COIR PROCESSING TECHNOLOGIES

Improvement of drying, softening, bleaching and dyeing coir fibre/yarn and printing coir floor coverings
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FOREWORD

Coconut fibre, or coir, is a low-value by-product of coconut production. In most countries coir is discarded as waste, sometimes it is used as a fuel, in few instances it is processed into products.

Coconut production is largely the domain of small, poor farmers, mainly for the sale of copra. Coconut farmers, however, could earn an additional income if there were a demand for coconut fibre. Productive use of the fibrous material contained in the husk practically only takes place in India and Sri Lanka. As coir is a coarse, short fibre, traditional applications for coir are generally low-cost mats and nets, brooms and brushes, and fillings for mattresses and upholstery. These applications are facing strong competition from synthetic materials, thus eroding the demand for coir. Renewable, natural materials like coir do have, however, potential for uptake in profitable applications, provided they meet the required standards set by the markets. This relates in particular to technical standards without excluding the importance of issues like reliability of supply, price competitiveness, etc.

The present Technical Paper is the reflection of the work undertaken by a project financed by the Common Fund for Commodities, which specifically focused on technology development in relation to the usability of coir in traditional and improved applications. The project, entitled Improvement in Drying, Softening, Bleaching, Dyeing Coir Fibre/Yarn and in Printing Coir Floor Coverings, was implemented by the Food and Agriculture Organization of the United Nations (FAO) in two countries, namely India and Sri Lanka. An international workshop was organized by the Coir Board of India and its Central Coir Research Institute (CCRI) in December 1997 in the framework of the project, the proceedings of which were published separately by the CCRI.

This Technical Paper has been commissioned by the Common Fund in line with its policy to make results and experiences obtained in its projects available to a wider audience. It is intended to provide both an account of the project’s technical achievements and findings, as well as to place the experiences obtained in the context of the current insights and state-of-the-art in coir processing technologies.

It is the wish of the Common Fund that this publication in the series of CFC Technical Papers will contribute to a further development of the coir sector, and may result in a continuing uptake of promising techniques, leading to higher value addition for coir and coir products.

Rolf W. Boehnke
Managing Director
Common Fund for Commodities
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1. Introduction

1.1 Background to the project

The techno-economic manual represents the final document of the project, which started officially on 1 June 1995 and was completed 31 December 1999. A need to improve the economic viability of coir fibres on world markets led to a proposal for making improvements to the obsolete processing technologies in use. This resulted in a programme of research and development (R&D) activities on wet processing technologies, the outcome of which is described herein. The Executive Board of the Common Fund for Commodities (CFC) approved the proposal entitled “IMPROVEMENT IN DRYING, SOFTENING, BLEACHING, DYEING COIR FIBRE/YARN AND IN PRINTING COIR FLOOR COVERINGS” in March 1993. The Food and Agriculture Organization of the United Nations (FAO) was designated the Project Executing Agency (PEA). The assigned project implementation agencies in the partnership countries were the Coir Board of India, Cochin, India and the Coconut Development Authority, Colombo, Sri Lanka.

1.2 Objectives and activities

The focus of the project was on coir wet processing technologies, and was directed towards the research and transfer of technologies that would encourage further demand for traditional coir products, for example, coir fibre, yarn and floor coverings (mats, matting and carpets) by improving quality and enhancing appeal. The project required that these technologies should be appropriate and cost effective, and would upgrade the production of coir and yarn manufacture at village level.

A strategy was proposed containing five activities for a period of two years to improve drying, dyeing, softening, and bleaching technologies, as well as the printability of coir mats, rugs and carpets. Drying was implemented in Sri Lanka by the Coconut Development Authority (CDA), while the other activities were located in India, and implemented by the Coir Board of India (CBI) with the close involvement of the Central Coir Research Institute (CCRI), Kalavoor.

1.3 Execution

The CCRI is a specialized institution for the R & D of coir, and a constituent part of the Coir Board of India. The CBI through the Ministry of Commerce provides government representation for the coir industry. The CCRI needs to be exposed to international standards of testing and up-to-date technology in order to be able to supply coir exporters with the improved technologies and product certificates that are essential to enable them to remain competitive. CCRI research staff are involved in many different aspects of research, development and testing for the coir production sector. Improvements with the technologies of fibre extraction, spinning and weaving, dyeing and finishing were extensively covered during the R&D programme that formed part of the project. Much attention was also given to the bio-technological processing of coir fibre extraction, bleaching and softening.

Much has been achieved in India within the framework of the FAO/CFC project on wet processing of coir. The project has given a measure of focus to the CCRI research groups on the processing technologies required, and enabled them to target and re-align their work programmes. This will have long term post-project implications. Methods have been developed to assess the research achievements made, both technically and economically. Thanks to the current project, the Institute has been able to purchase essential research equipment such as the HPLC, GC and a UV/VIS spectrophotometer. This equipment can be used to measure the concentration and composition of a broad range of chemicals, such as dyestuffs and auxiliary chemicals in processing liquors or effluents.
In Sri Lanka, project activities on drying technology were undertaken by the CDA, which is essentially a trading and advisory organization and not a research centre. The CDA has some limited laboratory facilities on site with which to investigate foods from coconuts but none for non-food products such as coir. It recruited specialists, allocated laboratory space and made a concerted effort to redress some of these deficiencies. The CDA made full use of external contractors for the construction of rigs and prototypes. By the end of the project a prototype drier was working within designated parameters of design, but lack of industrial R&D facilities and limited international orientation on the part of the CDA was an obstacle to achieving the goal of developing a fully functional and operating drying unit for coir fibre products.
2. Coconut - Tree of Life

2.1 Coconut production

Coconut trees are grown in tropical countries mainly for the high oil content of the endosperm (copra), which is widely used in both food and non-food industries (e.g. margarine and soaps). Large production areas, in particular, are found along the coastal regions in the wet tropical areas of Asia in the Philippines, Indonesia, India, Sri Lanka and Malaysia. (See Table 1). In these countries millions of people make a living from the coconut palm and its many products.

Table 1: Coconut production in major producing countries

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>million tonnes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td>11 200</td>
<td>12 317</td>
<td>14 380</td>
<td>13 990</td>
<td>14 710</td>
<td>30.3</td>
</tr>
<tr>
<td>Philippines</td>
<td>9 142</td>
<td>8 910</td>
<td>9 079</td>
<td>11 586</td>
<td>11 273</td>
<td>23.2</td>
</tr>
<tr>
<td>India</td>
<td>4 192</td>
<td>6 188</td>
<td>7 590</td>
<td>9 718</td>
<td>9 900</td>
<td>20.4</td>
</tr>
<tr>
<td>Sri Lanka</td>
<td>1 692</td>
<td>1 828</td>
<td>1 689</td>
<td>2 009</td>
<td>1 999</td>
<td>4.1</td>
</tr>
<tr>
<td>Malaysia</td>
<td>1 211</td>
<td>1 061</td>
<td>1 033</td>
<td>1 003</td>
<td>967</td>
<td>2.0</td>
</tr>
<tr>
<td>Thailand</td>
<td>781</td>
<td>1 433</td>
<td>1 379</td>
<td>1 433</td>
<td>1 430</td>
<td>2.9</td>
</tr>
<tr>
<td>Other Asia</td>
<td>564</td>
<td>1 312</td>
<td>1 553</td>
<td>1 666</td>
<td>1 825</td>
<td>3.7</td>
</tr>
<tr>
<td>Total Asia</td>
<td>28 782</td>
<td>33 048</td>
<td>36 703</td>
<td>41 405</td>
<td>42 104</td>
<td>86.7</td>
</tr>
<tr>
<td>Mozambique</td>
<td>453</td>
<td>420</td>
<td>425</td>
<td>439</td>
<td>445</td>
<td>0.9</td>
</tr>
<tr>
<td>Tanzania</td>
<td>310</td>
<td>358</td>
<td>357</td>
<td>370</td>
<td>355</td>
<td>0.7</td>
</tr>
<tr>
<td>Other Africa</td>
<td>890</td>
<td>1 158</td>
<td>952</td>
<td>975</td>
<td>1 011</td>
<td>2.1</td>
</tr>
<tr>
<td>Total Africa</td>
<td>1 653</td>
<td>1 936</td>
<td>1 734</td>
<td>1 784</td>
<td>1 811</td>
<td>3.7</td>
</tr>
<tr>
<td>Oceania</td>
<td>2 317</td>
<td>2 213</td>
<td>1 891</td>
<td>1 866</td>
<td>1 878</td>
<td>3.8</td>
</tr>
<tr>
<td>Latin America</td>
<td>2 266</td>
<td>2 807</td>
<td>2 945</td>
<td>2 359</td>
<td>2 311</td>
<td>4.7</td>
</tr>
<tr>
<td>TOTAL WORLD</td>
<td>35 018</td>
<td>40 005</td>
<td>43 274</td>
<td>47 854</td>
<td>48 525</td>
<td>100</td>
</tr>
</tbody>
</table>
Total world productivity has increased substantially from 35 million tonnes around 1980 to almost 50 million tonnes today. Yield varies from region to region (3,500 to 6,000 nuts/ha/year), which is due to a number of factors. One tree may yield on average 70-100 nuts to a maximum of 150 nuts per year. The kernel (copra, coco-water and shell) comprises 65 per cent of total weight, while the husk contributes 35 per cent.

Besides the valuable contents of the nuts, the palm yields husks, shells, leaves and the stem which are used domestically as raw materials for many products from fuel to building materials.

2.2 Coir

Coir fibres are extracted from the husks surrounding the coconut (Figure 1). In most areas coir is a by-product of copra production, and the husks are left on the fields as a mulch or used as fertilizer because of high potash content. India and Sri Lanka are the main countries where coir is extracted by traditional methods for the commercial production of a variety of products, including brushes and brooms, ropes and yarns for nets and bags and mats, and padding for mattresses. However, worldwide only a small part of the fibres available are currently used for these purposes (Table 2). The average fibre yield is dependent on geographical area and the variety of the coconut tree. In the south of India and Sri Lanka, for example, where the best quality fibres are produced the average yield is 80-90 g fibre per husk. Caribbean husks, by contrast, are relatively thick and may yield up to 150 g of fibre.

![Cross-section of coconut](image)

**Figure 1 – Cross-section of coconut**
Table 2: Estimation of the availability of coir raw materials

<table>
<thead>
<tr>
<th></th>
<th>PHILIPPINES</th>
<th>INDONESIA</th>
<th>INDIA</th>
<th>SRI LANKA</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>tonnes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Potential Fibre production #</td>
<td>700 000</td>
<td>1 000 000</td>
<td>600 000</td>
<td>260 000</td>
</tr>
<tr>
<td>Fibre Industry</td>
<td>-</td>
<td>-</td>
<td>300 000</td>
<td>100 000</td>
</tr>
<tr>
<td>Domestic use *</td>
<td>70 000</td>
<td>100 000</td>
<td>60 000</td>
<td>26 000</td>
</tr>
<tr>
<td>Non-extracted fibres</td>
<td>630 000</td>
<td>900 000</td>
<td>240 000</td>
<td>134 000</td>
</tr>
</tbody>
</table>

# Estimated annual coconut production capacity x fibre yield (80-90 g/nut)
* Estimated 10 per cent of total production

Husks are composed of 70 per cent pith and 30 per cent fibre on a dry weight basis. The ratio of yield of long, medium and short fibre, respectively, is on average 60:30:10. Based on these data and combined with the production data in Table 1, the maximum total world production of coir fibre (included short fibres) can be estimated to range between 5 and 6 million tonnes per year. Only a small part (less than 10 per cent) of this potential enters commercial trade. Continuous expanding production of brown fibre reached 216 000 tonnes (70 per cent India, 27 per cent Sri Lanka) in 1996, while white fibre production (again, mainly in India) has remained stable at 125 000 tonnes.

2.3 Coir markets

Coir has faced a declining market for traditional products in recent decades. Despite their comparatively low trade value, the fibres provide significant economic support to populations in specific areas of the producing countries (for example, in the southern Indian states of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh, and in west and south Sri Lanka). Women in these areas are particularly dependent on coir production for their livelihood.

Traditionally, coir has been processed into a range of products such as yarns for the production of floor coverings, mats and matting, cordage and nets, bristle fibres for brooms and brushes, and for use with domestic mattress and upholstery industries. These markets have been dwindling in recent years due to strong competition from synthetic products. However, there is a firm trend in the industrial countries towards the production and use of more environmentally benign products and systems, which may help to mitigate the adverse ecological affects of current production methods. The effects of chemical industries, atmospheric degradation, global warming, fast-declining natural resource base, deforestation, waste production, pollution and similar global issues have increased the demand for environmentally benign products. Renewable raw materials such as plant fibres and products, therefore, may have good market perspectives if they can be produced at an economically competitive price and on a scale where quality and supply can be guaranteed. Currently, expanding export markets for coir can be seen in the demand for erosion control mats and other geotextile applications for civil engineering, or in the demand from the automotive and mattress industries for rubberised coir pads.

2.4 Coir market diversification

Cost effective and environmentally safe technologies have been investigated for drying, bleaching, softening and dyeing of fibre and yarn, and for fast printing of coir products to encourage increased demand
for coir products (fibre, yarn, door mats, matting, runners and carpets). To upgrade coir products to meet the standards required of export markets, efforts must start at village production levels. Marketing of ecologically safe coir products should imply and include, however, the whole production chain from fibre extraction to end product and disposal or re-use when no longer required. It follows that production methods should be safe for the health of the workers involved in the coir industry, without negative effects on production performance.

Demand for geotextile products is increasing, but still comprises only two per cent of the total volume of coir exports from India (April-October 1998).

A large number of alternative end uses for coir based products may become feasible, for example, for the production of fibre reinforced composite materials, fibreboard and similar building materials (for example, for insulation)\(^5\). Innovative product development and marketing requires concerted action by a number of different players in the production chain. The close involvement of local governments, combined with investment by private enterprises and the support of public research institutions is required for innovation, manufacturing and sales.

2.5 Coir pith

As a by-product of coir fibre extraction large quantities of pith are obtained, which have been accumulating at production sites over the years. The extraction of 1 kg of fibre generates more than 2 kg of coir pith. Recently, however, the product has gained commercial interest as a substitute for peat moss in horticultural substrate cultivation. Low susceptibility to biodegradation and a highly porous structure enables coir pith to absorb large volumes of water (more than 50 per cent by weight), which makes it highly suitable in a potting mixture. For horticultural use, the product has to meet specific chemical and biological standards of pH, electrical conductivity and elemental composition\(^7\). Repression of sodium and potassium from the cation complex of the coir may be desirable for many sensitive horticultural products. Technical information to describe microbial contamination and product safety is another concern for users.

Exports of coir pith from India has increased from less than two per cent of the volume produced in 1997 to almost four per cent in 1998. Coir pith is also supplied from other production areas (e.g. Sri Lanka, the Philippines and Indonesia), and the penetration of coir pith into markets for horticultural and garden substrates is gaining interest\(^8\).

2.6 Charcoal

Coconuts shells, which comprises 12 per cent of the weight of the coconut, could be utilized more efficiently. Commercial production of charcoal from the coconut shell provides for an increasingly important export market for cocos producing areas. Carbonization of one tonne of coconut shells produces of the order 300 kg of charcoal, which can be converted into 120 kg of activated carbon. The combustion of waste gases can be utilized to enhance the efficiency of the processes and to generate power. The market for activated carbon in filter materials, absorbents and similar uses could be increased substantially if controlled processing and product certification were available. An alternative domestic application for charcoal could be as fuel for cooking or for drying agricultural products (for example, copra and/or coir).
3. Coir Fibre Processing

3.1 Fibre extraction

The effectiveness of the wet processes investigated by the project team, such as bleaching and dyeing of coir, are strongly dependent on the procedures used to extract fibres from the husks and the pre-treatment given the fibres. Both state-of-the-art and commonly used technologies for fibre extraction are described.

3.1.1 Traditional fibre extraction

The traditional production of fibres from the husks is a laborious and time-consuming process. This is highly polluting of surface waters and results in the accumulation of large dumps of pith. After manual separation of the nut from the husk, the husks are processed by various retting techniques, and generally in ponds of brackish waters (for three to six months) or in salt backwaters or lagoons. This requires 10-12 months of anaerobic (bacterial) fermentation. By retting the fibres they are softened and can be decorticated and extracted by beating, which is usually done by hand. After hackling, washing and drying (in the shade) the fibres are loosened manually and cleaned.

Traditional practices of this kind yield the highest quality of (white) fibre for spinning and weaving. Retted fibres from green husks are the most suitable fibres for dyeing and bleaching.

For the production of more coarse brown yarns, shorter periods of retting may be applied. These find an increasing outlet in geotextile applications.

Alternatively, mechanical processing using either defibering or decorticating equipment can be used to process the husks after only five days of immersion in water tanks. Crushing the husk in a breaker opens the fibres. By using revolving “drums” the coarse long fibres are separated from the short woody parts and the pith. The stronger fibres are washed, cleaned, dried, hackled and combed. The quality of the fibre is greatly affected by these procedures.

3.1.2 Green decortication and enzyme treatments

New environmentally friendly methods of fibre production are of interest. These can be locally exploited on relative small-scale, and have the potential to produce a more constant quality of fibres. Novel developments by the CCRI using a biotechnological approach with specific microbial enzymes, for example, have substantially reduced the retting time from three to five days. High quality fibre production has been maintained.

Similar protocols can be developed to enhance the properties of the fibres with regard to surface properties such as smoothness and porosity. By using specific (microbial) lignolytic enzymes (laccase/phenoloxidase), the fibre surface can be bleached (or activated to react more easily with the dyes). Similar technology has been developed by NOVO-Nordisk to reduce the amounts of chemicals required to produce wood chips or fibreboard.

3.1.3 Fibre properties (quality)

The different fibre extraction processes yield different but also varying qualities of fibres: generally 56-65 per cent long fibres of over 150 mm (up to 350 mm staple length) and 5-8 per cent short fibres of under 50 mm. The fibre fineness varies between 50 and 300 µm. The fibres are composed of individual fibre
cells of about 1 mm length and 5-8 µm diameter. The tensile strength of coir is relatively low when compared to sisal or abaca fibres, but it is less impaired by immersion in water\textsuperscript{19}. Coir fibre has the advantage of stretching beyond its elastic limit without rupturing, as well as having the power to take up a permanent stretch. Its resistance to microbial degradation and salt water is unique.

The chemical composition of coir and other plant fibres is given in Table 3, which shows that brown coir fibres contain relatively low amounts of cellulose (35 per cent) but have high lignin content (32 per cent\textsuperscript{20}). This exceptionally high lignin content implies that the available dyeing and bleaching techniques for textile fibres cannot simply be transferred to coir.

Table 3: Chemical composition of plant fibres\textsuperscript{21,22}

<table>
<thead>
<tr>
<th>Fibre Waxes</th>
<th>Cellulose</th>
<th>Hemicellulose</th>
<th>Pectin</th>
<th>Lignin</th>
<th>Extractives</th>
<th>Fats &amp; Waxes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>91.8</td>
<td>6.3</td>
<td>-</td>
<td>-</td>
<td>1.1</td>
<td>0.7</td>
</tr>
<tr>
<td>Flax (bast)</td>
<td>71.2</td>
<td>18.5</td>
<td>2.0</td>
<td>2.2</td>
<td>4.3</td>
<td>1.6</td>
</tr>
<tr>
<td>Hemp (bast)</td>
<td>78.3</td>
<td>5.4</td>
<td>2.5</td>
<td>2.9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Jute (bast)</td>
<td>71.5</td>
<td>13.3</td>
<td>0.2</td>
<td>13.1</td>
<td>1.2</td>
<td>0.6</td>
</tr>
<tr>
<td>Coir (brown)</td>
<td>35.6</td>
<td>15.4</td>
<td>5.1</td>
<td>32.7</td>
<td>3.0</td>
<td>-</td>
</tr>
<tr>
<td>Coir (white)</td>
<td>36.7</td>
<td>15.2</td>
<td>4.7</td>
<td>32.5</td>
<td>3.1</td>
<td>-</td>
</tr>
<tr>
<td>Coir pith</td>
<td>19.9</td>
<td>11.9</td>
<td>7.0</td>
<td>53.3</td>
<td>0.3</td>
<td>-</td>
</tr>
<tr>
<td>Sisal</td>
<td>73.1</td>
<td>13.3</td>
<td>0.9</td>
<td>11.0</td>
<td>1.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Abaca</td>
<td>70.2</td>
<td>21.7</td>
<td>0.6</td>
<td>5.6</td>
<td>1.6</td>
<td>0.2</td>
</tr>
</tbody>
</table>

3.2 Bleaching

Bleaching of coir fibres and yarn is undertaken to obtain lighter coloured fibres and more commercially attractive products. Coir yarns and fibres are bleached enhance the performance and appeal of the products (for example, for mats and matting). Bleaching provides for the production of lighter shades of fibres and yarns, and the fibres produced will be light yellow instead of brown. Several hues and (pastel) shades of dyed coir can be obtained when the coir is bleached.

It is estimated that 20 per cent of the coir fibres and yarns used in the production of mats, matting, rugs and carpets are bleached. The target of the CFC/FAO project has been to standardise the bleaching processes used in the coir industry, and to develop a low cost bleaching process that also improves the light fastness of the bleached coir products.

Chemical methods for bleaching lignocellulosic fibres have been developed in textile and paper and pulp industries\textsuperscript{23}. The different conditions of bleaching (chemical concentrations, pH, temperature and time) will affect the fastness of the bleached products and the properties (tensile and softness) of the fibre. The bleaching process is designed to remove the coloured components or to convert them to colourless substances. Either by reduction or oxidation, the conjugated double bonds responsible for absorption of light in the visible wavelength range can be eliminated. The lignin component in the cellulosic fibres is the main characteristic that will determine colouring.
3.2.1 Hydrogen peroxide bleaching

Because of environmental concern, the use of chlorine dioxide based bleaching stages has been eliminated in most industrial bleaching procedures. The interest in totally chlorine free bleaching processes has led to the development of peroxide based bleaching. Hydrogen peroxide is a universal bleaching agent, which is cheap and can be used safely. However, hydrogen peroxide is an irritant for the eyes and respiratory system, and it is important to adopt safety measures to protect workers in the bleaching plant. (Figure 2).

Figure 2 – Cold peroxide bleaching of coir

The efficiency of peroxide bleaching can be affected substantially by pH or by the presence of contaminants in the processing water (e.g. ionic metal complexes). For efficient use of chemicals (such as buffers and sequestrates), methods to prevent premature degradation of the peroxide can be adjusted to suit the available water quality. Under alkaline conditions, hydrogen peroxide is unstable and decomposes to produce reactive oxygen, which provides the bleaching effect. The addition of magnesium sulphate and sodium silicate to the medium is required to stabilise the peroxide in alkaline conditions. Surfactants are used to increase the fibre surface reactivity. Other components may consume large parts of the reactivity (transition metal ions and anti-oxidants). For the bleaching process it is important to achieve the optimum degree of hydrogen peroxide stability, so that the full potential of the bleaching activity can be exploited.

Recipes for bleaching coir fibres effectively without the use of halogen-containing chemicals have been devised at the CCRF²⁴. After a survey of the common practices used by industry, a choice was made for a standard process based on bleaching performance and cost (as described in Appendix A).
The hydrogen peroxide treatment was demonstrated and proved to be the preferred method for cold or hot bleaching of coir fibres (Figure 2 and 3, respectively). Hydrogen peroxide bleaching of coir fibres has now become common practice in the coir processing industry in India. Chlorine treatments have been reduced substantially, whereas they were commonly used in the past. A combined process with bleaching powder (containing five per cent Cl₂) and peroxide bleaching was selected as the most effective and cheapest available. A substantial reduction of costs has been obtained by the introduction of novel peroxide bleaching recipes by industry.

Figure 3 – Industrial-scale bleaching treatment

3.2.2 Peracetic acid bleaching

The use of peracetic acid as a bleaching agent has recently received more attention. The results so far with coir were not satisfactory and more recipes need to be explored in the future. Peracids are highly reactive and have a high oxidation potential. Prolonged storage is unsuitable for peracids and thus on-site production is preferred, which has been one of the limitations of commercial adoption and use so far. The possibilities for bleaching at acidic pH levels may offer some advantages over alkaline processing with regard to strength and softness of the final fibre product.

There is a need for further investigation on chemical aspects of bleaching of coir with peracetic acid. New recipes reported to be applicable for bleaching of other lignocellulosic raw materials (for example, wood pulps and jute) need to be tested on coir fibres.
3.2.3 Bio-bleaching

In addition to chemical bleaching, opportunities for bio-bleaching of coir were of interest to the project team at the CCRI, and were investigated within the programme of the CFC/FAO project. The effects of specific microbial enzymes on the bleaching of coir are currently under review. The effects of anaerobic microbial (enzyme) treatment on the bleaching of fibres appear to offer promise. A pilot study has been carried out on the capacity of certain bacterial strains to facilitate bleaching procedures. Previous successes with biotechnological improvements for coir retting and composting of coir pith encouraged this approach. Based on relevant literature data, microorganisms and enzymes were identified that could be exploited for the development of biotechnological bleaching procedures. Microbial cultures were purchased and conditions studied for maintenance, growth and multiplication. The effectiveness of biological treatments on the bleaching of fibres remains to be established. The costs for these treatments are difficult to assess, and have not been indicated in reporting. The investigations require a more fundamental approach and greater use of the analytical equipment made available by the CFC/FAO project.

The goal of bio-bleaching is to imitate the wood-decaying action of white rot fungi. The action of specific enzymes that are able to remove the lignin from the cellulose fibres has been reported for pulp bleaching, and is being commercialised as a bleach booster. The action of xylanases and/or cellulases is used to liberate lignin from the cell walls. By degradation of xylan from the fibre surface, lignin can be more easily removed. In order to maintain the mechanical properties of the fibre, treatment should not result in a degradation of fibre strength. Since fibre strength is directly related to the degree of cellulose polymerisation, only surface action by the cellulytic enzymes is desirable. In the case of coir, however, the relatively large quantities of lignin in the fibre play an important role in the integrity of the fibre structure. Lignolytic enzymes, for example, phenoloxidase, peroxidase and laccase can achieve degradation of lignin. The various bio-bleaching systems are considered useful as pre-bleaching steps, which provide a higher brightness.

3.2.4 Assessment of bleaching efficiency (analysis and qualification)

Tools to measure (or quantify) the effectiveness of a bleaching procedure are of interest for qualification of the treated fibres, and for the production of a more homogenous product. Equipment available to the CCRI (to measure the brightness index) should be evaluated for its suitability to assess bleached coir and coir products. The purchase of additional equipment is recommended.

Analytical methods to measure the amount of residual chemicals (peroxide/halogens/phenolics) in the effluent produced by the bleaching processes need to be investigated and implemented in the research programme to follow the CF/FAO project. At the present, a 10 per cent weight loss is observed when the fibres are bleached, which implies an effluent contaminated with substantial amounts of organic residues. This is typically being discharged without further treatment by local industries. Suitable methods for effluent treatment, chemical recovery and re-use need to be developed.

3.2.5 Standardisation of bleaching procedures

The previous experience of the CCRI with chemical bleaching by local industries was a good basis for the search for improved and standardised bleaching procedures for coir. A literature survey of the various chemical bleaching techniques and a comparison of the methods used by the local processors was undertaken. This took account of the various environmental issues involved. The cost effectiveness of the procedures was also assessed in the review. Although only few international publications and some obsolete literature were quoted by the project team, a reasonably straightforward strategy was chosen for the work planned. Better access to international literature in the fields of interest would have enhanced the efficiency of the researchers, with better use of their time and other resources.
3.2.6 Laboratory facilities

A laboratory was set up to carry out the experimental work for improvements to bleaching procedures. A range of recipes was tried, and the yarns compared. Testing of treated samples for light-fastness was performed. Combinations were made with bleaching of pre-treated softened yarns. (See Section 3.4). No quantitative data on bleaching performance, chemical consumption and effectiveness of chemical absorption could be produced, because of lack of equipment or limited experience of the techniques required. Only organoleptic data were given. The effects of bleaching chemicals on yarn strength were measured in a similar manner to that for analysing the softened fibres. There were no indications in the work plan for a more profound use of the analytical equipment made available.

Methods for chemical recovery and effluent treatment similar to softening activities should be studied, prior to industrial implementation. The purchase of chemicals needed to carry out the chemical work was sometimes considered a bottleneck for performing the research work efficiently.

A selection of essential equipment for undertaking research tasks is required, in addition to the range of analytical tools normally available in an R&D fibres laboratory, for chemical titration of peroxide, pH measurement and similar analysis. These include a reflector/colorimeter or ISO-brightness meter. Preferential climate conditioned testing should be undertaken. One important factor, frequently overlooked in R&D work, is an assessment of the work of the researchers within the international scientific network. For this to be done, it is essential that the work undertaken be published in suitable technical journals.

3.3 Dyeing

Dyeing of coir products is considered to be essential for diversification of markets and for enhancing the appeal of the products to consumers. Manufacturers and exporters of diversified coir products in India encounter several obstacles when marketing their products, despite the increased demand for ecological products in Western Europe. Export markets for diversified coir products have come under threat due to bans on the use of certain dyestuffs in the industrial countries. Moreover, ISO-certification and eco-labelling have become common practice for European industry and trade, to provide for an ecologically safe product that can be guaranteed to meet the needs of the customer. The performance of the dyes on coir products should also meet the highest quality standards.

The development of environmentally safe and up-to-date dyeing technologies for coir fibre products is essential to enhance commercial viability of what is a valuable renewable commodity. Improved technologies for coir processing and effluent treatment should be suitable for use with local scale production, and also economically feasible to encourage uptake and implementation.

3.3.1 Traditional dyeing practices

Traditional dyeing practices for coir fibres and yarns are widely used in India. Many co-operative coir mills still make use of outdated dyeing methods using, for example, wood heated tubs with basic dyes, minimum effluent recovery or treatment and labour-intensive practices that can result in poor health and unsafe conditions for workers (Figure 4). These companies mainly supply the domestic market, where the demands on product safety are less strict. The use of banned dyes has, thus far, created few problems for local markets. A willingness to make changes is obstructed by the limited possibilities available for investment in equipment and wastewater treatment systems. Despite government restrictions on effluent disposal, large quantities of exhausted dyes and chemicals are drained and discharged without further treatment.
3.3.2 Banned dyes

Banned dyestuffs comprise a group of azo-dyes, which are able to release (by azo-reduction) one or more of 20 listed carcinogenic (or potentially carcinogenic) aromatic amines. (See Appendix B). Carcinogenic hazards have been reported especially for benzidine-based dyes.

Basic dyes

Banned dyestuffs, of which some remain in common use by the coir industry, are mainly of the group of basic or cationic dyes. In general, the dyeing performance of basic dyes on coir is better than acid or direct dyes. For good adsorption of the dye the fibre must contain acidic groups. This type of dye provides bright shades, which can be attributed to the swelling of the fibres in the alkaline medium. The result is faster and better absorbency of the dyestuff. The fastness of basic dyes towards washing, rubbing and light is less than that for direct dyes. However, the products dyed with direct dyes are considered to be dull, and therefore less attractive to the market.

Basic dyes fall broadly into four chemical groups:

| I  | - | triphenylmethane derivatives, e.g. malachite green |
|II  | - | thiazine, e.g. methylene blue |
|III | - | oxazines, e.g. medola blue |
|IV  | - | azines |
### Alternative dyes

The possibilities for replacing the banned basic dyes by alternative dyestuffs have been explored in the laboratories of the CCRI\(^a\). A large number of acid, basic and direct dyes have been tested for their performance on coir fibre dyeing. (See Appendix B). An extensive shade card has been prepared, based on (non-banned) basic, acidic and direct dyes with a large number of recipes for new shades available. Recipes for particular shades can be produced on request for the relatively minor consultation charge of Rs 50 (US$1.25).

#### Acid dyes

Acid dyes are most commonly used for dyeing wool and nylon. Amine end groups that play an important role in dye uptake are not present in cellulosic fibres. In cellulosic fibres, the affinity of the dye for the fibre surface is essential. The majority of acid dyes are sodium salts of aromatic sulphonic acids, some of which contain carboxylic acid or phenolic groups. The different dying compounds may contain nitroso, nitro, monoazo, diazo, triphenylmethane and anthraquinone groups. The maximum binding capacity of the fibre is affected by a number of variables that determine dye uptake (such as dye concentration, pH and temperature). Diffusion of the dye anions into the fibre is a major determinant of dyeing efficiency for coir fibres in acidic medium. Swelling of cellulosic fibres under acidic conditions is limited. The degradation of the fibres (hydrolytic depolymerisation of cellulose and lignin) at low pH levels is detrimental to fibre strength properties.

#### Direct dyes

Like acid dyes, direct dyes are mainly sulphonated azo compounds (although more complex), which can be directly adsorbed on to cellulosic fibres. Direct dyes are globally classified as benzidine derivatives and related aromatic amino compounds or polyazo dyes, based on amino naphthol sulphonic acids.

Direct dyes are applied by boiling the fibre material and gradually adding salt, which promotes adsorption on to the fibre. The affinity of the dyes is affected by salt concentrations (ionic strength) temperature, pH and fibre surface (a feature that can be altered with pre-treatment). The differences in rates of exhaustion of the various direct dyes make dyeing of compound shades difficult to reproduce. Poor wash-fastness may require after-treatment (with formaldehyde or metallic salts, or diazotizing), which improves the fastness of the dyes.

#### Reactive dyes

In reactive dyeing, the dye molecules are attached to the fibre via covalent bonding, which imparts superior dye fastness. Highly reactive triazine compounds are utilised as coupling agent between dye and fibre. Most commonly, cyanuric chloride and its derivatives can be combined with water-soluble acid dyes, and react under mild alkaline conditions with cellulose without affecting the fibre structure. Because of high reactivity only mild conditions are needed to couple the dye. A step-wise sequence is applied to form covalent ester or ether bridges with cellulose. In principle, practically all types of chromophores can be coupled in this way. Generally, the dye is applied in a neutral bath with added salt to promote exhaustion. Fixation under alkaline conditions (usually Na\(_2\)CO\(_3\)) competes with the hydrolysis of the dye, which reduces dyeing efficiency. Hydrolysis of the reactive chlorine groups occurs as a side reaction in alkaline aqueous systems, which may deactivate the reagent and hinder fixation. Other reactive dyes are based upon diazine derivatives or coupling agents with vinyl sulphone groups. Generally, the reactive dyes are susceptible to acid hydrolysis, although stability depends on the attached chromophore.
Vat dyes

Vat dyes are water insoluble components, which are adsorbed by the fibre in the form of reduced non-coloured soluble components. By oxidation in air or by the addition of oxidising agents the colour is reproduced on the fibre. A well-known example of a natural occurring vat dye is indigo. Many synthetic variants of indigoid and anthraquinone types of dyes are available.

Other dyes

Novel areas of research are planned and should be explored for ecological improved dyeing of coir – to determine methods that may be suitable for domestic industry. Several suggestions have been made to investigate alternative dyeing methods and materials for coir.

The use of metal complex dyes (comparable with chromium complexes as are used for wool) has been suggested. A range of brilliant colours can be obtained with chelate compounds using different metal salts as mordents. However, in modern dye-houses the dyeing procedures involving mordents are time consuming, and not used. Further, concern for contamination from effluents containing transition metals or heavy metals has encouraged the replacement of metal complex dyes largely by directly absorbed dyes.

Dyeing with food-approved dyes has been suggested, but this will require suitable methods of fixation, which may be achievable by converting them into reactive dyes. This should be further explored, although cost may become a limiting factor. So far, experiments with natural dyes such as henna and turmeric have not been successful since colour fastness have been unsatisfactory. Methods for curing to enhance the absorption/adhesion of the dyes to the fibre surface remain of interest.

3.3.4 Dyeing technologies

Experience with industrial dyeing at the CCRI has proven to be particularly useful for project activities focussed on dyeing. Existing and conventional dyeing technologies used by local industry were evaluated and the recipes in-use re-formulated by the CCRI. Comparative dyeing cost calculations were made for the different systems. The implementation of improved technologies for dyeing and drying was monitored, and environmentally safe dyestuffs (i.e. acceptable for export markets) were developed, promoted and introduced.

Traditionally, coir is dyed in large vessels (made of copper or aluminium, 1 200 mm diameter and 750 mm high) heated by fuelwood (Figure 4). The required quantities of dyestuff (depending on the depth of shade required) and chemicals are added as a paste when the liquor in the vessel has reached the required temperature. For dyeing 60 kg of coir yarn a fibre to liquor ratio of 1:12 is used, while smaller quantities of coir fibre (30 kg) are dyed at a 1:20 ratio. The dye bath is stirred manually and the material is turned frequently to obtain even distribution of the dye. After dyeing the material is removed, washed with cold water and air dried in the shade. Some mechanical improvements include the use of special-purpose fixed stainless steel vats equipped with a valve for draining dye effluents. Heating comes from electrical elements built into the housing of the vat (Figure 5).
3.3.5 Project achievements

The mechanized system of coir dyeing developed by the CCRI includes the use of dye vats with forced circulation of dye liquor, to give uniform dyeing. Combined with a temperature controlled dyeing process, shade consistency is improved. After hoisting the dyed coir yarn (Figure 6) from the vat and draining and spin drying, the fibre is dried in a conventional drier (convey or belt/hot air). The higher costs of dyeing by this method are compensated by better quality dyed coir materials and improved consistency between batches.

In addition to the number of commercial companies involved with dyeing, some larger co-operatives have also introduced mechanized dye-house methods, based on the CCRI dye-house model (Figures 5 and 6). A number of smaller co-operative societies have established joint facilities for dyeing, to accommodate the batch production of small quantities of fibres or yarns. Options and opportunities for setting up additional central dyeing house facilities of this kind should be considered by industry at large.

Several international chemical companies were requested to provide samples of dyestuffs for experimental purposes by the project team, but without success. Dyes were obtained only from local suppliers. A literature survey yielded a few recent local publications on toxicity of dyes and a list of obsolete or non-specified Chemical Abstracts references. Nevertheless, a set of experiments to evaluate the various dyes was planned in detail, implemented and undertaken satisfactorily. Testing for fastness of dyed coir materials was qualified visually. A range of chemical additives was used and new ranges of shades were developed by a combination of different dyestuffs.
The absence of equipment was noted, for this was detrimental to the progress made. Experiments to use the “crockmeter” to assess rubbing fastness were carried out in cooperation with the South India Textile Research Institute (SITRA) at Coimbatore. Research on the influence of fibre pre-treatment (retting, softening and bleaching) on dyeing performance should receive more attention in any future R&D programmes at the CCRI.

3.4 Softening

The aim of softening is to improve the feel of the coir products, since the coarse and hard fibres tend to protrude from the yarn and woven matting and this is detrimental to feel. Improvements would have a positive impact on the appeal of the consumer towards the use of coir floor coverings. Methods similar to sisal yarn finishing could be used, such as singeing (but with inherent fire risk involved) or cropping the yarn to improve product quality.

3.4.1 Chemical softeners

There are several chemicals on the market for softening textiles that have been investigated by the research team at the CCRI. Different textile finishing chemicals have been tested. The cheapest method found was an alkaline treatment, which was effective to a certain extent, but was detrimental to the strength of the yarn. Scouring agents are used before the application of softeners. The use of epoxy based softeners and (amino) silicon-derivatives have been investigated in detail. The best performance was obtained with the silicones, but this did not give fully satisfactory results, as the yarn had a slippery feel. Moreover, the costs of
the chemicals were such that it would probably prohibit their introduction into domestic coir processing industries. Thus far, no suitable chemicals have been found for softening coir yarn satisfactorily.

3.4.2 Vegetable batching oil

It would be beneficial to industry if the softening of fibres could be undertaken prior to spinning by hand. Irregularities in the make up of the yarn are part of the reason for roughness. Other comparable plant fibre yarns (such as jute and sisal) are spun with the aid of a batching oil, which facilitates spinning. A vegetable oil (castor oil) was successfully applied to evaluate its effects on spinning performance (based on breaking counts, strength, texture, etc.) and preliminary trials for scaled-up production (to 500 kg) have been undertaken. It was found that a better quality yarn (less hairiness) could be spun with the modified fibre. The dye uptake of these oil-treated yarns was comparable with untreated yarns, without loss of softening. The use of batching oil is considered to be essential for the production of sliver for use in fully mechanized spinning systems.

3.4.3 Bio-softening

Bio-softening was another approach explored by the CCRI research team, to improve the softening of coir fibres. This research is currently underway alongside the bio-bleaching work, and aims to achieve a bio-polishing effect with the use of specific microorganisms, with selected enzyme specificity towards surface cell wall components. However, no detailed information was available to describe the effect of the different components on the physical properties of the fibre, at the time that the work programme of the CFC/FAO project was concluded. The rigid lignin network between fibre cells prevents flexible behaviour. Softening of the fibre without affecting the fibre strength will be a considerable challenge for future work.

3.4.4 Assessment

Quantification of the effect of softening remains a problem. Measurement of the flexural rigidity has been developed, but the results do not comply with sensorial perception. So far only subjective qualification has been possible, which necessitates further design of testing protocols and methods to assess the effect of softening on the yarn or fabric surface. The perception of softness of a yarn is not directly related to the bending of the fibre, as was earlier assumed in the testing device developed by the project team for measuring flexural rigidity.

3.4.5 Project achievements

A relevant database on information of chemical treatments for softening textile materials was collated, although the number of recent reports available was strictly limited. A laboratory was set up and orders were placed for supplies of glassware, chemicals and equipment based on a number of invited quotations. A number of different recipes to attain fibre softness were considered and selections made on the basis of well-reasoned theory and with respect to the economics of the processes involved. Commercial products from national and international supply companies were considered. Experiments were reported in detail, although only limited quantitative data could be produced. Some possibilities for bio-polishing were explored.

The effect of the various chemical treatments on the appearance of the yarns was recorded and, in some cases, strength parameters (tensile and elongation) were measured. Unfortunately, the methods used were not described nor was statistical data analysis undertaken and, consequently, no conclusions were drawn from experimental findings. No equipment was available to the project team to measure the effects of the different chemical treatment on the stiffness and strength properties of the fibre.
So far the research into softening has been successful, although the search for cheaper methods requires further effort. The effects of the cost of the treatments on end-product prices and performance ratios should be discussed with those in domestic industry, for there may be some interest in supporting further work of this kind. Chemical recovery and effluent management should receive further attention, and well before the industrial implementation stage. This will ensure that any new processes are environmentally benign.

Better access to up-dated international literature will improve the performance of the project team for any future work. Direct contact with the chemicals supplying industries will facilitate the implementation stage, and help provide for a more appropriate and far-reaching range of experiments.

3.5 Printing

Stencil printing has been introduced for the production of a diversified range of coir products, and is now common practice with the manufacture of coir mats in southern India. Print design is preferred over weaving design and applicable for most creel, carnatic and fibre mats.

3.5.1 Stencilling

The most common technique currently in use is dye spraying over a stencil plate, in which the pattern has been cut away (Figure 7). The number of stencil plates available depends largely on the number of colours used in the design. Thus far stencil designs are largely made traditionally, with sketching and cutting of the separate plates by hand. Computer added design (CAD for generating new designs is being introduced. Due to the uneven surface of the mats other methods of stencilling/pattern application have not been considered suitable. Alternatively, the dye can be brushed on to the coir mat, which gives better penetration of the dye and with less dye wasted on the stencil plate. This method is, however, more labour intensive and thus not used on a significant scale by domestic industry.

3.5.2 Dyes

The use of reactive dyes in printing has been investigated by the project team, but found to be too expensive for local industry. The advantage of better fastness of reactive dyes is overshadowed by the less satisfactory colours produced (less brilliant) and costs, which are higher than those derived with the use of traditional basic dyes.

Durability of the print is not as yet an important marketing issue, and thus work with reactive dye printing has not been continued.
3.5.3 CAD system

The CCRI purchased a complete CAD system (funded by the Coir Board of India) in support of their dyeing R&D programme (independent of the CFC/FAO project), which enables the designer to transfer novel designs quickly and easily to stencil plates. The flexibility of the system is a considerable advantage and allows for a more diversified range of product design. Further, products that can be specifically tailored to meet the demands of a particular client (Figure 8). The CCRI has introduced CAD facilities to domestic industry, and charges apply for the stencil plates produced. Higher rates are charged for more exclusive of designs.

3.5.4 Project achievements

From the literature available on textile printing, a number of suitable pigments and formulations for printing were traced. Industrial inquiries were undertaken to survey the suitability of current designs on different coir products. Novel designs for coir products that make use of stencilling techniques were investigated. Other techniques (e.g. non-stencilling) were not explored or introduced due to the uneven surface of the products. There is a crucial need for industry to develop new designs that will encourage market development. This may enable coir products to be re-positioned within the different fibres markets for mats and/or wall coverings. Other remaining objectives from the programme of the CFC/FAO project are the development of print methods and materials that are rubbing, light and wash fast.
3.6 Drying

Coconuts thrive in wet tropical climates, where monsoon rains prevent drying of wet processed products in the open air for much of the year. Therefore, it is essential for industrial productivity and export markets that suitable drying equipment be available at the various stages of production, to enable producers to continue to supply markets. Suitable drying equipment should meet criteria for throughput, reliability, ease of use and cost effectiveness.

The CFC/FAO project set targets to develop a cost-effective drier for coir fibres based on low cost energy use. The CDA project team in Sri Lanka undertook this work. Domestic exporters recommended requirements for a commercial drier capable of handling a fibre throughput of two tonnes per hour, and with moisture reduction from 50 per cent to 15 per cent in a single pass.

3.6.1 Drying technologies

Suitable drying technologies for coir products should be cheap and effective. The more sophisticated technologies in use in modern food industries such as vacuum-drying, freeze drying, microwave drying or radio-frequent drying are neither practical for bulky fibre products nor likely to be economically viable. Drum drying is a conductive drying technique with efficient heat transfer, in which contact time with the hot drum is important. It is especially suitable for flowing powders. Hot air drying is the most obvious method for drying coir fibres, where drying rate can be controlled by air temperature and velocity of materials flow. In a fluid-bed dryer (or, alternative, spouted, pneumatic or vibrating bed dryers) the contact of the fibres with the air is improved by stirring the material, which results in a higher heat transfer coefficient to the product. The efficiency of the process is largely dependent on the cost of energy for generating the hot air.
3.6.2 Project achievements

Developing and implementing the R&D activities required for drying was difficult from the outset. The CDA, which provided services and facilities to domestic coconut industries, was not equipped for fibres R&D, and the need to gain access to a fibre laboratory was considered a priority. Neither the Coconut Cultivation Board (CCB) nor the Coconut Research Institute (CRI) in Sri Lanka are directly involved with fibres research, but manage programmes for growing, breeding and other agronomic practices, and for the production of copra-derived products.

![Prototype coir drier being charged with wet fibres](image)

**Figure 9 – Prototype coir drier being charged with wet fibres**

An engineering team was put together and the various project components were explored with some preliminary design work which considered options for the different sources of heat energy available, and the preferred choice of design of drier. This eventually centred on a drum with rotating baffles and wet fibre feed at one end and discharge of dry fibres at the other. Heat was provided from an oil-fired furnace. A fibres laboratory was established at the main CDA office in Colombo. Practical work involved the construction of a pre-prototype drier and testing followed by modification and re-design. A second rig, designated a prototype was constructed and also tested and demonstrated to domestic fibre manufacturers (Figure 9). Work was undertaken at a commercial fibre mill in Lunuwila and at the CRI.

The value of the fibres laboratory established in Colombo was strictly limited, and the equipment installed was insufficient to perform the most basic of tasks. Preliminary measurements were undertaken with borrowed equipment, although basic data on fibres drying was not available. Equipment available for measuring moisture content did not perform well, and an improved device for moisture measurement in the field was constructed and tested. Trials were carried out that satisfactorily conformed to the requirements specified in the draft Sri Lanka Standard for Mattress Fibre.
Lack of information to describe the basic characteristics of fibre drying was a disadvantage that raises issues for the choice of design of the drier, and for the choice of heat energy. Motives underlying choice did not conform with conclusions that could be drawn from a more fundamental survey of existing drying systems available to the sector. The project team accepted costs (for drier and energy) on the basis of the scale of operation required, small-scale and of the order one tonne day of fibre throughput. The drum design selected was only suitable for processing fibres which were non-orientated.

The performance of both drying rigs was explored. Several passes (3–4) were necessary to obtain the required levels of drying (moisture reduction) for the batch of fibres under test, although performance was superior with the prototype drier (the second drier). Capacity was far too low to make the rig commercially viable. For a target production of one tonne fibre throughput per 10 hour day (dried to 15 per cent moisture), an input of at least 1.35 tonne wet fibres is required, equivalent to a capacity of 2.25 kg/min, not taking into account levels of pith contamination. With high levels of pith adhering to the fibres throughput was considerably less than 2 kg/min, thereby producing production runs that could not meet targets. Notwithstanding this lack of throughput, demonstrations were made to invited fibre millers in 1997 (pre-prototype) and 1998 (prototype), and the work of the CDA project team was generally well received. Feedback was positive for the work programmed, for the effort made by the CDA project team and for the equipment. Many suggestions were made for modification to the design of the drier and to the programme, for implementation post-project.

Given the experimental nature of the drying equipment and the investigations made, an element of extrapolation is required to project this work into the practical reality of large-scale drying that will be required of industrial drying practices for coir Sri Lanka. Location of plant, design of plant, materials flow into and out of the plant, choice of energy resources and the development of an industrial processing model that suits the current modus operandi of mill owners, is likely to result in a more cost-effective and efficient operation. Planning for this will be essential post-project, if domestic industry is to provide a drying facility for those periods of the year when rains limit sun-drying. Some form of centralisation and/or cooperative venture may be undertaken between the different mills, with the mill owners responsible for the financial investment required of the venture. Managers of the drying plant may also be able to undertake certification of the fibres dried, which will provide a measure of quality for the end product and boost the value of international sales of fibre.

The work of the project team has stimulated local industry to consider these and other future options. For more than six months in a typical year, rain places limitations on drying and this results in the production of mixed quality fibres. The project has raised some of the issues involved, and encouraged local industry to become further involved. It remains early days, however, and much additional work remains to be done to produce appropriate design drying equipment/systems with a choice of options that will encourage commercially viability.

### 3.6.3 Power generation

The choice of power sources for the drier was always an issue with important economic implications for the use of electricity or fossil-based fuels for heating. The environmental issues that influence choices, however, are firm and should be considered for any future options. Solar heating systems could be an alternative, with or without conversion of biomass (heat energy derived from photosynthesis), for example, with the production of heat by fermentation or direct combustion. Resources available to the coir industry include large quantities of waste biomass (coconut shells, waste fibres and pith). A comparison of the incremental costs of unit power should be made throughout the life span expected of a drying plant that the various options can be factored in. This will also enable realistic operating costs to be established, and thus charge out rates for users to be scaled accordingly.

No investigations were made of drying systems used for tea or copra, for example, both of which are available in Sri Lanka. Neither were options explored for use of equipment that would burn wood chips,
cocopith, shell and other crop residues. Comparative evaluations of this kind may have helped to enable efficiencies and, importantly, economies of use to be determined. Enhanced performance would have been obtained if some preliminary calculations had been made before design was finalised to determine, for example, energy input, optimal temperature and fibre residence time in the drier with changes in airflow, capacity and similar. Heat loss for the design selected was large, and corrosion levels on the fabric of the drum are expected to be high. Drying contaminated fibres was found to be wasteful of time and energy, and some form of pre-cleaning operation should have been considered and introduced. This is recommended for any continuation of the work on drying.
4. Economic Aspects of Coir Fibre Production

The economics of coir fibre production are based upon a multi-linked chain in which much of production is dependent on cheap and abundantly available manual labour. Because of socio-economic conditions prevailing at the village level, mechanising the fibre extraction plant may not the most obvious way forward. Mechanisation practices have to be introduced with sensitivity, that people are not put out-of-work without providing any real alternatives for income earning in the community.

The situation is further complicated because there are few alternatives to manual work within local communities. Livelihoods have to remain sustainable for social well being. There are neither simple nor appropriate technologies developed and applicable, nor those that can be easily adapted from other fibre industries. Spinning, weaving and matting of coir employs large numbers of people in the south of India and Sri Lanka. At village level, home workers supply co-operatives and private enterprises with raw materials (such as yarns and mats) of varying quality for further treatment or trade (Figure 10). Increasing productivity is only of interest when market demand expands. Investment in expensive equipment is not economically or practically viable as long as labour costs are low. However, traditional practices cannot remain entrenched in a constantly changing industrial sector.

![Figure 10 - Hand spinning of coir yarn](image)

As markets become more open, competition may be expected from other coconut producing areas where traditional industries and trade unions are not, for example, bound to maintain employment levels. Investment in added value, for example, for materials currently considered waste, presents attractive options to the entrepreneur. In areas where labour costs are higher, such as the Philippines, mechanized spinning has been successfully introduced. Eventually, more opportunities for employment, better wages, improved conditions of working and a better quality of life for coir industry workers may be achieved by increased use of mechanisation, and the higher productivity that this brings.
4.1 Fibre extraction and yarn production

According to prices quoted on the Alleppey market* in India, coir husks cost within the range Rs 500 for 1000 husks which, after retting, may yield 90 kg fibres at a price of Rs 8-10/kg (or US$0.20-0.25 /kg*). Green decorticated fibre may cost up to Rs 7.50/kg. There is little fibre wastage in spinning, so around 98 kg of yarn is produced from 100kg of fibre. High quality Anjengo yarns may yield around Rs 25/kg, while Vycome is quoted at Rs 17.50/kg. Traditional hand spinning of fibre to yarn using a spinning wheel requires three people, who may produce 12-15 kg of yarn per day. Export prices for finished coir products such as handloom mats and matting, rugs and carpets range between Rs 70-80/kg.

Prices and costs of production should be considered in context; in the context of international fibres industries developments in recent years and, importantly, within the context of the out-moded and ancient industrial production methods that characterise coir fibre and yarn production in the partner countries. Notwithstanding a reasonably buoyant market for these products in recent times, neither India nor Sri Lanka have modernised their domestic industries. Local producer industries in Kerala State in India, for example, support over 300 000 direct workers (and families) working for more than 750 cooperatives. More than 30 per cent work with handlooms (of which there are an estimated 50 000). The handloom industry has come under increasing economic and technical pressure as the result of inefficiencies within the system, competition from powerloom cloth, lack of quality and shrinking markets. Public sector support is being introduced to enhance investment from the commercial sector with changes to mechanized coir extraction, and motorised spinning of yarn, in an effort to accommodate the social changes required.

Considering the labour-intensive nature of current production, however, wages remain low (below Rs 10/h). This is currently considered a reasonable income (of the order US$2/day) by the unions that support the workers and the public services within which industrial labour managed. There are, however, cycles of poverty herein that prevent the industrial workers (and their service communities) from raising their standards of living when earnings are this low. To achieve greater wealth in the community, productivity has to be raised within the industry upon which the community is dependent. Alternatively, additional economic activities have to be introduced to augment or replace the main source of income. Both approaches are underway within the coir producing communities in which the CFC/FAO project was implemented.

4.2 Bleaching

Hydrogen peroxide recipes developed by the project team for bleaching coir fibres and coir products have been successfully introduced to domestic industry, with substantial saving of costs (of the order 50 per cent) and with considerable benefits for the environment. Further cost reductions are recommended, including recipes for a pre-treatment step with the use of bleaching powder (five per cent Cl₂). If introduced, however, this would have some ecological disadvantages. Costs for chemicals needed with the use of recommended chlorine-free bleaching recipes (Appendix A) have been calculated. For the hot process (recipe A) these are Rs 587 per 100 kg coir yarn, and for the cold process (recipe B) Rs 758 or, respectively, Rs 817 and Rs 1,107 for fibre. These cost were slightly higher when compared to the recipes in use with domestic industry using combined cold (peroxide and chlorine) bleaching processes.

4.3 Dyeing

The costs of dyeing coir using conventional and mechanized methods have been compared for standard recipes (Table 4). On average the costs of dyeing are increased by the use of mechanized methods, but uniformity and consistency of shade was improved.

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* Exchange rate India Rs 40=US$1
Table 4: Costs of dyeing

<table>
<thead>
<tr>
<th>Shade</th>
<th>Conventional</th>
<th>Medium-scale</th>
<th>Mechanised</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small-scale (Rs/kg)</td>
<td>Medium-scale (Rs/kg)</td>
<td>Mechanised (Rs/kg)</td>
</tr>
<tr>
<td>1.00% red</td>
<td>3.34</td>
<td>4.10</td>
<td>6.28</td>
</tr>
<tr>
<td>0.30% blue</td>
<td>2.79</td>
<td>4.50</td>
<td>5.79</td>
</tr>
<tr>
<td>0.25% green</td>
<td>2.60</td>
<td>4.50</td>
<td>5.60</td>
</tr>
<tr>
<td>0.25% brown</td>
<td>2.48</td>
<td>4.50</td>
<td>5.97</td>
</tr>
<tr>
<td>1.00% black</td>
<td>4.80</td>
<td>5.25</td>
<td>7.79</td>
</tr>
</tbody>
</table>

The additional costs per kg of dyed coir fibre is estimated at Rs 1-2 for acidic dyes, Rs 2-3 for the most commonly used basic dyes and Rs 3-4 for direct dyes. The total current market for dyestuffs for the Indian coir industry is estimated at 50 tonnes per year. The costs of dyes are estimated to range between Rs 6-10/kg.

4.4 Softening

So far, chemical methods developed by the project for softening coir fibres have not been introduced into normal practice by the coir producing industry. Cost effectiveness was not proven. However, semi-bulk scale trials of spraying vegetable oil emulsions (e.g. castor oil at Rs 8/kg) on to the fibres (0.2 per cent w/w) have been successfully tried, with considerable improvements noted for yarn quality.

4.5 Printing

Basic dyes are preferred because they give a more brilliant colour and are cheaper (Rs 0.25-0.75 per mat at 25 per cent surface covering). The reactive dyes give a better fastness, but have not been taken up by industry mainly because of cost (Rs 1-3 per mat at 25 per cent surface covering). Printing with reactive dyestuffs (e.g. procion brilliant red M8B, urea and sodium bicarbonate) will cost Rs 1.05 per mat (0.34 m²). A printed mat of this kind may retail at up to US$20 in Europe or the United States.

4.6 Drying

The costs of drying coir are relatively high and will add substantially to raw material costs. No cost calculations have been provided by the CCRI project team, but the energy required for removing 25 per cent weight water (requiring at least 2.5x10⁶ J/kg) adds approximately US$0.01-0.02/kg fibre without considering investment costs. For raw materials, which normally cost less than US$0.20/kg, this means a 10-20 per cent increase in costs.
5. Marketing

5.1 Eco-friendly and natural image of coir

Coir industries in India and Sri Lanka have a strong export orientation with the sale of traditionally-made yarn, mats, matting, rugs and carpets. (Figure 11). Since the mid-1970s, export markets have begun to decline because of severe competition from synthetic fibres. A gradual recovery during the last decade can be ascribed partly to increasing ecological awareness on the part of consumers in the industrial countries. Besides superior performance for durable matting, a strong marketing argument for coir is its eco-friendly and natural image.

![Figure 11 - Woven coir carpets of various patterns](image)

Exporters of dyed coir products, however, are confronted with banned dyestuffs and legislation in Europe (and especially in Germany) for ecologically safe products. Buyers of coir products insist that banned dyes not be used. The more advanced private companies have the vision and funds to be able to invest in improved dyeing technology and wastewater treatment systems. The many thousands of small-scale producers are less fortunate. Domestic industry in India was firm that all banned dyes have been removed from production lines, and are no longer in use. Companies have switched to alternative recipes, including those developed by the CFC/FAO project.

In order to explore and exploit the larger export markets for diversified coir products, environmentally safe technologies need to be developed and implemented by local producing industries.

It follows that special attention has to be given to the chemical processes of bleaching and dyeing involved with manufacturing, for the improvements in ecological performance of the products that are
possible. More efficient methods for processing and chemical recovery and wastewater treatment are of interest to the scientist and technician, but also essential for industrial application. On laboratory scale, the dyeing of coir has been given due attention by the project team at the CCRI, exemplifying the range of improvements possible at industrial production level. This technology now needs to be applied to factory conditions. Eco-labelling is one of the important issues for export market promotion, and will require the development of a recognized certifying institute.

5.2 **Price and performance of improved products**

The additional costs of the dyestuffs and the reduced brilliance of the dyed fibres hamper the introduction of preferential direct or reactive dyes, when compared to basic dyes. The fastness of direct dyes is better but, for many applications, the durability of the products is not a marketing issue. Data to qualify the current contribution of these alternative dyes within the market were not available.

5.3 **Marketing strategy**

Since many of the coir exporting companies are relatively small- or medium-scale enterprises, access to up-to-date marketing information is strictly limited. This restricts their ability to keep abreast of changing market needs. Marketing is also hampered by the inability of the producer to meet the material needs of the larger markets. Most producers provide a wide range of different products, and sell these in relatively small numbers. This contrasts with requirements of the larger conglomerate supermarkets in Europe and elsewhere demanding relatively large quantities of a single item, with firm demands on quality and delivery to schedule for this item. An ‘exclusive’ product such as this may be marketed only once. However, if successful, further sales of a different (but similar) product are possible during the following year. Thus there is continuity in markets for the coir fibre producer, but for different products.

For the co-operatives it is difficult to penetrate export markets, since marketing of coir products is centrally organized. Profits are marginal and insufficient to provide capital for investment in, for example, new equipment or technologies. Minimum export prices for coir products are established to guarantee the income of workers (with the interests of the producer/entrepreneur a second priority). Private enterprises, which may be more inclined to invest in mechanisation and improved technologies, are also confined to the same fixed prices. Thus there is little incentive for industrial change. The introduction of power-looms would raise productivity and result in lower labour costs. However, labour unions attempt to retain traditional methods of weaving and matting with the use of wooden hand looms, to secure levels of income and this leads to an entrenchment of traditional practices. Industrial productivity cannot easily be improved in these circumstances.

5.4 **Supply**

Access to a reliable and guaranteed supply of raw materials and products of high quality standard is a considerable threat to coir export markets. Further, the quality of fibre supplied can be mixed. Meeting standards and delivery schedules required of buyers is important to ensure customer satisfaction. Natural materials such as coir fibres, however, are rarely uniform and security of supply can be variable as unseasonable weather or the demands of competing markets may, for example, bring a measure of risk. Traders are normally required to work hard to meet the demands of the client.

5.5 **Promotional programmes**

For increasing exports, the publicity required for coir and coir products is an important marketing tool. Providing information and raising awareness on the part of the client, of the advantages of coir, for example, and its ecological performance, is challenging. This requires considerable effort and investment.
However, marketing information to describe new and/or existing products is essential, and should address the ecological aspects involved in relation to, for example, renewable resources and humane production systems. But ecological arguments notwithstanding, buyers will not be interested if prices are unattractive. Guaranteed supplies of high quality products should be emphasised. Demands by the customer for design and shades of colour should be met, as required. Existing marketing and distribution systems, should be used to the full, with the cooperation of local commercial partners.
6. Recommendations for Further Technical Developments

6.1 General

Research groups (and individual scientists) as exemplified by the CFC/FAO project team at the CCRI, and those elsewhere in other coconut growing areas, need to be exposed to, and to keep abreast of, current developments and information in their respective fields of endeavour. They need to network regularly with the acknowledged international R&D groups working in these fields. For the CCRI this includes fibre extraction and processing technologies, chemical processes (dyeing, bleaching and softening) and biochemical processing (retting, bio-pulping and bio-bleaching). Modern communication methods such as access to the Internet and e-mail networking and conferencing may provide suitable low-cost tools, where funding is strictly limited for access to journals and travel.

Exposure to international R&D work in similar areas of plant fibre product development (such as sisal, jute, kenaf and similar) and of textile finishing technologies would enhance the efficiency and relevance of current work programmes, and help plan for the future. A regular review of international work that would be of interest to the domestic coir industry could be compiled and distributed by newsletter into the domestic industrial community – and may prove to be financially self-supporting.

Access to international literature and modern handbooks is essential. Library resources at the CCRI and the CDA remain strictly limited. More resources are required, and might be planned in co-operation with others with an interest in using this resource, such as domestic industry and regional academia/education.

Training of research staff on newly available equipment is recommended, or the recruitment of dedicated technicians or analysts for routine analysis of samples. This would enable greater use to be made of analytical equipment within the different R&D groups at the CCRI. There is risk involved with providing greater access to expensive equipment, but adequate training should largely overcome risks of this kind.

More could be done to raise revenue at the CCRI with the provision of R&D services and technical consultancies to domestic industries.

Further exploration of scientific background, up-to-date technical information and, importantly, a fundamental knowledge of fibre processing technologies will be essential to consolidate the reputation of the CCRI as a consulting base for domestic industry.

Improved facilities are recommended, for example, improved access to a wider selection of the technical equipment available, for providing better services to customers (such as exporters). Future opportunities may involve the establishment of certifying laboratories (for ISO/ASTM/eco-labelling, for example).

International Coir Fibres Centre. The CCRI have made proposals to become a world centre for coir fibres R&D. This is an excellent long-term aim, and will provide a considerable challenge to the Director and staff of the CCRI and to the Coir Board of India. Reputations are earned, however, and cannot simply be assigned. An enhancement of international contacts may be achieved by the publication of research results in the relevant (referenced) international journals. This will provide for an exchange of technologies and information with other coconut producing areas, that the CCRI may become central to the network of Pacific and Indian Ocean coir fibre R&D workers.
6.2 Dyeing

Improved testing methods to evaluate dye bath exhaustion are to be introduced at the CCRI. This is encouraging. The subjective methods currently in use (i.e. visual comparison) need better quantification and standardisation to reduce requirements for chemicals and, importantly, to assess chemicals lost and wastewater discharged. With the UV/VIS spectrophotometer purchased within the project budget, it is now possible to quantify the concentration of dye in solution. Training the researchers to enable them to make full use of this equipment is essential. Alternatively, one option is to employ a full time Chemical Analyst to carry out routine analysis work of this kind.

Improvements to light, wash and rubbing fastness of the effect of direct/reactive dyes on coir is of interest. External advice from suppliers of dyestuffs on the use of these products would enable domestic coir industries to improve the quality of their products. Equipment to test the (water) fastness of dyes is essential to enable the dyeing procedures and the quality of the dyed products (e.g. Linitest steam pressure vat) to be determined.

In order to introduce modern methods and technologies or to upgrade traditional or existing processing and effluent treatment systems, the CCRI is recommended to seek the assistance of a specialist company or supplier of dyestuffs and dyeing technology.

Setting up central dye-houses is one option for smaller (co-operative) enterprises, to enable them to overcome investment barriers.

New colour ranges for novel dyes should be developed and introduced.

The feasibility of introducing alternative dyes such as water-based reactive and direct dyes, natural pigments and organic dyes and food-approved dyes should be further investigated. The use of specific cross-linking agents that open possibilities for low temperature dyeing is also of interest, to reduce the costs of heating.

Information should be generated on dye penetration into the fibre, and the effects of fibre pre-treatment on dye uptake. This should be done in relation to existing and modernised processing practices and plant, and with respect to the work recommended for colour fastness.

6.3 Bleaching

Possibilities of further reducing the use of bleaching powder (containing chlorine) in bleaching recipes should be explored for the environmental benefits that may follow, notwithstanding some additional costs involved.

Investigations are recommended for pre-treatment processes that combine the use of bleaching chemicals and bio-bleaching, in order to quantify the reduction in the use of the bleaching chemicals required.

Biochemical methods of effluent treatment are of interest and should be explored, to reduce chemical waste discharge and the effects of pollution.

New recipes of peracetic acid bleaching should be investigated.
Tools to measure the effectiveness of bleaching procedures (brightness index) are essential for laboratory studies, to enable work to be evaluated accurately and to enhance the quality of reporting.

Analytical methods to improve the quantification of the use of bleaching chemicals in the different bleaching recipes are required. This should include before and after treatment of fibres or yarns, and the measurement of extractives (phenolics) and residual chemicals in effluent streams.

6.4 Softening

Softening of coir yarns could be improved by the introduction of more mechanized fibre processing (before spinning). If the fibres were to be carded and stretched into a sliver before spinning, much fibre irregularity could be reduced. The addition of batching oil would enable spinners to produce a finer count of yarn, which will affect the weight of the fabric. Mechanization of weaving is a logical next step for industrial development in the regions covered by the CFC/FAO project.

The development and implementation of testing protocols and methods to assess the effects of softening on fibre, yarn or fabric surfaces (e.g. abrasion or airflow resistance and optical methods to assess regularity of yarn and/or hairiness) are recommended.

A better understanding is required of the intrinsic physio-chemical properties of the lignin matrix in coir fibre in order to obtain improved fibre fineness, elongation and softening.

6.5 Printing

An evaluation of a range of suitable (i.e. commercial) spraying equipment for use with applying dyes to stencil plates should be undertaken.

A simple device to achieve a more even distribution of the dye on the mat would be of value for the improvements that may develop for printed coir products.

Better working conditions are required for print workers. Improved health and safety aspects of spraying would come from better ventilation during spraying, or from the use of closed systems.

Productivity of work would improve with more automation in the print/spray shop.

6.6 Drying

Pre-cleaning of fibres should be undertaken, as far as may be practical, before drying, to enhance the performance of the drier and to reduce energy losses from drying pith mixed with the fibres. (Pith is highly water absorbent and drying it is wasteful of heat energy).

A commercial fibre drier should have the flexibility to handle fibres with different drying characteristics, that retention time can be adjusted to suit moisture content and the levels of drying required.

Shared use of driers is required, that the investment in plant and access to technical management can be offered to a network of mills and producers. Central drying plants with sufficient drying capacity for market demand should be installed. Use and servicing charges should reflect running and replacement costs for the plant.

Further work is required to explore the potential for drying coir products on equipment already available and in use for other agricultural commodities.
7. **Equipment Requirements**

An ability to analyse raw fibres (and other materials) prior to investigation and then to be able to determine changes, if any, from treatment is essential for any R&D fibres programme. Detailed knowledge on chemical composition and ultrastructural organization of the raw materials and derived products are the basic tools for rational process improvements. For this, the research team requires access to a recommended selection of basic equipment and to a testing facility under controlled atmosphere conditions. This, in essence, forms the basis of a fibres laboratory. Without high quality analytical measurement and control, the results from the most motivated of research teams can be of limited value. Identifying what was available and what was required to augment current resources was an essential part of the field programme of the CFC/FAO project. At the CCRI in India, upgrading of the laboratory was required. The CDA in Sri Lanka did not have access to a fibres laboratory, and this severely limited their understanding of the characteristics of wet fibres and the changes that took place during drying. A limited selection of analytical equipment is essential for laboratory work. This includes:

**Specialist Equipment Softness/Smoothness.** Suitable equipment is required to provide for testing for yarn softness and smoothness of fabric surfaces, and for experimentation, treatments and methods. (Existing textile equipment should be adapted to coir testing).

**Reflection Meter.** Required for the qualification of bleaching efficiency measurement, and to determine the brightness index of bleached coir products. (Estimated cost US$30 000).

**Instron Pulling Bench.** Required for measuring fibre/yarn strength. (Estimated cost US$40 000).

**Climatically Controlled Laboratory.** This is a room in which temperature and humidity can be controlled for testing fibre and fibre product properties. A laboratory of this kind is recommended for the CCRI. (Estimated cost US$75 000, including installation costs).

**Analytical Equipment.** Access to more advanced chemical analytical equipment for identification of chemical components (such as FT-IR, NMR, mass spectrometry, etc.) is essential for providing a sound scientific foundation for R&D fibre programmes. Since these are costly (over US$100 000) and highly specialist equipment, strategic alliances with other advanced R&D laboratories is recommended.

**Microscopic Technologies.** Access to advanced microscopic equipment (UV microscopy/fluorescence microscopy/electron microscopy, etc.) is required for detailed morphological studies of fibres and cell walls (such as the distribution of cell wall components, porosity and surface smoothness). Since these are costly (over US$100 000) and highly specialist equipment, strategic alliances with other expert R&D laboratories is recommended.

**Test Spray Equipment.** For a more even distribution of dyes, access to spraying test equipment to enhance printing procedures could reduce the amount of dye needed. This should include computer-controlled equipment. More advanced (e.g. CAD) printing equipment (without the need for stencil cutting) may also be suitable for printing coir products. Equipment of this kind should be introduced and explored. (Existing equipment should be adapted to treat coir).

**Biotechnical Developments.** The introduction, management and control of biological processes can be further encouraged with the use of appropriate equipment. This to include the use of fermentors (on laboratory scale) with possibilities for measurement and control of gas flows, which are important for a quick and accurate assessment of enzyme activity, and for determining the efficiency of substrate conversion. (Estimated cost US$30 000).
8. Conclusions

8.1 Development of technology

A substantial part of the initial targets for the project to develop technologies to produce better quality and more attractive coir products with better consumer acceptance have been achieved. Although there is still work to be carried out as a follow up to the various project team activities, much more is now known of the chemical and biochemical aspects of wet processing of coir as the result of CFC/FAO project investments.

Many of the achievements from coir bleaching research, developed within the project programme at the CCRI, have been introduced into the coir industry of southern India. A further reduction of chlorine containing bleaching agents in the recipes used is recommended. The studies of the effects of bio-bleaching on industrial chemical requirements should be continued. Appropriate effluent treatment and chemical recovery systems should be developed.

Alternative dyestuffs, replacing the banned dyes used in coir dyeing and covering a whole range of shades, have been evaluated and presented to the coir processing industry. Modern technologies of coir dyeing have been introduced at various locations.

Achievements with chemical softening of coir yarn have been reported. It was concluded that the results were not sufficient to justify further investigations along these lines, mainly because the developed methods are too expensive to be introduced to the domestic coir producing industry. To obtain more supple yarns the focus has now shifted towards making improvements with spinning technologies. The use of vegetable oil as a batching agent has resulted in promising improvements in the production of more regular yarns. Further improvements in spinning technologies (pre-treatment and mechanization) will lead to a better (finer) and more consistent quality, and a more competitive position for yarns in the market.

Printing/stencilling technology has been widely introduced in the market and has contributed substantially to the diversification of product design. Improved performance of printed mats with regard to fastness of the dye should be considered.

Investment by the coir trade in the industrial drying of coir will become attractive only when the additional costs can be covered within the prices for coir and coir products prevailing in the market. This is directly related to the supply of products with confirmed specifications of quality required of markets.

8.2 Coir market development

Although some additional mechanisation has been introduced for fibre extraction, and novel accelerated retting technologies have recently been shown to offer substantial improvements over existing practices, the general approach to existing systems of production remain unchanged. Retting continues to pollute surface waters, and working conditions for people remain unhealthy. Existing mechanical defibration procedures and equipment are extremely dangerous, even for skilled workers, and fingers and hands continue to be lost. People, however, continue to work with this equipment within antiquated industrial systems.

Costs of alternative technologies are high, and have generally not been introduced. R&D costs are equally high, and funds are difficult to raise for this traditional fibre commodity, since earnings from fibre production remain marginal. The majority of fibre producers operate on a small-scale at a village level and
are unable to contribute towards the costs of R&D programmes. The public sector may need to provide for industrial continuity, and also to encourage traders and others to develop and exploit novel markets that could provide a measure of security for smallholders and small-scale processors.
9. Novel Technological Developments and Chemical Processing

A recent effort to diversify and encourage the further use of coir fibre has come from a research project implemented within the framework of the FAO Intergovernmental Group on Hard Fibres (IGG/Hard Fibres) and the Common Fund for Commodities (CFC). The project aims to develop new technologies to produce building and construction materials from non-retted coir husks. The increased ecological consciousness of the industrialised countries (particularly in Western Europe) has led to more interest in, and use of, renewable raw materials and environmentally safe products. A range of fibre based products have been introduced, or remain under development for automotive, building and construction, packaging and consumer goods and others industrial sectors.

Market possibilities of coir for selected applications should be evaluated – and continue to be evaluated - as a major programme of investigation required of coconut fibre producers and importers. It is not sufficient to remain with traditional markets. This should include the development of novel technologies to produce durable and ecologically safe building products such as boards, poles and panels with the use of green husks. Products such as these have the potential to add value to unprocessed green coconut husks, and to substitute for dwindling timber supplies and, ultimately, to reduce deforestation.

Other chemical processing technologies that should be explored and developed in the near future relate to ecological safe treatment processes. More work is recommended to enhance the suitability and use of coir fibre raw materials for fire retardation (for building applications, mattresses and similar uses) or for prolonged durability (for geotextile and horticultural substrate applications). It has been possible to demonstrate that coir fibres can be treated effectively by hydrophobation or acetylation on laboratory-scale, which will prolong the functional life-time of coir products by a factor of two or three.
10. Recommendations for Post-Project Activities

The current worldwide trend of increased industrial interest in renewable raw materials for technical applications should be explored further. For example, this should encompass fibre composites for the automotive industry or for similar applications for building and construction. The development of innovative technologies for plant fibre products for non-traditional uses has led to increased demand. Technical possibilities for the use and application for coir fibres have not been fully investigated.

Possibilities for the production of (non-bleached) paper pulp - which can be applied to paperboards for packaging - have been briefly explored by the CCRI. Further work of this kind is recommended, including more in-depth research on pulping technology.

The production of coir non-wovens for technical applications such as insulation materials, geotextiles, laminates and (bio-) filters should be encouraged. The availability of non-woven fibre products (e.g. interlacing/needle punched mats) of qualifiable/known specification in sufficient quantity on the market, will lead to substantial opportunities for product diversification.

The market for coir geotextiles for agricultural and horticultural application can be substantially expanded when product specifications can be given with confidence according to ISO/ASTM standards, and when the durability (e.g. resistance to bio-degradation) of the product is known with confidence.

The use of coir fibre in fibre reinforced composite applications has not been studied in-depth. Except for phenol formaldehyde resin matrix composites in fibreboards, the application of coir fibres has received little attention thus far. Use of composites with thermoplastics has been reported. Further research in this area should be undertaken.

Inorganic matrix composites such as fibre reinforced cement have been studied in several coconut producing countries with some commercial success, for example, in the Philippines. Domestic industry in India would benefit from the introduction of a similar programme at the CCRI, following through with discrete industrial developments.

Improvements with the production technologies required for rubberised coir manufacture are recommended. Promising markets for superior mattresses and upholstery made from rubberised coir could be exploited. This would require the development of adapted production technologies that are capable of producing consistently high quality products, and with reduced environmental impact.

The development of technologies for producing a tufted coir yarn on rubber mats would be advantageous to coir producers, with considerable market opportunities available.

Greater use of coir pith for horticultural applications (for peat replacement) is recommended; again, with considerable commercial opportunities available. Such markets have been little explored. The technical demands of mineral content and other relevant parameters have been established (e.g. the development of Dutch Horticultural Standards by RHP). Further, added value manufacturing is possible with producers adopting similar standards and encouraging manufacturers to produce to specification, with the certification of a product label attached. The CCRI could take an active role with developments of this kind, for example, with the establishment of certifying laboratory and ratification procedures.

The possibilities for improving the quality of coir yarn by novel spinning technologies should be investigated. Options to increase the fineness and softness of fibres by adapted wet processing technologies, and the improved mechanisation of combing and stretching (after softening) could lead to novel markets for coir fibre yarns.
R&D investigations are required for the use of additives such as fixing agents, brighteners, alternative (natural) dyestuffs and pigments, UV stabilizers and other auxiliary chemicals suitable for improving wet processing technologies for coir fibres manufacture.
Appendix A – Bleaching

Recipes for hydrogen peroxide bleaching developed in the CFC/FAO project. Fibre to liquor ratio 1:20 or for yarn 1:12.

Hot process

After washing with water the fibres are placed in a solution of hydrogen peroxide (8 g/l) and sodium silicate (5 g/l), and heated and kept at temperature 80-90oC for one hour, with frequent agitation. The material is taken out and washed with cold water and dried in the shade.

Cold process

After washing with water the fibres are placed at ambient temperature in the bleaching bath - a solution of hydrogen peroxide (10 g/l), sodium silicate (6 g/l), soda ash (2 g/l) and Lissapol D (2 g/l). The bleaching process is continued overnight, with frequent agitation. The bleached fibres are then taken out and washed with cold water and dried in the shade.
Appendix B – Dyeing

Table B.1 - List of banned basic amino or azo dyes in Germany

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Dyestuffs which can split into:

- benzidine
- 4-chloro-2-methylaniline
- 2- naphtylamine
- biphenyl-4-amine (=aminodiphenyl)
- o-dianisidine
- 3,3′-dichlorobenzidine
- 4-chloroaniline (chloro-o-toluidine)
- o-toluidine (=2-aminotoluene / 2-methylaniline)
- o-aminoazotoluene
- 2-amino-4-nitrotoluene
- 2,4-diaminotoluene
- 2,4-diaminoanisole
- 4,4′-diaminodiphenylmethane
- 4,4′-diamino-3,3′dimethyldiphenylmethane
- 4,4′-diamino-3,3′dichlorodiphenylmethane
- 4,4′-bis-(dimethylamino)diphenylmethane
- 4,4′-diaminodiphenylether
- 4,4′-diaminodiphenylsulphide
- 2,4,5-trimethylaniline
- p-cresidine
Table B.2 Dyestuffs used for dyeing coir fibre (brown or retted) in different shades

<table>
<thead>
<tr>
<th>Acid dyestuffs</th>
<th>Direct dyes</th>
<th>Auxiliaries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acid Brill blue BR</td>
<td>Direct fast red 5B</td>
<td>Azofast LRW</td>
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<tr>
<td>Nigrosine XLS</td>
<td>Direct fast orange SE</td>
<td></td>
</tr>
<tr>
<td>Patent blue ASD</td>
<td>Direct yellow 5 GL</td>
<td></td>
</tr>
<tr>
<td>Acid Orange II</td>
<td>Direct green B</td>
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</tr>
<tr>
<td>Acid Milling Red G</td>
<td>Direct sky blue D6B</td>
<td></td>
</tr>
<tr>
<td>Acid Milling Yellow G</td>
<td>Direct brown MR</td>
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<tr>
<td>Acid Violet</td>
<td>Direct black E</td>
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<tr>
<td></td>
<td>Direct fast violet 4BL</td>
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<tr>
<td></td>
<td>Chrysophenine CH</td>
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<td></td>
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<tr>
<td>Basic dyes</td>
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<tr>
<td>Auramine OA</td>
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<tr>
<td>Rhodamine B500</td>
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<tr>
<td>Malachite Green XLS</td>
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<tr>
<td>Methyl violet 2B</td>
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<tr>
<td>Methylene blue 2B</td>
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<tr>
<td>Magenta</td>
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<td>Bismarck Brown</td>
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<tr>
<td>Chrysoidene</td>
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<td></td>
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</tbody>
</table>
References


20. Institute ATO bv: Data chemical analysis.


30. Occupational Safety and Health Administration, US Department of Labour, OSHA Directives, CPL. 2-2.27.


