with and without enzyme.

The results of bleaching in CEH, DED (in other words ECF) and OCEH sequences following the Kraft and Soda-AQ processes by BCIC show that enzyme treatment improves both brightness and viscosity.


Bleachin
g in CEH
Soda-AQ
Control
Brightness: 78.12%
Yield: 95.10%
Viscosity: 8.13
Ecopulp
Brightness: 79.73%
Yield: 94.75%
Viscosity: 9.15
Pulpzyme
Brightness: 80.22%
Yield: 94.50%
Viscosity: 9.00
Developed Enzyme (IJSG)
Brightness: 79.28%
Yield: 95.27%
Viscosity: 9.05
Biobrite
Brightness: 80.32%
Yield: 94.35%
Viscosity: 8.85
Kraft
Control
Brightness: 76.38%
Yield: 95.70%
Viscosity: 8.30
Ecopulp
Brightness: 79.80%
Yield: 94.32%
Viscosity: 9.10
Pulpzyme
Brightness: 80.25%
Yield: 94.50%
Viscosity: 8.80
Developed Enzyme (IJSG)
Brightness: 79.24%
Yield: 94.50%
Viscosity: 9.34
Biobrite
Brightness: 80.00%
Yield: 94.33%
Viscosity: 8.75


Bleachi
ng in
Soda-
Control
Brightness: 79.15%
Yield: 95.12%
Viscosity: 12.12
Ecopulp
Brightness: 80.10%
Yield: 94.70%
Viscosity: 12.50
Pulpzyme
Brightness: 81.20%
Yield: 95.50%
Viscosity: 12.25
Developed Enzyme (project)
Brightness: 80.51%
Yield: 94.89%
Viscosity: 12.70
Biobrite
Brightness: 82.10%
Yield: 94.72%
Viscosity: 12.69
Kraft
Control
Brightness: 80.56%
Yield: 95.64%
Viscosity: 12.82
Ecopulp
Brightness: 81.60%
Yield: 94.65%
Viscosity: 12.70
Pulpzyme
Brightness: 81.70%
Yield: 95.28%
Viscosity: 12.80
Developed Enzyme (project)
Brightness: 81.70%
Yield: 95.20%
Viscosity: 13.08
Biobrite
Brightness: 82.20%
Yield: 94.85%
Viscosity: 13.10



(Ref.: Annex 2 – table 28, 29, 30, 31, 32 and 33)

The results of the biobleaching process can be summarized as:

- Reduction of active chlorine by 9-12% in CEH and by 15-17% in DED.
- Reduction of AOX in the effluent is due to reduced chlorine requirement. AOX decreases in proportion to the decreasing chlorine usage.
- Increase in effluent's BOD (Biological Oxygen Demand) and COD (Chemical Oxygen Demand), indicating that the effluent is more amenable to biological degradation. There is an increase in the bleach effluent resulting from the release of low molecular weight xylose from the pulp.

- Application of xylanase in OCEH sequence, before and after oxygen, does not reduce the chlorine requirement, but the brightness is improved by 2-3 units when xylanase is used after oxygen in Soda-AQ.
- The three commercial enzymes and the one isolated locally by the project leader reduce the Kappa number and improve the brightness.

The details of the experimental procedure are shown in ***Annex-2, Appendix-D.***

Centre Technique du Papier (CTP)

Bleaching experiments were conducted in conventional (CEH), Elementary Chlorine Free (DED) and Total Chlorine Free sequences. Experiments were also conducted with and without commercial enzyme (Xylanase from NOVO and Laccase).

Table 3: Brightness, bleaching yield and viscosity in various bleaching sequences

Pulp	**Soda**			**Soda-AQ**		
Bleach Sequences	**Brightness (%) ISO**	**Bleaching Yield (%)**	**Viscosity (%)**	**Brightness (%) ISO**	**Bleaching Yield (%)**	**Viscosity (%)**
CEH	82.2	94.4	6.5	80.9	93.7	8.5
DED	**81.3**	**95.4**	**12.8**	**81.7**	**94.3**	**23.8**
OP	71.5	95.9	8.5	69.9	95.3	14.2
OZP	87.5	89.5	3.8	85.8	90.1	5.2
XE CEH	80.4	91.0	7.6	80.2	91.5	10.0
LE CEH	79.9	93.2	7.3	79.9	92.3	9.6
XLE CEH	81.7	91.1	7.0	81.9	89.0	10.4
XLE DED	82.5	93.1	14.0	83.0	90.1	23.4
XLE OQP	69.6	91.2	8.1	80.0	90.0	15.0

The findings of the experiments can be summarized as follows:

- Reduction of Kappa number (30 to 35%) when Xylanase is used followed by alkali.
- Reduction of Kappa number is about 50% when two enzymes (Xylanase and Laccase) are used followed by alkali.
- There is no change of viscosity with the enzyme treatment.
- The DED sequence showed the highest brightness.
- The ECF and TCF sequences with xylanase – laccase improved the brightness and physical properties of handsheets.

(Ref.: Annex 4 – table 2, 3, 4, 5, 9, 10, 13 and 14)

CTP also conducted bleaching experiments in CEH, DED, OCEH and ODED sequences with Soda-AQ and Soda-AQ pretreated pulp with *C. subvermispora*.

Table 4: Brightness, bleaching yield and viscosity in various bleaching sequences with untreated pulp and treated pulp (*C. subvermispora*).

Pulp	**Soda-AQ**			**Soda-AQ (pretreated with *C. subvermispora*)**		
Bleaching Sequences	**Brightness (%) ISO**	Bleaching **Yield (%)**	**Viscosity (%)**	**Brightness (%) ISO**	Bleaching **Yield (%)**	**Viscosity (%)**
CEH	80.0	94.5	7.1	83.3	94.7	6.6
DED	83.6	96.8	12.0	85.2	95.3	10.9
OCEH	84.8	92.2	5.9	86.8	92.0	5.5
ODED	87.1	90.7	10.2	87.4	91.7	10.0

The summarized findings of the experiments are as follows:

- Application of oxygen reduces the chlorine requirement in the CEH sequence by 50% to 40% with untreated and treated pulp respectively.
- Oxygen delignification in untreated and treated pulp improves the brightness by 4.8 and 3.5 units respectively.
- Brightness was higher in the DED than the CEH sequences in both the treated and untreated pulp.
- Prior application of oxygen in DED improves the brightness from 83.6% to 87.1% and 85.2% to 87.4% with untreated & treated pulp.

(Ref.: Annex 4 – table 28, 29, 30 and 31)

CTP also conducted bleaching experiment with xylanase(X), enzyme followed by alkali (XE) and alkali followed by CEH.

All these experiments were conducted with Soda-AQ pulp and pretreated Soda-AQ pulp.

The results of these trials are summarized in the following table in terms of brightness, bleaching yield and viscosity in the Soda-AQ (untreated) and Soda-AQ (pretreated with *C. subvermispora*) processes.

Table 5: Brightness, bleaching yield and viscosity in various bleaching sequences with xylanase on untreated and treated (*C. subvermispora*) pulp

Pulp	**Soda-AQ (untreated)**			**Soda-AQ (pretreated with *C. subvermispora*)**		
Bleaching sequences	**Brightness (%) ISO**	Bleaching **Yield (%)**	**Viscosity (%)**	**Brightness (%) ISO**	**Bleaching** Yield (%)	**Viscosity (%)**
XCEH	80.6	93.23	6.5	83.2	93.09	6.5
ECEH	81.0	96.16	6.2	84.1	95.37	6.0
XE CEH	82.5	94.44	6.5	85.5	93.72	6.1
XEDED	83.9	93.1	14.9	85.1	94.4	15.5
OXECEH	84.8	91.0	6.5	87.4	89.0	6.1
OXEDED	86.1	92.5	11.1	87.0	93.1	12.8

(Ref.: Annex 4 – table 36, 37, 43, 44, 45 and 46).

Table 6: Reduction of Kappa Number

Stages	**Initial**	**X**	**XE**	**O**	**OXE**
Kappa No. of pulp 1 (Soda-AQ)	19.5	17.2	12.1	8.2	6.3
Kappa No. of Pulp 2 (Pretreated Soda-	16.2	14.9	12.3	9.0	6.7

AQ with *C. subvermispora*)					

(Ref.: Annex 4 – table 47).

Table 7: % of Cl_2 charge

Stages	CEH	DED	XEDCEH	XEDED	OCEH	ODED	XECEH	OXEDED
Pulp 1(Soda-AQ)	6.0	7.2	4.1	5.5	3.0	4.5	2.3	4.1
Pulp 2 (Pretreated Soda-AQ with *C. subvermispora*)	5.0	6.4	4.0	5.6	3.1	4.8	2.4	4.3

(Ref.: Annex 4 – table 48).

CTP also conducted bleaching experiments in XECEH sequence involving enzyme application in Kraft process.

Table 8

Stages	**Kraft Pulp**			**Biotreated Kraft Pulp**		
Bleaching Sequences	**Brightness (%) ISO**	**Bleaching Yield (%)**	**Viscosity (%)**	**Brightness (%) ISO**	**Bleaching Yield (%)**	**Viscosity (%)**
XECEH (Untreated pulp)	81.4		8	81.7		8.2
XECEH (Biotreated pulp)	83.7		6.4	83.9		6.4

The results of these trials are summarized as follows:

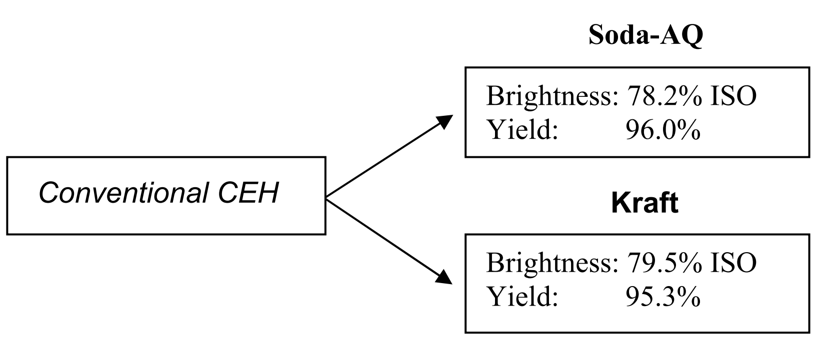
- Xylanase reduces the Kappa number more than the alkali extraction.
- Xylanase followed by alkali reduces the Kappa number more effectively, as addition of alkali helps to remove other soluble components.
- Pretreated Soda-AQ pulp reduces the Kappa number. This is because the initial Kappa number of treated pulp is less than that of the untreated pulp.
- Xylanase reduces chlorine use by 10% whereas alkali extraction reduces it by 12%.
- Alkali extraction reduces chlorine use by 12% (pretreated) and 18% (untreated).

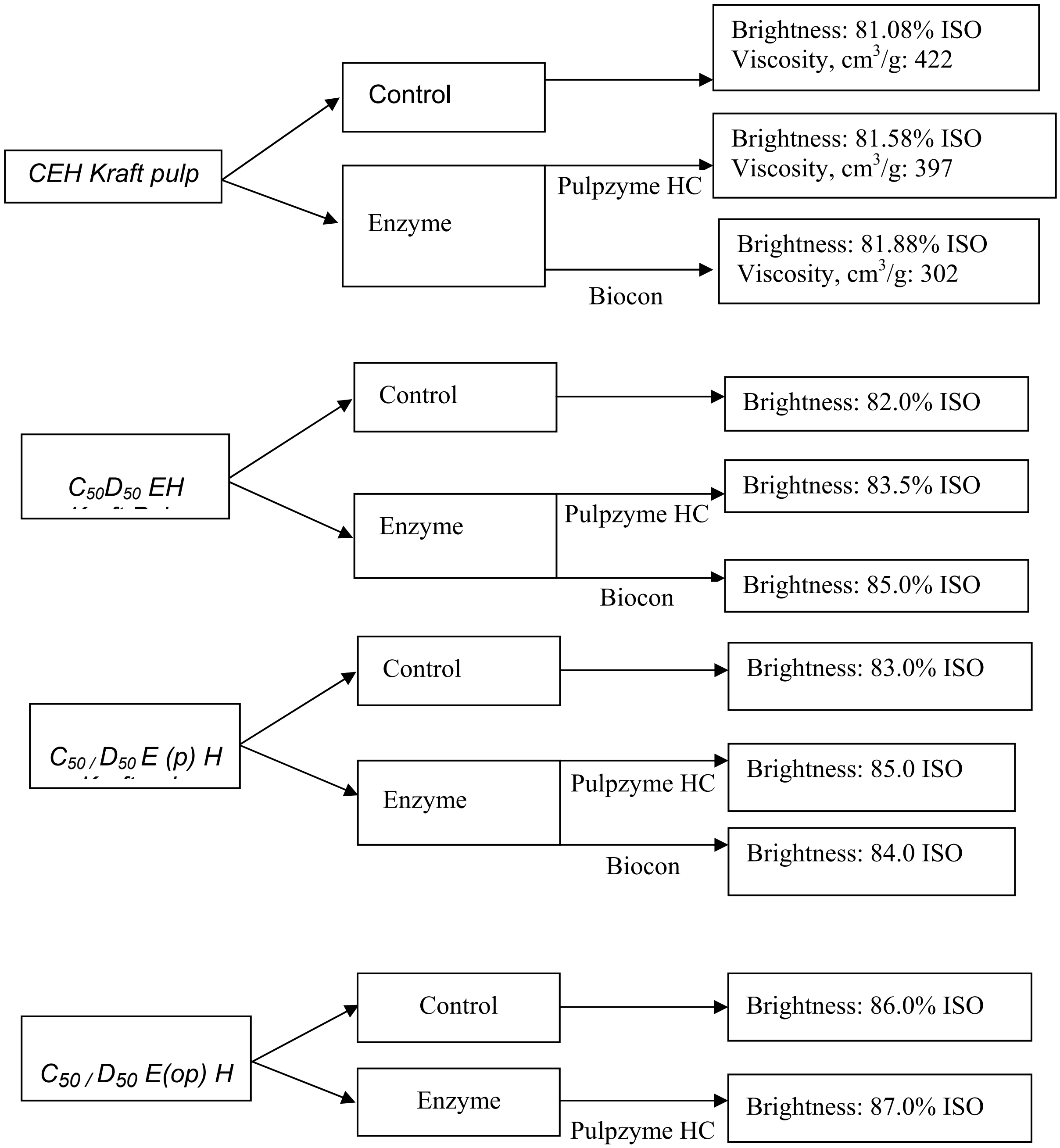
- Xylanase followed by alkali reduces chlorine use by 25% (pretreated) and 39% (untreated).
- There is a drop of viscosity (from 8.3 to 6.5) with XECEH sequence.
- Application of oxygen reduces chlorine use by 50% and 38% in the conventional and ECF bleaching sequence respectively.
- Oxygen followed by enzyme results in reduction of chlorine by 62% and 43% in conventional and ECF sequences respectively.
- The pulp produced with treated chips bleaches to higher brightness.
- The ECF bleaching sequence results in less COD and BOD.
- Oxygen delignification prior to bleaching reduces chemical consumption significantly.
- There is an increase of COD & BOD in the effluents prior to the bleaching sequences by O, XE and OXE.

(Ref.: Annex 4 – table 36, 37, 38, 43, 44, 45, 46, 47, 48, 49, 54 and 55)

<u>CPPRI</u>

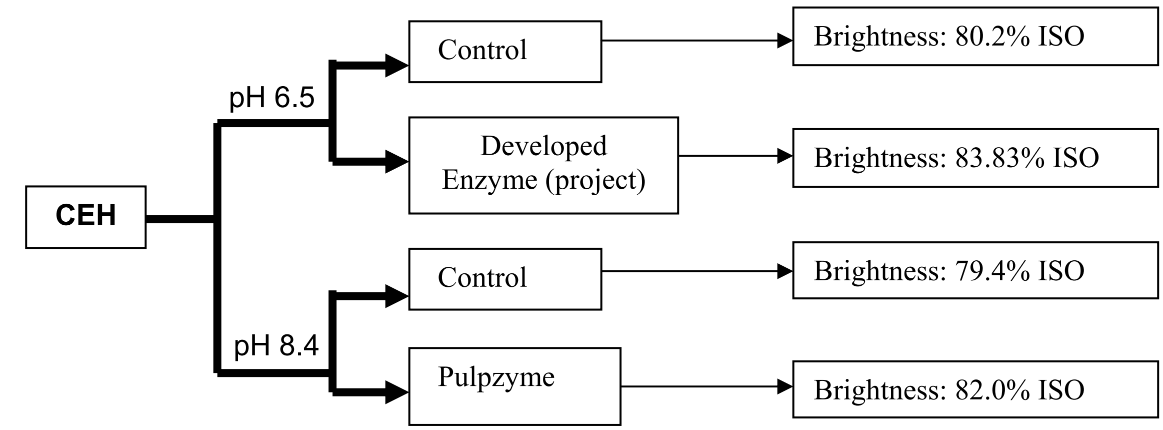
Bleaching experiments were conducted with Soda-AQ and Kraft pulp. CPPRI also conducted bleaching of Kraft pulp in CEH, C_{50}/ D_{50} EH, C_{50}/ D_{50} E ($_{P}$)H and C_{50}/ D_{50} E ($_{OP}$)H sequences using two commercial enzymes. The summary of the results is presented below.

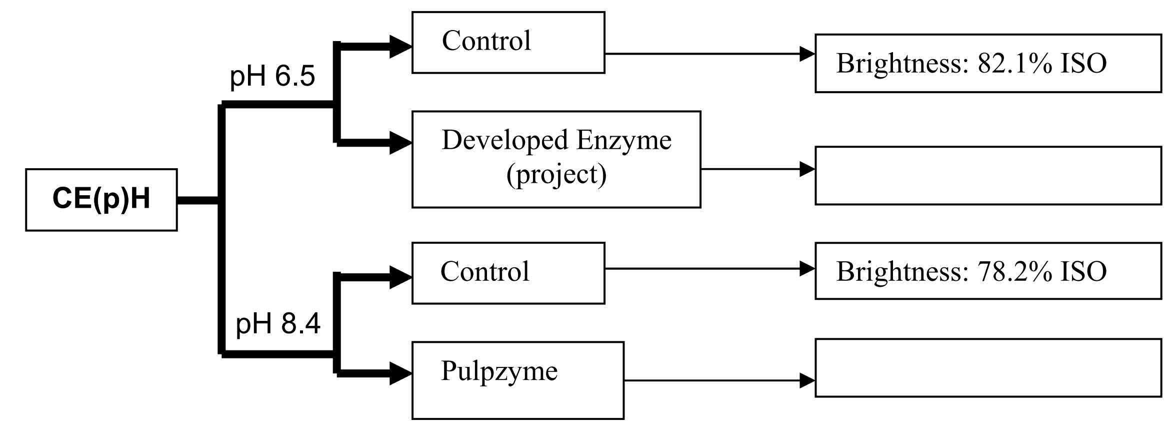


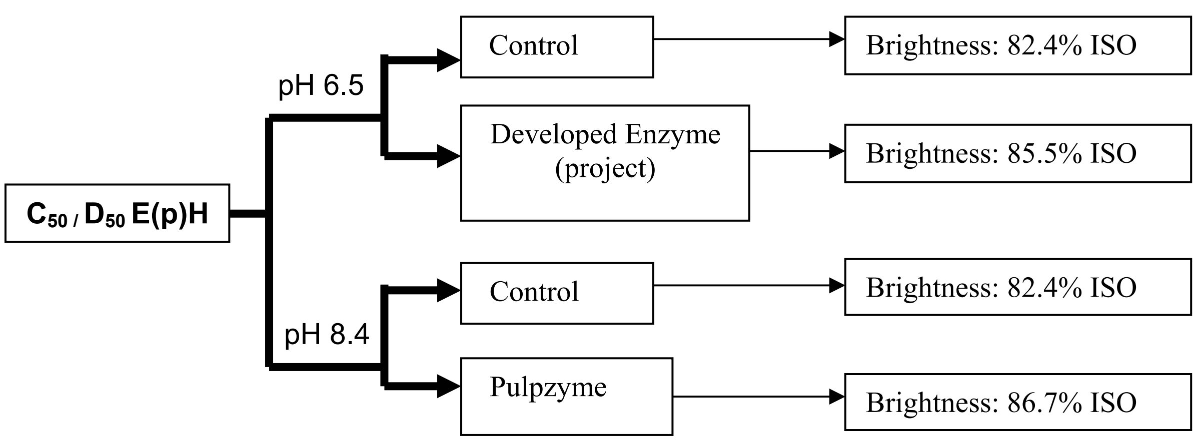


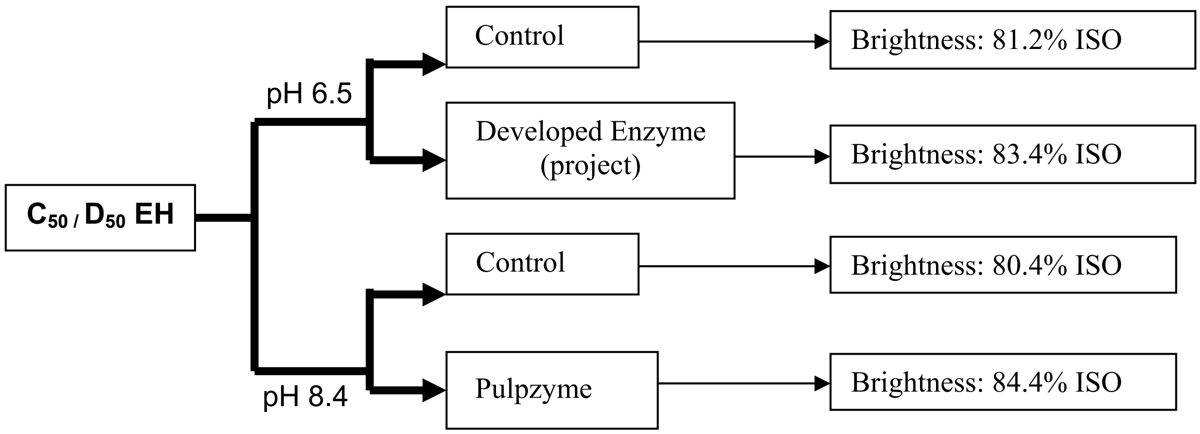
(Ref.: Annex 3 – table 17, 20, 28, 31 and 33)

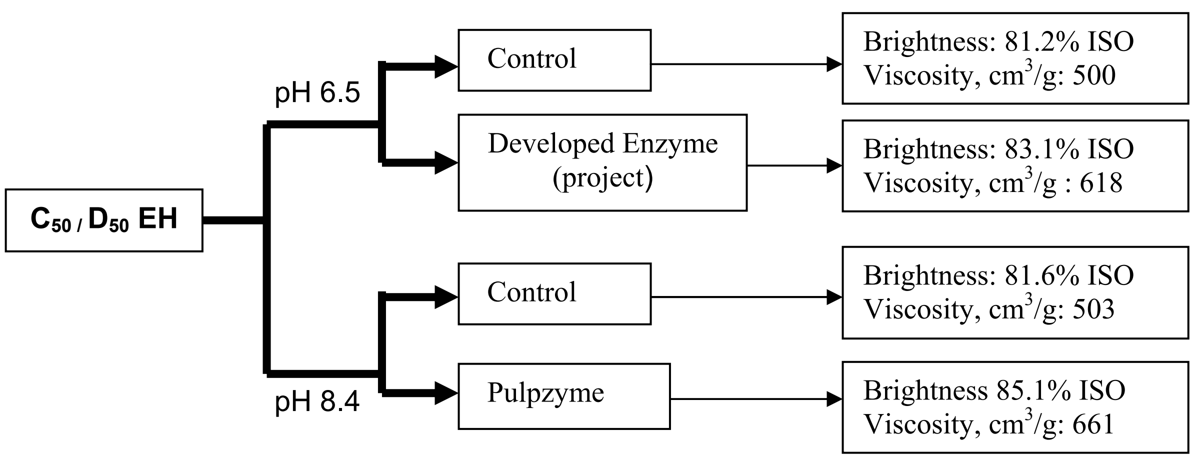
CPPRI also conducted bleaching experiments in various sequences with the pulp from the pilot plant scale trial (see below) using a commercial enzyme and also the one isolated in the course of the project.

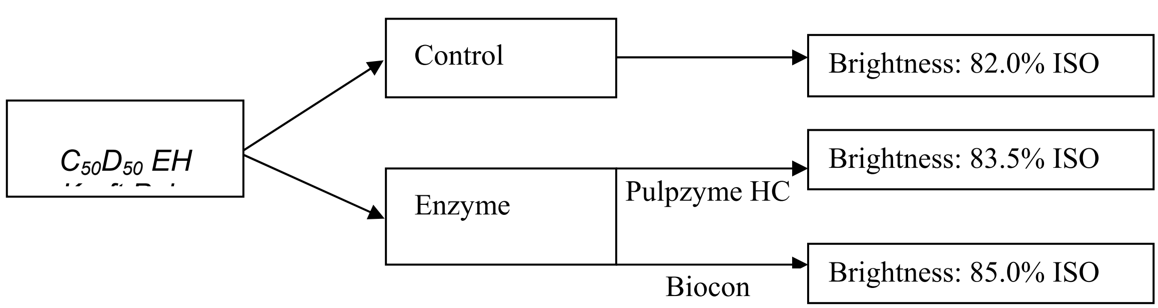

CEH
pH 6.5
pH 8.4
Control
Developed Enzyme (project)
Control
Pulpzyme
Brightness: 80.2% ISO
Brightness: 83.83% ISO
Brightness: 79.4% ISO
Brightness: 82.0% ISO


CE(p)H
pH 6.5
pH 8.4
Control
Developed Enzyme (project)
Control
Pulpzyme
Brightness: 82.1% ISO
Brightness: 78.2% ISO


C50 / D50 E(p)H
pH 6.5
pH 8.4
Control
Developed Enzyme (project)
Control
Pulpzyme
Brightness: 82.4% ISO
Brightness: 85.5% ISO
Brightness: 82.4% ISO
Brightness: 86.7% ISO


C_{50} / D_{50} EH
pH 6.5
pH 8.4
Control
Developed Enzyme (project)
Control
Pulpzyme
Brightness: 81.2% ISO
Brightness: 83.4% ISO
Brightness: 80.4% ISO
Brightness: 84.4% ISO


C_{50} / D_{50} EH
pH 6.5
pH 8.4
Control
Developed Enzyme (project)
Control
Pulpzyme
Brightness: 81.2% ISO Viscosity, cm^3/g: 500
Brightness: 83.1% ISO Viscosity, cm^3/g : 618
Brightness: 81.6% ISO Viscosity, cm^3/g: 503
Brightness 85.1% ISO Viscosity, cm^3/g: 661


$C_{50}D_{50}$ EH
Control
Enzyme
Pulpzyme HC
Biocon
Brightness: 82.0% ISO
Brightness: 83.5% ISO
Brightness: 85.0% ISO

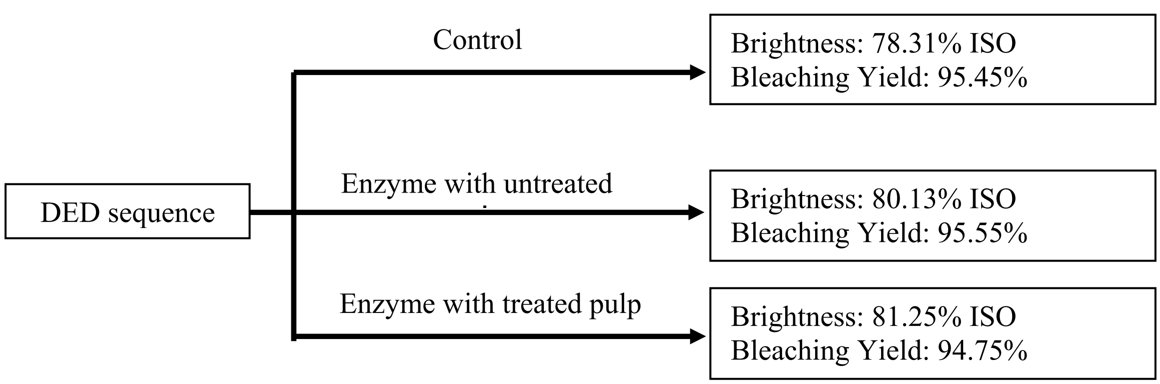
The results of the biobleaching process can be summarized as:

- Reduction of Kappa Number.
- Reduction of chemical requirements.
- Improvement of brightness.

(Ref.: Annex 3 – table 45, 46, 47, 48 and 49)

IBFC

Bleaching experiments were conducted following the Elemental Chlorine Free (ECF) sequence with and without enzyme using treated and untreated pulp.



(Ref.: Annex 5 – table 4)

The optimized results of the bleaching experiments in both Soda-AQ and Kraft processes, as well as with and without enzyme in various sequences has been compiled and are summarized in the following table. The table below shows that the XDED and OXCEH sequences conducted by BCIC produced desired results in terms of brightness in both Soda-AQ and Kraft processes. CTP optimized the bleaching conditions in the Soda-AQ process using the OCEH and XDED sequence that produced desired brightness of paper. Likewise, in the kraft process, CPPRI achieved the desired result using the $XC_{50}/D_{50}EH$, $XC_{50}/D_{50}E(p)H$ and $XC_{50}/D_{50}E(op)H$ sequences.

Table 9: Comparison of Brightness and Viscosity of Soda-AQ and Kraft pulp of different institutes (with control and enzyme):

Stages	Soda-AQ						Kraft					
Bleaching Sequence	**BCIC**		**CTP**		**CPPRI**		**BCIC**		**CTP**		**CPPRI**	
	Brightness (%) ISO	Viscosity	Brightness (%) ISO	Viscosity	Brightness (%) ISO	Viscosity	Brightness (%) ISO	Viscosity	Brightness (%) ISO	Viscosity	Brightness (%) ISO	Viscosity
CEH	78.12	8.13	80.9	8.5	78.2	-	76.38	8.3	-	-	81.08	422
XCEH	**79.2-80.3**	**8.85-9.15**		-	-	-	**79.2-80.2**	**8.75-9.34**	-	-	**81.58**	397
XECEH	-	-	80.2	10.0	-	-	-	-	81.4	8	-	-
DED	**79.15**	**12.12**	**81.7**	**23.8**	-	-	**80.56**	**12.82**	-	-	-	-
XDED	**80.5-82.1**	**12.25-12.70**	-	-	-	-	**81.6-82.2**	**12.72-13.10**	-	-	-	-
XEDED	**-**	**-**	**83.9**	**14.9**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
OCEH	**81.36**	**8.63**	**84.8**	**5.9**	**-**	**-**	**82.40**	**7.97**	**-**	**-**	**-**	**-**
OXCEH	**83.56**	**9.43**	**-**	**-**	**-**	**-**	**83.43**	**8.53**	**-**	**-**	**-**	**-**
XC$_{50}$/D$_{50}$ EH	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**83.5**	**-**
XC$_{50}$/D$_{50}$ E(p) H	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**85.0**	**-**
XC$_{50}$/D$_{50}$ E(op) H	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**87.0**	**-**

D. Bleaching of mechanical pulping

A&F conducted experiments of enzymatic pre-treatment on brightness of green jute paper made from Extruder /Refiner Pulp (**XRP**) and from Alkaline Peroxide Extruder Pulp (**APXP**) using xylanase and laccase enzymes.

The conclusions of the experiments are as follows:

Enzymatic pre-treatment

XRP pulp

- Laccase treatment before hydrogen peroxide bleaching raises the brightness by 2 to 3 units. This corresponds to a lower requirement of 0.5% to 1% hydrogen peroxide.
- Application of xylanase in the chemical pulp improves the brightness and reduces the chemical requirement in the bleaching sequences. In the mechanical pulping xylanase is not suitable, because the pulp has a very limited accessibility to the enzyme. However laccase and oxidative enzymes can improve the brightness by hydrolyzing lignin.
- Enzymatic treatment can be applied without loss of strength properties.

APXP pulp

- A xylanase treatment can reduce by 1 to 2% the amount of hydrogen peroxide, required in the APXP (Alkaline Peroxide Extruder Pulp) process.
- A low concentration of 1 unit of xylanase/g is sufficient.
- Laccase does not improve the brightness of the APXP pulp.

(Ref.: Annex 1 – page 34, 38 and 39)

Summary of Results Achieved under Objective 2:

Optimisation of pulping

In this part of the project, BCIC (Bangladesh), CPPRI (India), CTP (France) and IBFC (China) have optimized the conditions of pulping in laboratory scale using two main chemical processes

(Soda-AQ and Kraft) to produce bleachable grade pulp of Kappa number 20 (considered to be suitable for good quality paper). All the three institutes produced good quality pulp with 46%-48% yield.

Biopulping

- Application of biotechnology in the chemical process reduces the Kappa number by 15% and the cooking time.
- In both the Soda-AQ and kraft processes, cooking time can be reduced (from 120 minutes to 60 minutes in the Kraft process and from 90 minutes to 60 minutes in the Soda-AQ process). As a result, cooking cycles can be increased thus facilitating more mill throughputs.
- The physical properties of paper (burst, tear and tensile index) can be improved significantly (20-40%) in the biopulping process resulting in better quality paper.
- Application of biotechnology in mechanical pulping can reduce the energy requirements by 25%-30% and improve physical properties of the handsheet.

Bleaching

- The target brightness of 80% ISO was achieved in most of the sequences that were followed.
- Application of xylanase reduces the chlorine requirement by 15%.
- Application of xylanase followed by alkali reduces the chlorine requirement by 30%.
- Application of oxygen reduces the chlorine requirement by 40-45%.

Bleaching trials were conducted with four commercial and one isolated in Bangladesh in the course of the project. The efficacy of all the four enzymes was compared at BCIC and CTP. The results indicate that the efficacy of all 4 enzymes used did not vary greatly. However, the non-commercial enzyme in some of the bleaching sequences was marginally more effective. Among the four enzymes tried at CTP and BCIC, Biobrite seems more effective. At CPPRI in some sequences of bleaching the non-commercial enzyme showed better results while in other sequences the commercial enzymes produced better results.

OBJECTIVE 3:

To manage the black liquor produced during pulping and effluents generated during bleaching and identify suitable methods for green jute storage.

Target

- Reduce discharge of hazardous chemical effluents.
- Identify suitable methodology for storage of green jute.
- Develop suitable storing conditions for green jute.

Results achieved

Black Liquor Management

Experiments conducted at CPPRI

Effluent management in mills using kenaf and/or jute

Source of Waste Waters

In kenaf/jute-based mills, the major source of pollution is the bleaching section, if the mill is equipped with conventional soda recovery system. Besides the bleach plant effluent, the pollution load comes from weak washings and spillages from the pulp washing stages. Usually in modern mills it is expected that most of the paper machine effluent is reused/recycled in the mill after recovering the fiber in a fiber recovery unit such as primary clarifier etc.

Treatment Practices

(i) Primary Treatment

The effluent generated is usually first sent to a primary classifier for removal of suspended solids. Normally, the primary classifier removes 70-85% of suspended solids.

(ii) Secondary Treatment

After primary treatment the effluent is sent to the conventional secondary (biological) treatment system. If the mill has sufficient space then the effluent can be treated in an aerated lagoon. Where space is not sufficient, the effluent can be treated in an activated sludge system. The basic principles for both treatment systems are the same. The aerated lagoon requires long retention time and less operational cost, while an activated sludge system requires shorter retention time but needs more attention and requires comparatively higher operation & maintenance cost.

(iii) Tertiary Treatment

As a safeguard, in order to meet the discharge standards, the biologically treated effluents are further treated for removal of residual toxicity and colour.
(Ref.: Annex 3)

The management of black liquor generated during jute pulping revealed that jute black liquor is suitable for evaporation to high solid concentration and for further processing in the recovery boiler. It has high carbon content (38.1%), high calorie value (3438 cal/gram), low viscosity at high solid concentration and very low non-process elements concentrations. This makes it suitable for chemical recovery operations. However, the economic viability of such operations depends on mill size.

(1) Mill size: 30-50 TPD

For this category of paper mills, the chemical recovery system is not economically viable. Such mills can opt for the High Rate Biomethanation System followed by aerobic treatment. Lignin can be removed before biomethanation.

(2) Mill size: 50-100 TPD

In this category of mills, conventional chemical recovery is not economically viable as the capital and operational costs are very high. A fluidized bed type of chemical recovery system is preferable. In this type of chemical recovery system, chemicals in the form of soda ash can be recovered. No steam generation is possible in this recovery system. The process is suitable for mills using soda process for pulping.

(3) Mill size: 100-150 TPD

The Conventional Chemical Recovery System is recommended for this size of pulp mills with a cogeneration facility. Appropriate configuration of evaporators, recovery boiler etc. can be designed by considering the physico-chemical properties of the black liquor.

Storage of Green Jute/Kenaf Plants

A major constraint of using jute as a raw material for pulp and paper industry is that jute is an annual crop and harvested once a year, while pulp and paper industries are in operation round the year seven days a week. Therefore, jute plants are needed to be stored in large quantities in order to meet the demand of the paper mills. Normally, when the green plants are harvested, they are susceptible to microbial decomposition under the hot and humid climates in the harvesting season. In view of the above problems, storing protocol activities for green jute plant were initiated with the following objectives:

1) To isolate fungal strains responsible for the degradation of jute plants.
2) To find out the enzymes normally secreted by these organisms during rotting of jute plant.
3) To evaluate in vitro test the efficacy of some commercial fungicides in controlling the growth of these fungi.
4) To estimate the time required for reduction of moisture content (15-18%) after harvesting jute plant.
5) To develop proper model for storing dried jute plants.

Twelve (12) strains were isolated belonging to *Sclerotium*, *Aspergillus*, *Alternaria*, *Fusarium*, *Mucor, Macrophomina* and *Diplodia* sp. *Sclerotium* sp. was found to be the main strain for degradation of jute plants during harvesting. The maximum growth of *Sclerotium* is observed at 60-70% moisture content. *Sclerotium* does not easily grow on jute chips when the moisture content is 30% or less. The maximum growth of *Aspergillus* and *Macrophomina* is observed at 50-60% moisture level. Poor growth is observed at 25^0C and 40^0C for the strains S*clerotium, Macrophomina* and *Aspergillus*.

Among the fungi tested, *Sclerotium* sp. Shows–higher PGase activity (6.5 IU/ml) compared to xylanase (4.48 IU/ml) and CMcase (1.0 IU/ml) while *Aspergillus* sp. shows the highest xylanase activity (5.2 IU/ml).

Application of fungicide

The degradation of lignocellulosic materials of jute by different fungi such as Sclerotium sp., Aspergillus sp., Mecrophomina sp. as well as without presence of any fungi was studied. After comparing the degradation by different fungi, five fungicides i.e. Dithane M-45, Vitavax, Bavistin, Cupravit 50WP and Tilt 250 EC were evaluated for their fungitoxicity against the isolated strains.

It was shown that Tilt and Diathane are most effective in arresting the growth of *Sclerotium sp.* and *Macrophomina sp.* Diathane (1000 ppm) and Tilt (250 ppm) were sprayed separately on the infected plant in15 days interval. Of these two fungicides Tilt showed the better results in terms of fungicidal effectiveness. No growth of fungi was observed after the application of fungicide on green jute plant during storing.

Reduction of moisture content

The time required for reduction of moisture content of harvested jute was also determined. It was observed that the moisture content decreased gradually taking 8-10 days to reach 15-18% moisture content in the field. It was also observed that if the jute plants were stored in direct contact with the soil fungal growth was found in the bottom layer the plant.

Storing of jute plant

To develop a proper model for storing dried jute plants in various field conditions, the following two procedures were followed one based on the storing protocol of kenaf developed by IBCF and the second developed by IJSG.

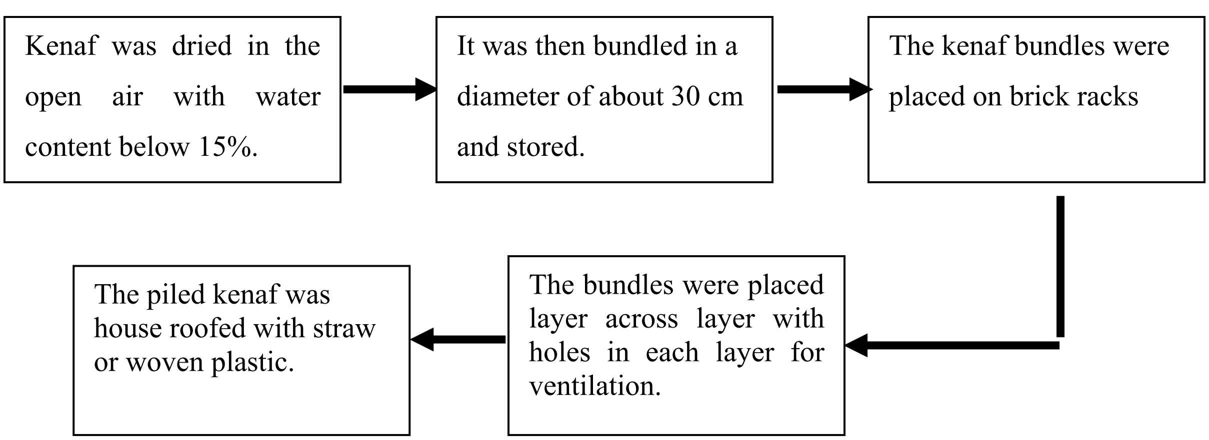
<u>IBFC</u>

The rate of microbial degradation (mildewing) of kenaf during storage depends on its water content and relative humidity (RH). The higher the water content and the ambient RH, the more susceptible it is for kenaf to get mildew and the faster is the growth rate of mildew. The experiments showed that if the moisture and RH of kenaf were controlled below 25% and 57% respectively, kenaf would not degrade even in the presence of mildew. However, it is difficult to control RH in open environments and it is therefore better to control the moisture content by drying the kenaf by aeration.

Fungicides are also effective in controlling kenaf mildewing. Of the 8 fungicides selected, Flusilaz, Mancozeb, Horizon and Thiophamate methyl were quite effective. Under RH of 100%, all treatments of fungicides on kenaf stored in the open air showed effective results in controlling mildewing. However, the best result was achieved with a combination of Flusilaz and Horizon. The mildew area on kenaf was less than 10% with the combined treatment of Flusilaz+Horizon, while with other treatments it was in the range of 20%.

IBFC conducted some small-scale experiments to identify the conditions of preventing kenaf mildewing.

The storing process was:

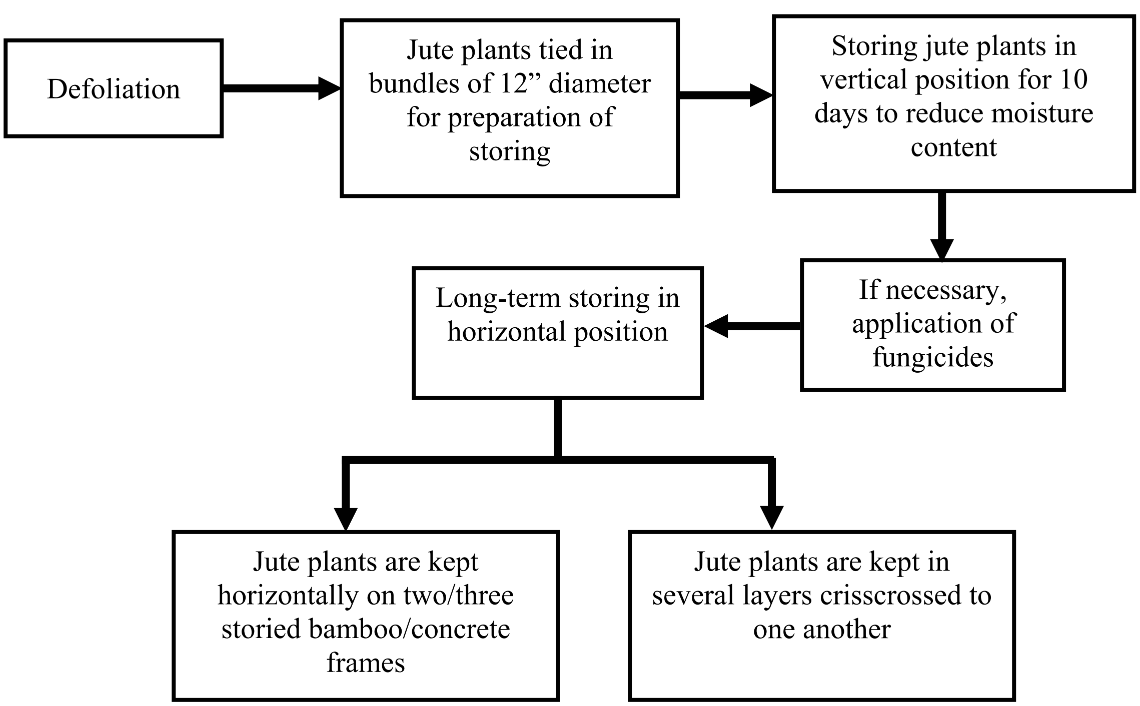


Polythene was used to cover the piled kenaf. After 9 months of storage through the long rainfall season, all kenaf was still fresh and there was little mildew. In addition, the practice of braided and fixed straw covering is cheap, environment friendly and easy to use. ***(Ref.: Annex 5)***

IJSG

After harvesting the jute plants, the moisture content of the plant is normally 65-75%. With this moisture content, if the jute plants are kept in horizontal position, the temperature rises up to 45-50^{0}C within 72 hours, which facilitates degradation by microorganism. In order to avoid growth of and degradation by microorganisms, the plants were bundled in a diameter of 12" and then kept in vertical position with a provision of flow of air. According to the experimental results, the moisture level of the plants drops to about 15-20% after 10 days.

Two models are suggested for long term storing with a minimum cost of investment. In one model the bundled jute plants are kept horizontally on two/three storied bamboo/concrete frames (picture). In another model, bundles of jute plants are kept in several layers crisscrossed to one another. Piled jute plants can be covered with a shade made of polythene sheet or straw to protect them from rain. The storing protocol for green jute plants is shown in the following diagram.



Summary of Results Achieved under Objective 3:

Storing and Black Liquor Management

Jute black liquor is suitable for evaporation to high solid concentration and for further processing in the recovery boiler. It has high carbon content (38.1%), high calorie value (3438 cals/gram), low viscosity at high solid concentration and very low non-process elements concentrations. This makes it suitable for chemical recovery operations.

Whole jute plant can be stored after drying the plant to a level of moisture content below 15%. In case of fungal attack, a number of fungicides are effective.

OBJECTIVE 4:

Large and commercial scale trial of whole jute plant for the production of pulp and paper.

Target

- Pilot and commercial scale trial of chemical pulping to produce unbleached and bleached paper.
  Assigned Institutes: BCIC and CPPRI
- To achieve brightness above 80% ISO suitable for writing paper.
  Assigned Institutes: BCIC and CPPRI
- Pilot scale trial of mechanical pulping suitable for the production of newsprint grade paper with brightness above 60% ISO.
  Assigned Institutes: A&F and CTP
- Establishment of techno-economic viability for utilizing whole jute for pulp and paper industry.

Results achieved

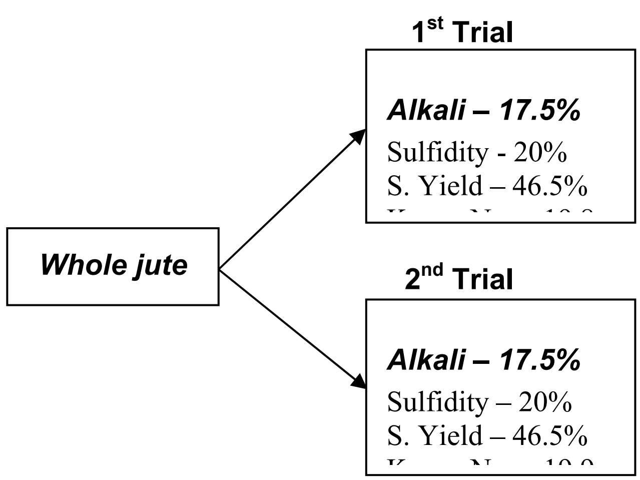
BCIC:

With the optimum conditions obtained at Karnaphuli Paper Mills Limited, BCIC conducted one large scale trial for the production of kraft paper (14 MT of dried jute plant which is equivalent to 56 MT of green jute plant) and one commercial trial for the production of writing paper (80 MT of dried jute plant equivalent to 320 MT of green jute plant). In these trials a stationery digester was used. For the production of kraft paper 12% alkali as Na_2O and 20% sulfidity were used. For the production of writing paper 15.5% alkali as Na_2O and 20% sulfidity were used. Bleaching of the washed, screened and refined pulp was conducted in the conventional bleaching sequence chlorine-alkali-hypochlorite (CEH). After the application of chlorine (0.22 of Kappa number of pulp) the pulp was washed and then alkali was used (2% NaOH). After alkali extraction, the pulp was again washed followed by hypochlorite (1.5%) treatment for final bleaching. Bleached pulp was used for making paper (70 gsm) in a paper machine of speed of 175-200 meter/minutes. The details on the experimental procedure are presented in **Annex-2, Appendix-E**.

- The yield of kraft pulp is 52%.
- The physical properties of kraft paper compared with that of bamboo are shown to be superior.
- The yield of pulp for writing paper is 45-48%.
- The physical properties of paper in the kraft process were compared with that of bamboo and hard wood are shown to be superior.
- The brightness of the paper is 80-83% ISO.
- Cooking temperatures and time of 1650C and 90 minutes respectively in both the trials.

CPPRI

CPPRI conducted two pilot scale trials of chemical pulping using the kraft process. The results of both the trials were almost the same. The results are shown below:



(Ref.: Annex 3 – table 40)

The pulp was used for bleaching in various sequences, such as: CEH, CE(p)H, C/DEH, C/DE(p)H. The results of the bleaching sequences are already been presented under Objective 2 of this report. The biobleaching experiments conducted have shown highly promising results in terms of reduction in Kappa number, reduction of chemical requirement during bleaching and improvement in brightness of the pulp. The data generated on enzyme pre-bleaching of jute provide new opportunities to adopt the technology as eco-friendly biotechnological application for papermaking from jute/kenaf.

A&F (Mechanical Pulping):

Green jute can be used to produce pulp with the APMP process. The energy input is very low compared to mechanical pulping of wood. A&F conducted mechanical pulping in 12 inch refiner.

- The alkaline peroxide process raises the brightness and strength properties of the hand sheets of green jute so much that it becomes suitable for newsprint. RMP turned out not to be suitable.

- APMP pulp (12-inch refiner) from green jute can be produced with only 25% of the energy needed to produce a TMP pulp for newsprint from wood.

- The average total yield after pressing, bleaching, refining and washing was 78.9%, which is comparable with the laboratory scale APMP experiment.

CTP (Mechanical Pulping):

Jute as a fiber resource had to be tested in mechanical pulping processes. CTP used two mechanical pulping processes to determine the suitability of whole jute for high-yield pulping. One process is Thermo-Mechanical Pulping (TMP) and the other process is Alkaline Peroxide Mechanical Pulping (APMP). CTP's high yield pulp making pilot plant facility operates under industrial conditions and simulates a mill processes. The results obtained from pilot plant studies can be up-scaled directly.

The results of the TMP process are summarized below:

- The TMP pulp that was obtained had weak mechanical properties. However, the pulp bleaching leads to 70% ISO brightness with 5% hydrogen peroxide charge.
- A chelation stage is necessary prior to the bleaching stage. Furthermore, the three commercial enzymes were tested prior to the bleaching stage with little effect.

The results of the APMP process are summarized below:

- Pulps of different chemical charges are obtained leading to pulp of mechanical properties suitable for newsprint papers.
- The brightness target of 60-65% ISO is achieved.
- 3% sodium hydroxide and 1% hydrogen peroxide is the best chemical charge for the impregnation stage and 3% hydrogen peroxide and 1.5% sodium hydroxide for the bleaching stage. However, these chemical charges can only be slightly reduced.
- At about 100 ml CSF the total energy consumption was comparable for APMP with 3% NoOH in the impregnation and TMP (about 2000 kwh/t).

Results Achieved under Objective 4:
Pilot Scale and Commercial Trial

After the optimization of pulping, BCIC conducted one large-scale trial (14 MT) and one commercial trial (80 MT). Whole jute plants were chipped using the available chipper after necessary adjustment. After the production of pulp, bleached paper was produced using the conventional sequence of bleaching (40-42 MT) in the existing paper machine. With the existing facilities of the chemical pulping mill of BCIC, whole jute plant was used commercially for the production of pulp and paper. The quality of paper is suitable for wrapping and different grades of writing paper. Physical properties of unbleached and writing paper are superior to paper made from bamboo and tropical wood. CPPRI (India) also successfully conducted pilot scale trials using chemical processing.

The commercial scale trial of chemical pulp using kenaf, originally envisaged in the project, was not performed and therefore it has not been possible to compare the pulp characteristics of jute and kenaf against each other as well as conduct a comparative study regarding on the yield, cost and physical properties of paper from jute and kenaf. This is a shortcoming that needs to be addressed in the future. However, it is expected that jute can produce better pulp than kenaf, because the fiber (bark) to stick ratio is 1:2, whereas fiber (bark) to stick ratio of kenaf is around 1:3. Ultimate fiber length of bark of both kenaf and jute is around 2 mm whereas that of core is less than 1 mm. Moreover, the price of whole kenaf in Bangladesh/India is comparatively less. Therefore, it is perhaps a preferable raw material for the paper industry.

Pilot scale mechanical pulping (high yielding) conditions were also optimized CTP, and A&F. The yield of mechanical pulping was 80%. The paper is suitable for newsprint.

Up-Scaling of Biopulping

Initially in the laboratory scale, 61 biopulping experiments were conducted for bleachable grade pulp of Kappa number 20 using different microbial strains in the both the Soda-AQ and kraft processes.

Upscaling of biopulping took place at the IJSG and BCIC facilities. It was conducted by mixing jute chips with micro-organism in a ribbon mixture in a temperature controlled room. Locally indigenous materials (wheat bran and molasses) were used to reduce the pretreatment cost of biopulping.

A 50 kg trial was conducted with and without aeration. The results obtained from the trial were more or less same as the laboratory experiments in terms of reduction of the Kappa number, yield and improvement of physical properties. An additional trial was also conducted to verify these results. The summarized results are as follows:

Pulping experiments	Medium used with chips	Results achieved
8 biopulping experiments were conducted with variation of media using *F. lignosus*.	Glucose + salt solution	For both wheat bran and molasses as media ❖ Kappa number can be reduced by approximately 20% under the same cooking condition both in the Soda-AQ and Kraft processes. The physical properties of hand sheet (burst, tear and tensile indices) improved significantly (20-40%).
	Wheat bran	
	Bagasse	
	Molasses	
50 kg trail experiments with and without aeration using *F. lignosus*.	Wheat bran with and without aeration	There is no significant difference with and without aeration

Techno Economic Feasibility Study

The study was conducted by an independent consulting firm and made use of the data obtained in the course of the implementation of the project to calculate manufacturing costs of both chemical and mechanical pulp from jute and kenaf. The calculations made did not take into account the location of the mill site as this could not be specifically defined at this stage.-The location of the mill site is expected to have a major impact on manufacturing costs.

As a raw material, the cost of green jute was assumed at the level of Tk 1,000/green metric ton at the mill site, for green jute with moisture content of about 75% that needs to be dried to about 15% moisture content for processing. For the purposes of comparison, the cost of kenaf (whole plant) was also assumed at Tk 800/green metric ton under the same moisture condition as green jute. Under these conditions, the production of 1.00 Adt of pulp requires the processing of 2.38 Adt of green jute. It is assumed that a manufacturing capacity of 100 Adt/day is suitable for green jute pulp, considering economies of scale and 343 days of the mill operation.

Biopulping results in economies arising from reductions in chemical inputs, shorter cooking times and improvement of the physical properties of the fiber. The results of biopulping in both chemical and mechanical processes are quite encouraging but these results need to be corroborated by larger pilot scale trails for pulp and paper production where 14 days of pretreatment of the raw material with microorganism may be a problem in the case of production facilities of 100Adt/day.

Experimental results of biological bleaching show a reduction in the consumption of chlorine dioxide by 10-18% when xylanase is used for the first stage of multiple bleaching stages with a concomitant improvement in brightness. This results in cost savings of US$3.66/Pulp Adt. Given the fact that the purchase cost of xylanase is US$5.00/Pulp Adt, the savings from the reduction chlorine dioxide input is almost offset by the cost of xylanase. Should it be feasible to produce xylanase locally at a cost of US$1.50/Pulp Adt, then this would effectively result in cost saving of US$2/Pulp Adt.

The experimental results show that xylanase bleaching in the mechanical process is not sufficiently efficient to improve the brightness. Enzymes pretreatment is not suitable because, during impregnation, alkali removes xylans in the pulp.

The calculations made in the study included variable costs of raw materials, energy, chemicals and labour. Labour wages were calculated according to the variable exigencies of pulp manufacturing operations and the mill maintenance cost was estimated at US$23.00/Adt for general maintenance of the facility. Further, facility depreciation was calculated on the basis of 20 years for equipment and 30 years for building facilities, maintaining a book value of 10%. The LDC rate of interest on loans of 0.9% set by Japan Bank for International Cooperation (JBIC), i.e. 30 years repayment term with 10 years grace was used a the basis of calculation. The head office cost was calculated on the basis of the above interest rate assumptions, the inland freight cost to local market and a corporate tax at the rate of 37.5%.

The investment costs of a manufacturing facility for both chemical and mechanical pulp was calculated to be:

Chemical Pulp Facility:	US$ 77,382,000
Mechanical Pulp Facility:	US$ 59,604,800

The pulp mill construction schedule was assumed to commence two years prior to the commencement of the Pulp Mill Operation.

Manufacturing Cost

In view of the many variables used under the above assumptions, mill production costs were calculated using four different situations (see Tables below):

1. Case 1 - Jute using current costs of chemicals in Bangladesh
2. Case 2 - Jute using current costs of chemicals in India
3. Case 3 - Kenaf using current costs of chemicals in Bangladesh
4. Case 4 - Kenaf using current costs of chemicals in India

Estimation of the Jute Chemical Pulp Production Cost in Bangladesh (US$/Adt)

		Whole Jute		***Whole Kenaf***	
		Case 1	**Case 2**	**Case 3**	**Case 4**
Variable Costs	Raw materials	147	147	118	118
	Energy	37	37	37	37
	Chemicals	80	**57**	80	**57**
	Others	18	18	18	18
Total		**282**	**259**	**253**	**230**
Fixed Costs	Labor	10	10	10	10
	Maintenance	23	23	23	23
	Administration	5	5	5	5
	Depreciation	82	82	82	82
Total		**120**	**120**	**120**	**120**
Factory Manufacturing Cost		***402***	***379***	***373***	***350***

Mechanical Pulp Manufacturing Cost US$/Adt

		Whole Jute		***Whole Kenaf***	
		Case 1	**Case 2**	**Case 3**	**Case 4**
Variable Costs	Raw materials	77	77	62	62
	Energy	43	43	43	43
	Chemicals	78	**65**	78	**65**
	Others	14	14	14	14
Total		**212**	**199**	**197**	**184**
Fixed Costs	Labor	9	9	9	9
	Maintenance	20	20	20	20
	Administration	5	5	5	5
	Depreciation	60	60	60	60
Total		**94**	**94**	**94**	**94**

Factory Manufacturing Cost		***306***	***293***	***291***	***278***

On the basis of the calculations made, Case 4 appears to be the most feasible and competitive among the options.

The study concludes that the sale of fine paper from chemical pulp and newsprint paper from mechanical pulp in the Bangladesh domestic market is the best option if it is supported by government subsidies such as reduction or exemption of import taxes for chemicals and/or financial assistance on VAT, Corporate Tax, etc. The construction of Pulp Mill in the EPZ may constitute such government assistance.

This report was prepared on the basis of numerous assumptions such as prices of raw materials, inland freight, interest rate, local tax and sales prices for pulp and paper. A more detailed feasibility study is recommended that would validated these assumptions, and also include costs of cultivation, the logistics of storing the raw materials as well as market demand.

Feasibility Analysis in Each Case

	Intrest Rate	VAT			
Case A	0.9%	0.0 %	Case1 Chemical Price Banglades	Jute
Case B	4.9%	0.0 %	Case2 Chemical Price India	Jute
Case C	0.9%	15.0 %	Case3 Chemical Price Banglades	Keanf
Case D	4.9%	15.0 %	Case4 Chemical Price India	Kenaf

Interest Rate of 0.9% represents the rate applicable for Project under Yen-Credit from Japan
Interest Rate of 4.9% represents the rate appplicable for commercial reference in US$

	Chemical Pulp				Mechnaical Pulp				Fine	News-
	Case1	Case2	Case3	Case4	Case1	Case2	Case3	Case4	Paper	print
Case A										
Factory manufacturing Cost	402	380	372	350	306	293	291	278	640	520
Intrest Cost	18	18	18	18	13	13	13	13	12	12
VAT	0	0	0	0	0	0	0	0	0	0
Other Head offe cost	15	15	15	15	13	13	13	13	18	18
Total Manufacturing Cost	**435**	**412**	**405**	**383**	**332**	**319**	**317**	**304**	**670**	**550**
Case B										
Factory manufacturing Cost	402	380	372	350	306	293	291	278	640	520
Intrest Cost	96	96	96	96	71	71	71	71	66	66
VAT	0	0	0	0	0	0	0	0	0	0
Other Head offe cost	15	15	15	15	13	13	13	13	18	18
Total Manufacturing Cost	**513**	**491**	**484**	**461**	**390**	**377**	**375**	**361**	**724**	**604**
Case C										
Factory manufacturing Cost	402	380	372	350	306	293	291	278	640	520
Intrest Cost	18	18	18	18	13	13	13	13	12	12
VAT	60	57	56	53	46	44	44	42	96	78
Other Head offe cost	15	15	15	15	13	13	13	13	18	18
Total Manufacturing Cost	**495**	**469**	**461**	**435**	**378**	**363**	**360**	**345**	**766**	**628**
Case D										
Factory manufacturing Cost	402	380	372	350	306	293	291	278	640	520
Intrest Cost	96	96	96	96	71	71	71	71	66	66
VAT	60	57	56	53	46	44	44	42	96	78
Other Head offe cost	15	15	15	15	13	13	13	13	18	18
Total Manufacturing Cost	**573**	**548**	**539**	**514**	**436**	**421**	**418**	**403**	**820**	**682**
Sale Price(Domestic Market)	600	600	600	600	425	425	425	425	870	720

Profit After Tax (TAX 37.5%)

Case A	103	117	122	136	58	66	68	76	125	106
Case B	54	68	73	87	22	30	32	40	91	72
Case C	66	82	87	103	29	39	40	50	65	57
Case D	17	33	38	54	-7	3	4	14	31	24

Red Letter indicates not feasible

Minimum Profit (after Tax) Level, Feasible for the Project
10%of the Annual return on Equity and repayment of the Loan during 20years

Chemical Pulp	56 US$/ADT
Mechanical Pulp	50 US$/ADT
Fine Paper	50 US$/ADT
Newsprint Paper	50 US$/ADT

OBJECTIVE - 5: Dissemination of results and completion of the project

A dissemination workshop was held in Dhaka, 11 May 2004 under the Chairmanship of the Secretary, Ministry of Jute, Government of the People's Republic of Bangladesh. The workshop was attended by the Ambassador of the Republic of France in Bangladesh; the Secretary, Ministry of Industries; the Minister for Industries; the Principal Secretary to the Prime Minister, Minister for Textiles and Jute and representatives of industry and NGOs.

The workshop was inaugurated by the Secretary General, International Jute Study Group, Dhaka. It was also attended by the Principal Project Manager, Common Fund for Commodities (CFC), representatives of IJSG, UNIDO, the collaborating parties and the Project Leader.

Target

The main findings of the report were presented at the workshop together with those of the economic pre-feasibility study. The presentations were followed by extensive debate. The minutes of the workshop and the list of participants are included in **Annex 7**.

Results achieved

The dissemination workshop was followed up by a meeting of representatives of CFC, IJSG, UNIDO, the collaborating parties and the Project Leader. The draft CPR was discussed and some amendment were proposed for the preparation of the final report. The draft CPR met with the overall agreement of all participants.

IV. Lessons Learned

There was some over-lapping in pulping and bleaching experiments. However, this had the trade off of confirming the reproducibility the experimental results.

As is expected with all applied research projects, new needs became apparent during the implementation of the project. Addressing these needs (e.g. scaling-up biopulping; conducting more detailed comparison between jute and kenaf processing) requires more time and resources.

The relatively large number of parties in the technical implementation of the project made coordination of activities rather difficult but obstacles were overcome in most part.

More emphasis should had been given at the inception of the project on economic aspects and therefore, introduce benchmarks against which the commercial viability of the developed technologies could be tested. The strategy in the development of a jute/kenaf based pulp mill must involve a critical analysis of supply and storage of the raw material, the pulping process technology, development and marketing of the product. Of these the project addressed adequately the pulping process technology and storage.

V. Conclusions

1. In terms of physical properties jute and kenaf are suitable raw materials for the production of pulp and paper by the Soda-AQ and Kraft processes and can substitute bamboo and tropical hardwood.

2. Various grades of paper (wrapping and writing paper) can be produced in the chemical process using the existing chemical based paper mills.

2. Mechanical pulping conducted in the APMP process showed that newsprint grade of paper can be produced. However, the experiments were conducted in small scales and there is need to conduct more pilot scale trials using 1/2 MT of dried jute plant to ascertain the effectiveness and efficiency of the APMP process.

3. Biopulping experiments showed promising results in terms of reduction of energy and chemical requirements, and resulted in pulp with improved physical properties. Biotreated pulp was shown to reduce the Kappa number significantly. Consequently chemical treatment in bleaching can be reduced. The biopulping technologies developed could be effective in small-scale paper mills, manually operated paper mills (where normally jute is used and female workers are mostly employed) and in mechanical pulping (especially in the APMP process).

4. Enzymes can significantly reduce chemical requirement in the conventional and ECF bleaching sequence. Thus, enzyme application can make the product cost effective and environment friendly. Large-scale enzyme application should be conducted in existing chemical paper mills to generate awareness of the process.

VI. Recommendations

1. Conduct further large-scale experiments to ascertain the efficacy of the APMP-mechanical pulping process as well as the effectiveness of biopulping.

2. Ascertain the impact of supply and storage-related factors (e.g. cost at the farm-level, maintenance of supply volume and quality, transportation and storage) on production costs.

3. Ascertain the impact of government policies on costs of production of pulp from jute/kenaf.

4. Determine mill capacities in relation to the overhead costs of production. The minimum economic size of a bleached softwood or hardwood chemical market pulp mill is about 700/800 t/d to compete in the international market. Such mills are unlikely to be installed in jute producing developing countries. Therefore, it is important to consider the potential of installing specialty pulp mills that can compete internationally with a capacity of 50-200 t/d.

5. In relation to points 2-4 above, a comprehensive pre-feasibility study would be appropriate.

6. Enhance the awareness of investors and/or mill managers of the potential of jute-derived pulp not only by itself but also as additive to conventional pulps to impart some special characteristics that cannot be obtained using wood pulp alone.