A CENTURY OF RESEARCH AT CIRCOT









भाकृअनुप
ICAR

ICAR-Central Institute for Research on Cotton Technology, Mumbai (1924 - 2024)

Centenary Celebration
ICAR-CIRCOT
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A CENTURY OF RESEARCH AT CIRCOT

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1924 - 2024

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Foreword

ICAR-CIRCOT is celebrating the centenary year and contributed significantly to research on cotton technology. The journey started in December, 1924 under the aegis of the erstwhile Indian Central Cotton Committee as a testing laboratory to monitor fibre quality in breeding programmes undertaken in different parts of the country. This institution grew in size over the years to become India's premier establishment for technological research on cotton. In 1966, the Institute came under the administrative control of the ICAR with widened mandate and responsibilities. CIRCOT's wide-ranging role in cotton technology research is highlighted in the book being published on the occasion of the centenary celebration which describes the CIRCOT's commitment and competence. India's cotton breeding programme under AICRP has made prodigious strides through development of over 450 high-yielding varieties and hybrids, enabling the country to be the top producer of cotton in the world today. CIRCOT has been working in cooperation with breeders in the country by ensuring cotton quality in all breeding trials under this project. CIRCOT's role can be likened to that of a quality ombudsman committed to ensure that genotypes developed through AICRP do meet the needs of textile industry, both in fibre attributes and spinning performance. Thanks to the team work in cotton breeding research, Indian cotton has risen in brand value and is highly sought after by overseas importers.

CIRCOT is working in cotton improvement programmes of the country as well as strengthening cotton value chain. Development and standardization of test methods, basic and applied researches in all aspects of cotton and its by-products, offering training programmes, academic pursuits, commercial textile testing services, establishing centres of excellence, etc., are activities for which CIRCOT has earned reputation worldwide. On the occasion of its centenary, the Institute is bringing out a book highlighting its hundred years' research accomplishments in an exclusive style. Cotton has been facing challenges from manmade fibres in the last many decades. Blended textiles are increasingly preferred over pure cotton fabrics for many end-uses. Newer and newer chemical finishing technologies alone can make up for the deficiencies in cotton quality and thus arrest the diminishing share of cotton in textile applications. Institutes like CIRCOT have limitless scope to work in this domain of research. CIRCOT's pursuits in textile finishing, exploring alternative uses for cotton, by-products utilization, etc., are initiatives that can serve to augment demand for this fibre and strengthen cotton economy in its entirety. Let's hope that the Centenary celebration will energize CIRCOT scientists to perform with renewed zest and commitment in the years to come. It is appropriate that the Institute is presenting a concise account of its research findings in the form of a book entitled *A Century of Research at CIRCOT* as a part of the Centenary celebration. I am sure the book will be useful for all the stakeholders.

(Himanshu Pathak)

8th November, 2023
New Delhi

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MESSAGE

Textiles play a prominent role in shaping our national economy. Cotton constitutes nearly 65-75% of the raw materials used in Indian textile manufacture. Aiming for the healthy growth of the textile economy, research institutions like ICAR-CIRCOT have the responsibility to develop technologies for appropriate use of cotton. Besides supplying the fibre needed to sustain a huge industry, the cotton plant also provides us with several by-products and plant residues which can be put to various end uses as indeed shown by the investigations at CIRCOT. Exhaustive use of by-products will indirectly help the cotton farmer with augmented net returns from cotton cultivation. ICAR-CIRCOT have, in the last many decades, undertaken several researches leading to viable technologies for better utilization of cotton and other plant parts.

Established as a cotton testing laboratory in 1924, ICAR-CIRCOT has grown in size, scope and significance, to the status of a national research institute, and now going to organize its Centenary with a succession of celebratory events including seminars, workshops, exhibitions, open days, stake-holders' meets, publications, etc. One important activity which marks the beginning of the year-long saga of celebrations, and which has already been accomplished, is the publication of the book *"A Century of Research at ICAR-CIRCOT"* chronicling the research findings of this Institute in the last one hundred years.

Scripted in an impeccable style and in a non-technical format, the book highlights most of what ICAR-CIRCOT has contributed to the knowledge about cotton and how best to exploit it for the national good. I am sure the book will be of interest to all classes of readers. I compliment the Director of ICAR-CIRCOT Dr. S. K. Shukla and the editorial team for their accomplishment.

(S. N. Jha)

New Delhi

10 November, 2023

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PREFACE

Founded as it was in 1924, CIRCOT is completing one hundred years of admirable service to the nation through technological research on cotton. For any institution, centenary is a momentous occasion to take stock of the major achievements it has made right from the day of its establishment. It is also the time to contemplate course corrections if any in the functioning style of the institution. CIRCOT's research and related attainments were summarized first in 1974 on the occasion of its Golden Jubilee, and repeated in 1998 before its Platinum Jubilee. The present volume titled "A Century of Research at CIRCOT" could be seen as a souvenir commemorating the Institute's centenary scheduled for celebration during the twelve months beginning from December, 2023.

The present book highlights the researches of CIRCOT over a period of 100 years from December, 1924. Set up as a testing laboratory to help cotton breeders in ascertaining the technical worth of new strains evolved by them, CIRCOT grew in size and scope over the decades to assume the role of a full-fledged research institute of national stature. CIRCOT's early researches were centred around unveiling the complex physical and chemical characteristics of cotton and their influence on technological performance of this fibre. As years passed, CIRCOT's interest spilled over to evolving technologies for improved performance of cotton in many textile applications. Still later, the ambit of research further expanded to include industrial utilization of by-products of cotton as well as waste materials generated in cotton cultivation and cotton processing in mills.

The contents of this book comprising 18 Chapters are presented in two Parts. Chapters 1 to 9 constituting Part 1 relate to research findings in the years from 1924 to 2000. The results are briefly stated, almost in bullet form. Chapters 10 to 18 are placed under Part 2 dealing with researches in the post-2000 period. In the latter Part, the presentation is more descriptive. One distinctive feature of this book is the absence of references (bibliography), data tables, graphs and diagrams. This has been so because the targeted readers are common, non-technical people whom the Book attempts to inform rather than educate. Discussions are, therefore, singularly qualitative.

Compilation of this Book has been the outcome of a group effort under the guidance of Dr. K. R. Krishna Iyer, former Director of CIRCOT (1995-2000) who also scripted, in a concise form, CIRCOT's research findings of the first 75 years that form Part 1 of this Book. Chapters in Part 2 are contributed by the present-day Scientists of this Institute. I place on record my gratitude to all the Scientists in the Editorial Team for their co-operation in compiling the book that encapsulates research findings of a century at CIRCOT.



S. K. Shukla
Director, CIRCOT

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PART 1

INTRODUCTION

King Cotton rules the world of textiles. Cotton is perhaps the oldest of textile fibres used by man. There are references to cotton fibre and cotton cloth in the *Sutra* literature attributed to a millennium before Christ. References to threads and clothes most probably made of cotton can be found in *Manu Smriti* . Relics gathered from the ruins excavated from Mohenjo Daro in Sindh have revealed that the antiquity of cotton can be traced to ancient Indian civilization of 3000 BC and beyond. CIRCOT had the privilege of examining tiny bits of yarn and fabric from Mohenjo Daro. Tests at this Institute revealed that the fabric was made of 34s count yarn presumably spun from *G.arboreum* cotton.

Historical records seem to show that Greek merchants traded in cotton cloth from India after invasion by Alexander the Great (320 BC). By the first century AD, Arabs and Greeks were transporting raw cotton and cotton cloth from India. Following the arrival of the English (1600 AD), Dacca muslin became an export item. Made as they were from coarse Asiatic cottons, the muslins used incredibly fine threads of 300s count spun by skilled craftsmen. Although the Indian sub-continent was recognized as an accredited home of cotton textile manufacture, and the first textile mill was established as early as in the first half of the 19th century, no serious actions were taken for increasing the cultivation and improving the quality of cotton. The varieties of cotton grown here were poor in fibre length, most of them falling below 20 mm in staple length. To improve the availability of better quality cotton, the Government of India constituted the Indian Central Cotton Committee (ICCC) in 1921 to take up a programme of research for augmenting the production and quality of cotton. Although cotton breeding was going on in Agricultural Departments in many parts of the country, there was no mechanism accessible to the breeder for ascertaining the quality of fibres except through cotton graders whose estimates were not authentic. One of the first actions of ICCC was, therefore, the setting up of a laboratory for authoritative testing of breeders' cotton samples and assessing their spinning potential. The Technological Laboratory with cotton testing and spinning facilities started functioning in Mumbai from December, 1924.

At the time when the Laboratory was established, the technology of cotton testing was in its infancy. In the early years, therefore, considerable attention was given to development and standardization of testing methods for fibres in order to estimate the spinning potential of genotypes under development in breeding stations. In due course, investigative studies of a fundamental nature such as understanding the foundations of yarn strength, influence of fibre properties on yarn quality, effects of machine settings on spinning performance, etc., were undertaken. By 1941, the Laboratory was equipped with ginning machines (both saw gins and roller gins) and pre-cleaning machines for processing genotypes developed by breeders. Detailed studies were made to understand the effect of machine settings and speeds on the quality of ginned cotton so as to arrive at the conditions most suitable for processing each variety of cotton.

One major step taken by the Laboratory in 1929 was to render assistance to textile mills by conducting fibre quality and spinnability tests on representative samples of all traded varieties of cotton received from trade associations in Mumbai and Ahmedabad, year after year. The test data supplied to mills helped them in planning their production schedules.

Another milestone in the functioning of the Laboratory was the commencement in 1932 of commercial testing of cotton fibre, yarn and fabric from private trade agencies against payment of scheduled test fees. Around the same time, the Laboratory started practical training courses for testing technicians from trade and industry. Interestingly, these two initiatives have grown into major activities of the institute in later years.

Post-independence period saw rapid changes in the Laboratory's priorities, outlook and functioning style. Newer research sections were added to the existing ones. Facilities for researches in Physics, Chemistry, Bio-physics and Microbiology came into being, fully equipped with modern sophisticated analytical instruments. Existing sections like fibretesting , yarn testing and fabric testing got strengthened with state-of-the-art scientific instruments. Additional working space was created by constructing new buildings within the available piece of land. Staff strength at every level received a boost, too.

A major structural transformation came about in 1966 when the ICCC was disbanded and the administrative control of the Laboratory shifted to ICAR, with wider and clearer mandate. Its name changed from “Technological Laboratory” to “Cotton Technological Research Laboratory” (CTRL) with the notional jump to the status of a “research laboratory”. A second name change followed in 1991 when the Laboratory was accorded another notional elevation to the stature of an “Institute” and CTRL was

rechristened as "Central Institute for Research on Cotton Technology" (CIRCOT), with its mandate spelt out with greater breadth.

Before long, CIRCOT underwent a lateral administrative shift from the Crops Division to the Engineering Division of ICAR which, in its wake, brought better visibility and recognition to the Institute, together with more generous budgetary allocations for its functioning. Enlarged mandate, increased availability of space for expansion of laboratories, liberal funding, highly qualified and accomplished scientific and technical staff, etc., characterized CIRCOT's entry into the 21st century.

This book attempts to chronicle the saga of research at CIRCOT spread over a period of one hundred years. It must, however, be understood that the huge volume of research findings CIRCOT has in its possession, cannot, by any stretch of imagination, be crammed into a single book except by limiting the narrative to the bare minimum size and at the same time restricting discussion to the most impactful innovations. That indeed has been the approach adopted by the panel of scientists who penned the 18 Chapters of this volume. After all, this book is meant to inform rather than educate the reader.

PART 1

Chapter 1

SUPPORT TO COTTON BREEDING RESEARCH

One of the most important functions of CIRCOT right from early days, after its inception in 1924, was its supportive role in cotton breeding research by providing information on fibre quality and spinnability of genotypes developed by cotton scientists all over India. Cotton improvement research is a laborious process that entails years of work to evolve a new variety having the desired fibre quality in combination with acceptable yield. Starting with a few seeds, chosen from germ plasm stocks, or from a new cross, the breeder makes selections of good plants during several successive generations until he is able to evolve a strain that gives consistent results in respect of yield and fibre quality besides resistance to pests and diseases. Other features like short duration and ginning outturn are also considered while making selections.

CIRCOT was started as a cotton testing laboratory under the aegis of the Indian Central Cotton Committee (ICCC) which had financed hundreds of cotton breeding and related researches in various tracts in the country. In 1966, the Indian Council of Agricultural Research (ICAR) which took over the functions of co-ordinating agricultural research on cotton in the country, after the abolition of the ICCC, launched the All-India Co-ordinated Cotton Improvement Project (AICCIP) in the following year. Simultaneously, CIRCOT which till then was known as Technological Laboratory of the ICCC, came under the administrative control of the ICAR with a change of name as Cotton Technological Research Laboratory (CTRL) which was later re-designated as the Central Institute for Research on Cotton Technology (CIRCOT), its present name. The AICCIP functions under the leadership of the Project Co-ordinator, and this Institute's Director is nominated as the Principal Investigator (Technology) in the AICCIP. The Institute thus offers fibre technology support to the entire gamut of breeding programmes under AICCIP by furnishing fibre quality data on length, strength, micronaire and maturity besides the spinnability index known as the highest standard count (HSC), that can be spun from each genotype.

1.1. STANDARD COTTONS

Certain established varieties were used as standards of reference for comparing the performance of new genotypes that were being developed through breeding programmes. Quality characteristics of Standard Cottons thus served as templates in varietal improvement

research. Standard Cottons were grown with utmost care in government or Agricultural University farms under strict departmental supervision. Every year, over 30 Standard Cottons grown in different research farms in the country were evaluated for fibre properties and spinning performance at CIRCOT. The results on these "Standard Varieties" were circulated in the form of Bulletins among breeders for their reference and guidance. The practice which began in 1927 was, however, discontinued by 1998.

1.2. TRADE VARIETIES

While most varieties perform well in respect of fibre quality and spinnability when grown as Standard Cottons in government farms under special care, the same cannot be said about these varieties when they arrive in cotton markets. There are several reasons for this. At CIRCOT, representative samples of cottons from trade bodies like CAI (erstwhile EICA) were assessed for their fibre properties as well as spinning potential. Data on these "Trade Varieties" also were published annually as bulletins for the benefit of the trade and industry. This practice too was discontinued towards the end of the last century following the arrival of hundreds of Bt hybrids developed by private seed companies.

1.3. SEED MULTIPLICATION

Once a variety evolved through breeding programme was released for cultivation, it was necessary to provide seeds to farmers. Available seeds were multiplied in government farms and later in selected cultivators' fields.

- CIRCOT had standardized the format for fibre, spinning and yarn tests in different stages of seed multiplication programmes. Feedback from CIRCOT on quality aspects of fibres in each stage enabled breeders to make corrections wherever the quality of the material from later stages of seed multiplication was found to be poorer than in earlier stages.

1.4. TARGETED QUALITY IMPROVEMENT

In addition to testing thousands of samples from breeding trials and providing quality data for breeders' guidance, CIRCOT has been providing norms for various fibre attributes to be targeted in selected breeding programmes.

- One of the significant roles played by CIRCOT in guiding breeders in selection process was manifested while fixing fibre quality norms for the superior variety Sujata : Mean length – 30 mm; Fineness (Micronaire) – 3.5 to 4.0 mg per inch; Mature fibres-over 60%; Bundle Strength – over 48 g/tex; Spinnability (HSC)-100s count.

- While developing the extra-long cotton Suvin, the quality targets fixed were : 2.5% Span Length – 38 mm; Bundle Strength – 50 g/tex; Spinnability (HSC) - 120s count.

1.5. MILESTONES IN VARIETAL IMPROVEMENT

- Through technological support by way of testing and providing inputs to cotton

breeders in varietal improvement research, CIRCOT helped the development of over 70 varieties in the first 50 years of its existence and of over 150 varieties and hybrids in 100 years.

- By stressing on the need to raise the staple length of Indian cotton and by providing inputs on fibre properties of strains under numerous trials, CIRCOT could enable the breeders all over the country to develop better quality cotton, ever since the Institute's inception in 1924. While in 1947 only 15% of Indian cottons had staple length above 22 mm, by 1974, the share of this category had risen to 67%.

- Traditionally India produced only short staple low yielding *desi* cottons which belonged to *G. arboreum* and *G. herbaceum* species. With increased emphasis on higher length and fineness as demanded by textile industry and prompted by CIRCOT, breeders developed several varieties belonging to *G. hirsutum* species which were inherently superior in yield. By 1974, the share of *G. hirsutum* cottons had risen to 50% from a mere 3% in 1947.

1.6. AGRICULTURAL PRACTICES AND COTTON QUALITY

Plant growth is influenced by factors such as the quality of seed sown, nutrition applied including water, cultural practices, plant protection measures, etc. Experiments conducted in agricultural research stations are mainly directed towards optimizing these factors so as to augment the yield of the crop. In cotton cultivation, however, fibre quality is an important consideration. CIRCOT has taken efforts in studying the influence of various agricultural practices on the physical properties of cotton fibre as well as its spinnnability. Some research highlights are listed below.

1.6.1. Effects of Water/Irrigation

Considerable effort has gone into understanding the influence of rainfall and irrigation on the fibre quality of different varieties of cotton. Some highlights of such studies are given here.

- Rainfall during maturation period is beneficial for fibre wall thickening as shown by increased fibre weight and maturity.

- In case of rainfed cottons, paucity of rain during cotton season could adversely affect fibre weight and maturity. Particularly noticeable has been the effect of rain during the maturation period on these two properties.

- In case of irrigated cotton, frequent supply of water did not show any effect on fibre length but fibre weight and maturity improved with frequency of irrigation.

- Some trials have shown that “heavy” irrigation helps raising fibre maturity to levels higher than “adequate” and “scanty” irrigation protocols, underscoring the importance of water in the wall thickening phase of fibre growth.

1.6.2. Seed Size and Fibre Quality

Dependence of the size of seed on the properties of fibres produced therefrom was put to detailed study at CIRCOT on several varieties of cotton.

- The studies had revealed that heavy seeds, by and large, give higher yield and display superior germination besides better fibre quality characterized by higher fibre weight and maturity.

1.6.3. Nutrients and Fibre Quality

Effects of chemical nutrients on fibre quality have been subject to rigorous study at CIRCOT through interaction with agricultural scientists.

- The use of groundnut cakes as source of nitrogen, besides application of farm yard manure, ammonium sulphate, town compost, etc. was found to be of little effect on fibre quality though with mixed effect on yield.
- Foliar application of urea and orthophosphoric acid did not significantly affect fibre properties.

1.6.4. Miscellaneous Studies in Agricultural Practices

A few miscellaneous agronomic studies conducted with the cooperation of cotton scientists had revealed some interesting results.

- Whether the plot is ploughed every year, every two years, every three years, or not ploughed at all, would not make any impact on fibre properties or ginning percentage, as shown by some studies at CIRCOT made in collaboration with agronomists.
- Similarly, as the spacing among plants was varied over a wide range in different trials with many varieties, no significant difference was found in major fibre properties like length, uniformity of length, fibre weight and maturity. This result is significant in today's context when scientists are recommending high density spacing as a means to augment productivity of cotton per acre.
- Wide shifts in the date of sowing were attempted on different varieties in several tracts to assess their impact on fibre quality. Although the results did not follow any uniform trend, early sowing appeared to favour improvement of some fibre properties like length, fibre weight and ginning percentage, besides augmenting the yield.
- Trials have been conducted with different genotypes to see how they perform in respect of fibre quality when grown in different localities with dissimilar soil types and weather conditions. While considerable differences could be seen in fibre quality characteristics like length, fibre weight, strength and maturity from one location to another, no conclusions of a general nature could be drawn from the data.

- Beneficial effects of synthetic hormones on the yield of cotton were well known even in the middle of the last century. It was necessary to ascertain what impact such hormones have on the quality of fibres. Some studies conducted on different varieties of cotton using growth regulators like alphanaphthalene acetic acid (NAA), Cycocel, Gibberellic acid, Phosfon and B-nine showed either no change or only marginal effect on fibre properties like length, fineness, strength and maturity, besides ginning percentage.

- Forecasting the size of standing crop before harvest is of great importance in agricultural economics. The forecasts are based on crop cutting experiments which will provide information on the yield at each location and for each variety of cotton. The forecast thus made may not agree with the figures emerging from baling press returns due to the interplay of other factors. CIRCOT studies spread over six crop years in early years (1932-1937) revealed that the disagreement could be attributed to domestic consumption of cotton as well as transaction as loose cotton. Suggestions for bringing about greater accuracy in forecasting cotton yield were also put forward. It is ironical nevertheless, that even today, the issue of disagreement between forecast by crop cutting method and the actual pressing figures remains unresolved.



Chapter 2
COTTON GINNING

Ginning is the first process to which harvested cotton is subjected. Ginning machines are of two kinds-saw gins and double roller (DR) gins. In the former type, circular saw discs mounted on a rotating shaft are made to catch fibres with their teeth and pull them away from the seeds trapped in slots. The saw gins are more suitable for ginning short and medium staple cottons and are popular in the northern states of Punjab, Haryana and Rajasthan which traditionally grew only such varieties. In the DR gin, fibres are made to stick to the leather-coved rollers while the seed, caught in a slot, is hit by a beater causing separation. DR gins are suitable for ginning cottons of all staple classes. Saw ginning is harsh and is known to cause more fibre breaks than roller ginning. With the spread of superior medium and long staple B*t* hybrids by the turn of the century, the ginning industry in these states is in the process of replacing saw gins with DR gins.

2.1. PERFORMANCE OF SAW GINS AND ROLLER GINS

Ever since the setting up of the ginning facility in 1941, CIRCOT has been engaged in researches on standardizing various machine settings, and identifying conditions for optimal ginning performance of every new variety of cotton developed by breeders. Such an effort was intended as much to ascertain the potential of new varieties as to guide the ginning industry in maximizing the output, with minimal fibre damage during processing. Important contributions made by CIRCOT during the first 50 years of its existence are listed out in this Section.

- Vast amounts of data have been generated at CIRCOT on the performance of different brands of Opener-cum-Cleaning machine and on the response of cottons belonging to a wide range of fibre quality levels. Opening and cleaning were found to facilitate higher ginning output per hour and higher ginning percentage (fibre yield), without any adverse effect on fibre quality. These results were common to both saw ginning and roller ginning.
- Saw gins give much higher output than Double Roller (DR) gins. Moreover, power consumed by the saw gin is considerably lower than that demanded by DR gins to process the same quantity of cotton.
- Saw gins, however, give 1% lower ginning percentage than DR gins. The lower fibre

yield must be attributed to the fuzz left in saw ginned seed as a result of fibre breakage inevitable in this machine.

- Saw ginned lint is neppier than roller ginned lint because of the severity of mechanical action in saw ginning.
- Higher saw gin speeds within the manufacturer's recommended range give higher output without hurting lint quality.
- Overlap and grid settings in DR gins need to be changed to suit staple length and seed size. An overlap adjusted to one-third of the staple length gives high output, together with good fibre quality.

2.2. GINNING OF SMALL SAMPLES

- For ginning small quantities of kapas such as those generated in early breeding trials, a Laboratory model roller gin (Lab gin) was designed at CIRCOT in the yearly years. This gin comes handy for ginning small samples of seed cotton for determining ginning percentage as well as for gathering lint samples for fibre quality tests. Several hundred small gins have so far been supplied to breeding and marketing centers all over the country.
- Considerable improvements have been made in the Lab gin over the years for augmenting its efficiency and aesthetic elegance. Information on later models of the small gin can be found in Chapter 10 (Part 2) of this book.
- An ingenious Ginning Percentage Balance (GP balance) designed at CIRCOT is handy for determining the quantity of lint derivable from seed cotton as a percentage of the weight of kapas, referred to as ginning percentage which is of high commercial significance. Any unknown quantity of kapas can be ginned on the Lab gin, and the lint and seeds are placed on the pans of GP balance. After a simple operation to achieve counterpoise, GP% can be read on the calibrated beam. Hundreds of GP balances manufactured under CIRCOT licence are in use in cotton breeding stations and marketing centres in the country.

2.3. ATTACHMENT STRENGTH AND EXTRACTION ENERGY

Some cottons demand more energy than others for ginning a specified quantity of cotton. Such differences arise from (a) varietal dependence of the force of attachment between fibre and seed as well as (b) the proportion of fibres breaking rather than being pulled out during ginning.

- The above conclusions followed extensive studies on the strength of attachment of fibres to the seed, using a special device designed at CIRCOT for this purpose. It was also evident from these studies that the strength of attachment is the lowest for *G. barbadense* (0.54g) and the highest for *G. arboreum* (1.4g), with *G. hirsutum* (0.56 g) and *G. herbaceum* (1.2g) possessing intermediate values.

- The above study was later extended to determine the work done (energy demanded) to pull out fibres from the seed, using another machine, a ballistic tester, specially designed for this purpose. Here too the results were similar, with *G. barbadense* cottons needing the least energy to pull out a single fibre (45.2 erg) and *G. arboreum* cottons demanding the highest (88.2 erg), with *G. hirsutum* (75 erg) and *G. herbaceum* (80 erg) occupying middle levels.

- Many years later (1990), the above studies were extended with the help of a commercially available machine from Shirley Institute. Tests with several new varieties of cotton revealed wide spread among varieties in respect of the energy demand for separating 1 kg of fibres from the seeds. Here again *G. barbadense* cottons needed the least energy (2000 joules/kg lint) while others were found to demand much more (up to 3000 joules/kg lint). It is significant to note that all these energy figures are very small compared to the energy demanded by ginning machines to extract fibres in commercial operation.

- All the above CIRCOT studies on strength of attachment and energy needed to extract fibres have led to the revelation made as early as in 1950 that the energy consumed by ginning machines is 50-80 times the energy required to pull out fibres from cotton seed. Ginning machines especially the DR gins are to be, therefore, seen as devices with poor energy efficiency. This finding even today remains as a challenge to researchers attempting innovations in ginning machines.

- CIRCOT studies have demonstrated that saw ginning gives more neps than roller ginning. At the same time, gin settings and speed of saw gins are found to have little effect on nep formation.

- The first-ever survey of ginning factories in India was conducted by CIRCOT between 1954 and 1956. The survey revealed several deficiencies in the ginning infrastructure in the country. Machines, mostly single roller gins, were very old and inefficient. Pre-cleaning of kapas and cleaning of ginned lint were not practised. Gin technicians and operators were untrained. Storage facilities for kapas and lint were poor and inadequate. All these deficiencies led to production of trashy and contaminated lint. CIRCOT had recommended modernization of ginneries as the solution to a multitude of problems in the supply of clean cotton to the textile industry which was already equipped with sophisticated machinery capable of delivering quality textiles.

2.4. MISCELLANEOUS STUDIES

2.4.1. Trash Level Standardisation

The presence of excessive trash in cotton is a much-discussed topic. CIRCOT has done pioneering work in the measurement and standardization of trash content. Some highlights follow.

- On a request from CCI, CIRCOT had in 1970 conducted a study of trash levels in baled

Indian cotton and had recommended upper limits for trash in cotton of different staple classes. Trash limits suggested to CCI were: ELS--3%; Long and Superior Medium staple – 4%; Medium and Short staple – 5%; and Closed Boll Types – 6%.

- Suggestions given to CCI also included the style of packaging as well as norms for cloth to be used for covering the bales. It is gratifying to recall that CIRCOT's suggestions had later formed the basis for BIS specifications (IS 12171) relating to Indian Standard Cotton bale.
- While deciding the trash limits, CIRCOT had attempted to balance the demands of cotton industry and trade on the one hand and the limitations of the ginning industry on the other.
- The reader needs to be reminded that there have been revisions of BIS specifications in later years in which CIRCOT 's amended trash limits namely 2.0%, 3.0%, 3.5% and 6% for the respective staple classes have been incorporated.

2.4.2. Effects of Storage

Carry-over of stocks of bales from one season to the next is not uncommon in cotton trade. Whether this practice has adverse effects on the performance of cotton thus traded has been put to detailed study by CIRCOT scientists, keeping in view the commercial importance of such a carry-over. Some highlights are reported here.

- In an early study of the effects of storage of bales of cotton in humid conditions prevailing in Mumbai, it was found that after one year of storage, the visual grade, colour, lustre and strength declined noticeably.
- In another study, two and a half years of storage in baled form in humid condition was found to cause deterioration of fibre strength and lustre besides increase in yarn breakage in processing.
- No changes were found in fibre properties like length, fibre weight and strength, even after three years when the material was kept fairly dry.
- In yet another study, two lots of bales of the same cotton were stored, one lot in Mumbai and the other in the place of origin which was drier. While the former showed deterioration in waste loss and fibre strength, no adverse effects were found in the lot kept at the place of growth even after four years. This result also confirmed the humidity effects on stored bales.
- Detailed studies at CIRCOT have shown that deterioration of cotton quality and adverse effects on yarn are attributable to the growth of micro-organisms promoted by humid conditions.

2.4.3. Neps in Cotton

Nep is a tiny pin-head sized cluster of immature fibres or broken bits of normal fibres coiled

around either leaf bits or seed coat fragments. Neps are generated mainly by the vigorous mechanical action during ginning. Lowering of lint grade, yarn appearance and yarn strength, breakages in spinning and uneven dyeing of fabric are caused by excessive presence of neps. Cotton neps have been studied in detail at CIRCOT. Significant findings are noted here.

- Extensive studies at CIRCOT on the incidence of neps at different stages of mechanical processing have shown that significant increase in nep count takes place at the scutcher during bale opening while at the card, considerable amounts of neps are removed whereby the card sliver emerges with fewer neps. Subsequent processes do not significantly affect the nep count but at the ring frame there is noticeable reduction in neps. The final product, the yarn, turns out to be a little nippier than the raw lint.
- The thoroughness and severity of precleaning do not have any noticeable impact on nep count in ginned lint.
- Saw ginning by virtue of its severe mechanical action gives significantly more neps in lint as compared to roller ginning.
- Studies at CIRCOT did not reveal any relation between neps in lint and neps in yarn. And as settings and speeds in gins were found to have no significant effect on the formation of neps in lint it was recommended that gin settings could be adjusted to maximize output without the risk of increasing the incidence of neps.
- Neppiness is measured on both lint and yarn. For lint, the number of neps in unit weight of cotton is taken as the measure of neppiness while in case of yarn the number of neps in unit length of the strand forms the index. In case of cotton lint, neps are counted from a thin web of fibres suitably illuminated and observed under magnification. Yarn samples are wound on black cards and examined in the same way as lint.
- As early as in 1958, a nep counting technique had been standardized at CIRCOT for cotton lint. In this method webs of lint are observed in a nep counting device and three types of neps namely those formed by (i) fibres, (ii) seed coat fragments and (iii) leaf bits are enumerated. The nep index is found out as the sum of the three numbers with appropriate weightage assigned to each, on the basis of preliminary studies.

2.4.4. High Density Bales

Pressing cotton lint into high density bales of reduced dimensions is advantageous for transportation. But in such bales, cotton is subjected to high pressure. Researches at CIRCOT in early years had shown that pressures as high as 40 lb/cft do not adversely affect fibre quality. This finding demonstrated the commercial viability of high density compact bales.

2.4.5. Combating Boll Weevil

In the early 20s of the last century boll weevil had caused severe cotton crop damage in USA. There was apprehension that the pest might enter India through cotton bales imported from USA. Fumigation of American cotton with hydrogen cyanide (HCN) was suggested by CIRCOT

to combat the boll weevil threat. After detailed studies with a highly resistant indigenous weevil, CIRCOT scientists formulated a fumigation protocol specifying the concentration of HCN and the duration of treatment that would eliminate the organism if present in imported cotton. Fumigation facility was set up at Bombay Port in 1925, and for many years the treatment of imported US cotton was supervised by CIRCOT staff.

2.4.6. Non-Textile Uses for Cotton

Studies on the non-textile uses of cotton were conducted in CIRCOT as early as in the 40s of the last century when cotton exports had dwindled because of World War II. Two new uses of cotton attempted by CIRCOT deserve mention.

- One was the use of cotton in making roads, a veritable precursor to geotextiles that have found several applications in recent years. A segment of road near CIRCOT reinforced with cotton fabric stood testimony to CIRCOT's wisdom to find alternative applications for cotton.
- The other non-textile use of cotton explored by CIRCOT was by recommending cotton fabric as the covering material for bales which were traditionally packed in hessian cloth. Advantages of using cotton cloth in place of hessian fabric were identified. Averting contamination of cotton with jute fibres and jute thread bits, compact appearance of bales, and thus increasing the demand for cotton from elite mills were seen as the main advantages of such an initiative. Although there was no immediate impact on bale packaging, in retrospect, the CIRCOT initiative could be seen as prophetic in as much as the ginning industry today has completely switched over to using cotton cloth as bale cover in conformity with international practice as well as the revised Indian Standard specifications.

Chapter 3

FIBRE QUALITY

In the early decades after CIRCOT was founded, the technology of cotton quality assessment was in its infancy. In order to help cotton scientists in their research efforts to evolve new genotypes with satisfactory fibre quality besides high yield, it was necessary for CIRCOT to evolve new methods of tests for fibre and yarn characterization and to modify existing methods for increased efficacy. It was also felt necessary to unravel the intricate relationships between fibre quality and yarn performance. Early researches at CIRCOT in cotton quality assessment included critical evaluation of different methods of test for fibre length, strength, fineness and maturity. Attempts were also made to develop prediction formulae for yarn characteristics using data on fibre properties. Significant findings are summarized in this Chapter.

3.1. FIBRE LENGTH

Length is the most important quality characteristic of the cotton fibre that determines its technological worth, primarily defined by its spinnability and yarn quality. The central value of length is expressed through parameters like staple length, halo length, mean length, modal length, median length, 2.5% span length, effective length etc., while length dispersion is expressed in terms of CV%, short fibre percentage, uniformity ratio (UR%), irregularity percentage, etc. From the very beginning, CIRCOT has been guiding breeders and the cotton industry by providing fibre length data on research samples as well as commercial samples. Besides providing test data, CIRCOT has been engaged in researches on standardization of test methods and designing new methods while at the same time carrying out studies on the influence of fibre length parameters on yarn characteristics. Most of these studies were conducted in the years prior to 2000.

Hand Stapling

For spot estimation of fibre length particularly in market yards and ginneries, traders pull out fibres from a few seeds and prepare a tuft of parallelized fibres through manipulation with fingers. Making use of a measuring scale, the trader estimates the "Staple Length" as the most representative length of fibres in the sample. Although highly subjective, this method gives consistent results at the hands of experts referred to as "graders". CIRCOT scientists have done

extensive studies to identify sources of errors and the likely role of subjectivity in staple length estimation. By the turn of the century, however, the cotton trade had switched over to grading cotton on the basis of 2.5% span length determined by using the Fibrograph.

Array/Baer Sorter Method

In this method, fibres from an aligned tuft formed on Baer Sorter representing a "numerical sample" are spread out on a black velvet board in decreasing order of length, and a trace of the fibre array is obtained on a piece of paper. A geometrical construction made on the trace gives the "effective length" and short fibre content (per cent). The trace can also be used to find the mean fibre length. This mean is referred to as mean length by number.

Balls Sorter

This is the oldest mechanical devise for fibre length measurement. It separates fibres from a numerical sample into various length groups. Fibres in each length group are collected together and weighed on a balance so as to calculate (a) the mean length based on weight and (b) a few length variability indices. The data from Balls Sorter can also be used to construct the length distribution diagram to get several statistical measures of length and its variability.

Fibrograph

This instrument gives fast and highly reproducible test results for fibre length. It is based on the principle that the amount of light intercepted by a tuft of fibres caught in a comb is proportional to the number of fibres within the light beam. The uninterrupted light is measured by photocells aided by electronic accessories. The Fibrograph gives 2.5% span length as the central value of length and uniformity ratio (UR) as the measure of length variability. In cotton trade and technology, 2.5% span length and UR are preferentially used today to represent cotton quality.

High Volume Instrument (HVI) System

The HVI system offers precise and consistent values of fibre property parameters. It is an automatic machine with computer-controlled calibration and diagnostics. The HVI system consists of different modules for the measurement of (a) fibre length, length uniformity, strength and breaking elongation, (b) Micronaire, (c) colour (Reflectance, Rd and Degree of Yellowness, +b) and (d) trash content.

Advanced Fibre Information System (AFIS)

This is a highly sophisticated equipment with separate modules for evaluating (a) fibre length and maturity indices, (b) micro-dust & trash, and (c) Neps. Fibres in sliver form are fed into the system that separates three components namely, fibre, micro-dust and trash. These components are carried forward through separate channels and evaluated by opto-electronic sensors supported by computer devices. Quality characteristics evaluated include average length by weight and number, their CV%, upper quartile length by weight, all measured on single hairs, fibre maturity indices, trash indices and nep count.

3.1.1. CIRCOT Researches on Fibre Length

Most detailed study on fibre quality made at CIRCOT has been in the domain of fibre length measurement. Development of test methods as well as comparison of results from existing test methods have interested CIRCOT scientists. Highlights are briefly discussed in this section.

- Many decades ago, a quick method to estimate length of fibres still attached to the unginned seed, was developed at CIRCOT for the benefit of breeders. Referred to as the Halo Length Disc method, this procedure makes use of a calibrated transparent plastic disc which can be carried to the farm for length estimation. Cotton fibres attached to the seed are combed out into a halo and placed on the disc and the representative "halo length" is read on its calibrated scale. Despite the subjectivity, the method comes handy for quick assessment of fibre staple. Hundreds of Halo Length Discs have been supplied by CIRCOT to breeders in the country.

- One of CIRCOT's early contributions (1934) in fibre length measurement was the design of the AN Stapling Apparatus (ANSA). This is a mechanical machine that gives mean fibre length at a faster speed than the then-existing Balls Sorter and Array methods. In this apparatus an aligned tuft of cotton fibres is cut into 3 segments and, from the weights of the first and third segments the mean length is found out by using a simple formula. Hundreds of pieces of ANSA have been sold to various organizations in the country.

- An ingenious but simple optical device that could measure the thickness diminution along the length of an aligned tuft of cotton fibres was designed in the early 1970s. This machine referred to as Interferometric Fibre Stapler (IFS) made use of interference bands to gauge the thickness attenuation of the fibre tuft, beginning from the aligned end. The data from IFS could be used to plot what is equivalent to the cumulative length distribution curve from which all fibre length parameters can be calculated. IFS could not, however, be commercialized as it was slow, delicate and demanded skill to operate.

3.1.2. Other Highlights on Fibre Length Studies

In early years, CIRCOT had made elaborate studies on length and length variability measures from Array (Baer Sorter) method and Balls Sorter. These studies had led to a conceptual understanding of statistical parameters like number average, weight average, numerical sample, length-biased sample etc. Some research highlights are given below.

- Both Balls Sorter and Baer Sorter make use of numerical sample for fibre length estimation. However, the mean length by weight given by the former is 5-10% higher than the mean length by number determined by using the latter.

- It has been ascertained from extensive studies at CIRCOT that the weight average of a numerical sample (aligned tuft sample) is equivalent to the number average of a length-biased sample (tong sample).

- From a multiplicity of studies employing different instruments for fibre quality measurements, it has been confirmed that central values like effective length, upper-half mean length, mean length, 2.5% span length, weight average length, etc. are all unequal length measures but highly correlated among themselves such that any of them can be used to characterize fibre length in varietal improvement research, for trading purposes and while processing cotton in a spinning mill.

- For comparison of length data from different methods, CIRCOT scientists have evolved several conversion formulae, supported by massive experimental results on several varieties covering wide range of fibre length.

- Mean length by weight from AFIS, based as it is on single fibre measurement, is highly correlated with, and numerically comparable to, Baer Sorter mean length.

- Length distribution by weight provided by AFIS can be used to extract the cumulative length distribution equivalent to the Comb Sorter array diagram from which Effective Length (EL) and Short Fibre Content (SFC) can be found out by geometrical construction. Interestingly, EL and SFC from the two methods are found to agree for all length ranges.

- Extensive data gathered at CIRCOT have shown that fibre length variability measures like SF%, CV%, Irregularity (%), UR etc. are poorly correlated among themselves, unlike the parameters representing central values of fibre length. However, it has been recommended by CIRCOT researchers that any one of the length variability indices could be used for in-house monitoring of raw material quality at different processing stages.

3.2. FIBRE FINENESS

Fine fibres make yarns of high tenacity (CSP) as there would be more number of fibres in the yarn cross section for each count. Fineness comes next to fibre length in its influence on yarn strength. Fibre fineness is expressed in terms of parameters such as weight per unit length of the fibre (gravimetric fineness), ribbon width, swollen hair diameter, area of cross section and the Micronaire value.

The Micronaire is an air-flow instrument which gauges the resistance offered by a given mass of fibres to the flow of air at a specified pressure. By virtue of their large specific surface area, fine fibres would offer higher resistance than coarse ones. Fibre fineness can be read on a scale calibrated in microgrammes per inch referred to as the Micronaire value. Besides the Micronaire apparatus, which has retained universal acceptance, other similar devices like Arealometer, Port-Ar, Air Permeameter, ATIRA Fineness Tester etc. which were popular for some years are no more in use in industry.

Fineness of single fibres can be determined by using the Vibroscope in which an electric field of variable frequency is applied to the fibre under a small tension. Resonant frequency at which the

fibre vibrates with maximum amplitude is found out and the linear density of the fibre is calculated by employing a simple formula.

3.2.1. CIRCOT Researches on Fibre Fineness Measurement

Extensive researches have been carried out at CIRCOT on the fineness of different varieties of cotton, comparison of results from different methods, inter-relationships between fineness and other fibre properties besides the influence of fineness on spinning performance. Major research highlights are listed below.

- Detailed studies at CIRCOT have led to the conclusion that gravimetric method for fineness determination based on the weight of middle segments of fibres is inaccurate as it tends to over-estimate fibre weight on account of the fact that fibres are tapered towards the base and tip. CIRCOT, therefore, recommended the use of the "whole fibre" method for more authentic gravimetric fineness measurement.
- A method of finding gravimetric fineness by using the data from AN Stapling apparatus had been suggested many years ago. Just with two additional steps of (i) weighing the first section of fibre tuft placed on the AN Apparatus and (ii) counting the number of fibres therein, the gravimetric fineness can be obtained as a by-product from length measurement, using a simple formula.
- Ribbon width of immature fibres is higher than that of mature fibres. This result demonstrates the fact that all fibres in a variety possess the same diameter in the uncollapsed state inside the boll; but on boll opening and desiccation, all fibres collapse into different ribbon widths. This fact is corroborated by the constancy of swollen hair diameter irrespective of fibre maturity within each variety. It also follows that cross-sectional perimeter is a distinctive characteristic of each variety.
- Finest Indian cottons like Sujata and DCH.32 have fibres of about 10 microns diameter (thickness) and a Micronaire of 3.2 g/inch while the coarsest variety like V-797 will measure 25 microns and possess a Micronaire value of 6.5 g/inch.
- Researches at CIRCOT have shown strong correlation among fineness measures like ribbon width, gravimetric fineness and Micronaire value. Regression equations have been worked out for conversion of data from one method to those in another.
- For small samples of cotton such as the lint from a single plant or from a few bolls generated in breeding experiments, a method of mixtures was suggested by CIRCOT scientists many years ago for determining the Micronaire value. The sample size required for the normal Micronaire test is 3.24 g. If the lint available is less, one can use the method of mixtures based on the fact that the average fineness of the mixture is the weighted harmonic mean of the components. Knowing the Micronaire reading of a standard component and that of the mixture, the Micronaire value of the small sample can be calculated by using a simple formula. This method can be used on lint samples as small as 0.5 g.

3.3. FIBRE MATURITY

The degree of cell wall development, referred to as fibre maturity, affects several yarn properties like strength, neppiness, dye uptake etc. Maturity is defined in many ways. One measure is the degree of thickening expressed as the ratio of cross-sectional area of the cell wall to the area of the circle having the same perimeter. The ratio of ribbon width to the width of the lumen is another measure. The most popular measures of maturity are those obtained from the relative dimensions of the lumen and the cell wall of the fibre swollen in caustic soda (18% w/w). A quick method based on the Micronaire readings obtained with and without a "spacer" introduced into the sample chamber of the apparatus is also quite popular. Some research highlights are presented here.

- To suit Indian cottons, CIRCOT developed a scheme to classify alkali swollen fibres into Mature, Half Mature and Immature fibres on the basis of relative sizes of lumen and wall, and from the three numbers, "Maturity Coefficient" (MC) is calculated by a simple formula. MC is nothing but the weighted sum of Mature, Half Mature and Immature fibres in a group of 100 fibres, the weightage for the three categories being 1, 0.6 and 0.4 respectively.

- Detailed experimental studies had shown that in the Micronaire difference method for maturity measurement, a spacer of 3/8 inch is more suited for Indian cottons than the ½ inch spacer prescribed by the machine designers for foreign/western cottons.

- An alternative method based on the Micronaire values for two different masses of the same sample was found to give accurate results. In this method, Micronaire readings are obtained at standard pressure for samples of 40 & 50 grains. The difference in these two readings is found to be correlated with the result from spacer method and with the maturity coefficient mentioned earlier.

- From data on several cottons, regression equations have been worked out to arrive at the percentage of mature fibres P_m from AFIS parameters such as Immature Fibre Content (IFC) and Maturity Ratio (MR).

- CIRCOT studies have shown very high correlations among the maturity measures obtained by various methods.

3.4. FIBRE STRENGTH

Fibre strength is considered to be next to length and fineness in order of importance among fibre properties that influence spinning performance. For cottons beyond a certain staple length, fibre strength may assume even greater significance. Strength is the tensile load (tension) at which the fibre breaks while "tenacity", otherwise known as "intrinsic strength", is the breaking load per unit linear density of the fibre and is expressed in grams per tex.

Fibre strength, being a characteristic with considerable influence on yarn strength and wear life of fabrics and garments made there from, has been put to detailed study at CIRCOT right from

early days of its inception. These studies have brought to light several basic facts about this important fibre characteristic. The influence of fibre strength on yarn behavior has also been subjected to a wide range of experimental and theoretical studies.

Fibre strength is basically decided by fibre structure and morphology but is also influenced by experimental conditions such as the specimen length, atmospheric humidity, speed of test (type of machine), and whether the test specimen is a single fibre or a bundle of fibres. Work on these aspects done at CIRCOT is summarized below.

3.4.1. Fibre Strength and Test Length

Unlike manmade fibres, cotton suffers rapid fall in strength with increasing test length, attributable to the presence of different types of weak places which also include "structural reversals" and morphological deformities discernible in electron micrographs.

- Researchers at CIRCOT have generated extensive data on strength fall with increasing test length both in single fibres and fibre bundles. Strength fall is as high as 30%-50% when test length is raised from 0 mm to 3 mm.

- Swelling in alkali under stretch removes some of the weak spots whereby fibre strength is increased and at the same time the strength fall with increasing test length is considerably subdued.

3.4.2. Fibre Strength and Moisture

The strength of cotton fibres increases with the humidity of the atmosphere in which it is conditioned and tested. Strength and tenacity data have to be, therefore, reported for the standard humidity of 65% RH. Several studies have been made at CIRCOT to understand the role of moisture in shaping the fibre strength. Salient findings are highlighted here.

- From extensive experimental data, CIRCOT scientists had worked out correction factors for tenacity data obtained at ambient humidity levels ranging from 25% RH to 95% RH so as to bring the test results to the standard humidity of 65% RH. These correction factors were useful in olden days when laboratories did not possess humidity control systems.

- Studies on different varieties of cotton have shown that fully wet cotton fibre is stronger by 30%-50% as compared to its strength at the standard atmosphere of 65% RH. It is surmised that segmental mobility of molecular chains facilitated by the removal of excessive hydrogen bonding permits more uniform distribution of stress in the loaded fibre rendering the wet fibre effectively stronger. It is interesting to note that the response of cotton is thus different from that of most other fibres like rayon, wool, silk, nylon, etc. that tend to become weaker on absorbing moisture.

- Experiments at CIRCOT have revealed that although moisture increases fibre strength, its effect on tenacity recorded by the HVI system is notably diminished. This is so

because the presence of moisture would increase fibre weight and thus reduce the number of fibres in a given mass leading to diminished surface area of fibres in the test specimen (fibre plug) placed in the HVI machine which would in turn record a higher Micronaire value. The increased Micronaire value would tend to push down the tenacity calculated as the breaking load per unit linear density (Micronaire). Fibre tenacity thus would remain largely unchanged despite increase in the fibre strength.

- CIRCOT studies have further shown that when moisture in the fibre varies from 6% to 9%, HVI tenacity would not show any significant change particularly if the test is performed at standard atmospheric (65% RH and 27 °C) conditions.

3.4.3. Fibre Strength and Speed of Test

Tensile test results are affected by the speed with which the specimen is stretched or loaded to the breaking point on the testing machine. CIRCOT researches have shown that irrespective of whether it is a constant rate of (i) loading (CRL) (ii) traverse (CRT) or (iii) extension (CRE) type of machine, the test result would be influenced by the time for break. Short time for break would yield a high value of strength and vice versa.

- Work at CIRCOT has demonstrated that test results from accelerated loading type of machine like the Pressley Tester, in which the time for break is less than one second, are 10% to 20% higher than those from the CRL type Stelometer in which the breaking time is 5-6 sec. It has been ascertained that about two thirds of the difference between the results is due to the overshoot of the moving weight in the Pressley tester and one-third attributable to the higher speed of test this machine. It is also seen that when the Pressley machine is made to work at a slow speed by means of a special drive mechanism, the results match with those from Stelometer.

3.4.4. Single Fibre Strength and Bundle Strength

Tenacity of a bundle of cotton fibres is always less than the average tenacity of components. In case of cotton fibres there can be 50-60% fall in tenacity from single fibre to bundle. The low strength realization in a bundle results from the non-simultaneity of breaks caused by unequal extensibility of individual fibres. Theoretical estimation of bundle strength from single fibre load-extension data had been attempted by scientists elsewhere with fair accuracy. By an altogether different approach CIRCOT scientists have arrived at a formula to predict bundle strength using data on single fibre tests.

- The theory developed at CIRCOT is based on the reality that breaking strength and breaking extension of cotton fibre are mutually independent whereas earlier theories assumed that stronger fibres are also more extensible, presuming thereby that the components have equal modulus.

- The CIRCOT theory yields a formula for bundle strength in terms of four parameters, all derivable from data on single fibres.

- The accuracy of bundle strength prediction by CIRCOT theory is proved to be better than by other theories, as illustrated with data on Suvin cotton.

3.5. LESSER KNOWN PROPERTIES OF COTTON

Fibre characteristics which are relatively less known about, such as lustre and clinging power (inter-fibre friction) have also been studied at CIRCOT though briefly. Highlights follow.

3.5.1. Fibre Lustre

Unlike manmade fibres, cotton in the raw state is far from lustrous. On mercerization accompanied by stretch, lustre as measured by contrast ratio (ratio of intensity of specular reflection to that of light diffusely reflected) increases by as much as 200%. Some findings are highlighted here.

- Lustre is a genetic character of cotton fibre, not dependent on environmental factors prevailing during growth.
- Indian varieties are comparatively less lustrous than Egyptian cottons.
- Stretch mercerization increases the lustre of cotton to the level of manmade fibres.
- Optical heterogeneity, resulting from the presence of voids and pores with dimensions close to the wave length of light, causes light scattering, with minimal specular reflection, unlike in the case of manmade fibres.

3.5.2. Fibre Friction (Clinging Power)

Inter-fibre friction was subjected to a rudimentary study at CIRCOT, of which some results are highlighted below.

- An existing method based on measurement of the force required to pull out a group of 10 fibres between two pads of the same cotton, was used for the study. Trials with many cottons had shown that varieties with high clinging power are spinnable to finer counts though the yarns are more irregular.
- The study also indicated that regularity of convolutions has greater influence on frictional property than the average number of convolutions per unit length of the fibre.
- Removal of wax reduces clinging power which can, however, be considerably increased by spraying chemicals like syton.

3.6. VARIATION IN PHYSICAL PROPERTIES

Cotton is known for its variability. Its fibre properties display differences among individual hairs in different locations on the seed surface as well as between different seeds in the same locule. These variations ultimately reflect in the average properties of the bulk sample. CIRCOT findings are summarized below.

- It has been confirmed from extensive studies at CIRCOT that fibre properties differ among fibres from different regions of the seed surface. Micropylar fibres are shorter, coarser, highly mature, stronger and thinly populated while at the chalazal end, they are longer finer, less mature and weaker, besides being densely populated. All those features are intermediate in case of side region fibres which constitute the bulk of any sample of cotton.

- Analysis of data shows that the CV% of any property within a single seed is nearly the same as the CV% for the bulk sample. In other words variations in fibre characteristics found in a bulk sample are accountable by variations present on a single seed.

- Measurable variations have been found in physical properties of fibres belonging to different length groups within some varieties. Extensive data on *G. hirsutum* cottons showed that higher length groups have finer fibres characterized by reduced fibre weight, ribbon width and swollen hair diameter. Fibre strength measured on single hairs showed lower values in longer length groups. However, since fibre weight also recorded a trend of decrease with increase in group length, the intrinsic strength (tenacity) remained notably unchanged.

Chapter 4

COTTON SPINNING

The Spinning Division of CIRCOT started functioning in 1924 itself, the year of the Institute's establishment. All the essential machines right from the blow-room to ring frame were installed in the same year. Keeping pace with the advent of new technologies, CIRCOT has been in the process of setting up modern machines as and when they became popular. The primary role of the Spinning Division of CIRCOT has been the assessment of spinning performance of new cotton strains being evolved by breeders and offer advice on their suitability or otherwise for textile use.

Spinnability is a term with wide meaning and implications. Primarily it refers to the finest (highest) count to which a cotton can be spun (HSC) such that the yarn has acceptable tenacity. Acceptability is governed by arbitrary but meaningful standards for yarn tenacity set by CIRCOT. Besides assessing spinnability of new experimental strains, CIRCOT has been conducting extensive researches towards standardizing the process conditions suitable for each evolved variety for the benefit of spinners using it. CIRCOT was equipped with the full range of spinning machines right from its inception in 1924, as stated earlier, and these machines were upgraded or replaced as and when newer and faster systems were available. The machines comprised blow-room, carding machines, comber, draw frames, slubbing, intermediate frames, etc. In later years open-end and core spinning machines too were added.

Samples that come for spinning tests at CIRCOT comprise

(a) small samples from breeding trials conducted at research centres all over the country for the so-called "micro-spinning trials",
(b) large samples of strains in advanced stages of breeding experiments for "full spinning trials",
(c) commercial samples from mills for both micro-spinning and full spinning trials against payment of scheduled fees and
(d) samples from agronomic and other research trials conducted at breeding stations. Thousands of spinning tests are conducted at CIRCOT every year.

4.1. RESEARCHES AT CIRCOT SPINNING DIVISION

The most significant research results of the Division are listed below.

- One of the early accomplishments of the Spinning Division has been the standardization

of the spinning technique for small samples such as those generated in early breeding experiments. Micro-spinning technique evolved at CIRCOT is suitable for samples as small as 60-150 grams depending on the count to be spun.

- Strength of yarn spun by CIRCOT's micro-spinning method was found to correlate well with that of the yarn spun by the normal bulk spinning method. The former, however, was higher by about 7%.

- In early years, the spinnability of cottons was judged from the CSP values of the yarns, all spun to a common count, in a manner followed in other countries. CIRCOT work showed that this method, however, can be used only within a small range of counts.

- A more meaningful index called Highest Spinnable Count (HSC) was evolved at CIRCOT in the 1960s. For arriving at HSC, each sample is spun to three counts. The CSP of the three yarns is plotted against count and the descending straight line joining the three points is drawn. The point of intersection between the descending line and the ascending line connecting the "standard" CSP values with yarn count is located. The intersection point represents the HSC of the cotton sample. The standard CSP norms were fixed by CIRCOT on the basis of studies on the performance of machinery used by industry and the properties of cotton cultivated in the country.

- With the replacement of the older spinning systems at CIRCOT with newer ones in 1976, 1982 and 2000 as part of modernization and strengthening of the laboratory facilities so as to remain in tune with the trend in textile industry, better quality yarns could be spun from the same cotton. For a more weighty assessment of the spinning potential of strains in newer systems, therefore, CIRCOT had to revise the CSP standards.

- The Standard CSPs can be expressed as linear functions of count C by the following formulae:

  CSP = 7.0 (C+200)……..(1968 Standards)
  CSP = 8.0 (C+200)……..(1976 Standards)
  CSP = 8.5 (C+200)…… (1982 Standards)
  CSP = 9.2 (C+200)……..(2000 Standards)

- An early study at CIRCOT revealed significant variations in count and strength of yarn at different positions in the bobbin. It was found that yarns become finer from the top to the bottom of the bobbin in case of coarse counts up to 40s. Lea strength, on the other hand, showed a decrease on going from top to bottom of the bobbin in very coarse yarns up to 12s count. For finer yarns, no change was found in strength towards the bottom.

- In the early years of CIRCOT when the technology of cotton spinning was still in its evolving phase, it was felt necessary to identify conditions of humidity and temperature most suitable for yarn manufacture. Several studies were conducted at CIRCOT under

different conditions of ambient temperature and humidity in the spinning room. In dry, warm conditions development of static charge in fibres at ring frame was found to cause mutual repulsion resulting in hairy, weak and irregular yarn. CIRCOT had recommended humidity levels above 40% RH for spinning Indian cotton. Research had also shown that CSP of yarn increases by about half percent for every unit rise in RH% up to 70% RH.

- Fraudulent mixing (adulteration) by adding inferior cotton to a superior variety, common in cotton trade, can have adverse effect on spinnability. Detailed study at CIRCOT had revealed that yarn quality can deteriorate even by mixing a small proportion of a short staple cotton. An increase of 10% of the proportion of short staple variety may pull down the HSC by 3 units.

- It is customary in mills to mix two varieties because of technical and economic compulsions. Selection of varieties has to be made in a judicious manner. CIRCOT studies showed that the disadvantage of mixing a superior cotton with a short staple variety can be partly overcome by choosing the latter in such a way that it differs less radically from the former in respect of ribbon width, fibre weight, wax content and clinging power.

4.1.1. Blended Yarns

The new age of today is of blended textiles. Thanks to the availability of a plethora of man-made fibres, most of which are synthetic, the textile manufacture is predominantly of blended yarns and fabrics which combine the qualities of component fibres. The first man-made fibre to be blended with cotton was rayon in the early half of the last century. Some researches are highlighted here.

- It is interesting to note that CIRCOT had conducted pioneering work on blending rayon staple fibres with cotton as early as in 1937. This work had shown that blended yarns from cotton and rayon fibres have high extension, give fewer breakages during processing despite being weaker and show higher ballistic work of rupture. The yarns were found to be nep-free, lustrous and lower in irregularity.

- By 1970, polyester fibre had become a popular material for blending with cotton. Egyptian and Sudanese long staple cottons were preferred by Indian mills for blending with polyester. Merits of using Indian cottons for blending with polyester was assessed through a detailed study at CIRCOT in 1974. Results of the study confirmed the suitability of Hybrid-4 and Sujata for blending with polyester staple fibre. Blended yarns with at least 50% polyester were found to be strong, extensible, even and nep-free, matching with the quality features of blends with imported cottons. On the basis of these studies CIRCOT had recommended Hybrid-4 and Sujata for blending with polyester for 50s and finer counts respectively.

4.1.2. Combing of Cotton

Partial elimination of short fibres is a normal mill practice for spinning finer and better quality yarns from the same variety of cotton. Results of some combing studies are listed below.

- In an early study at CIRCOT on four cottons combed to extract upto 30% noil, it was possible to spin yarns of up to 80s count from cottons which were normally spun to 30s count carded yarn. These combed yarns were characterized by reduced neps, higher strength, lower irregularity and fewer breaks at the ring frame, making it possible to spin fine counts even in high draft system. It was demonstrated that cottons which were spinnable only to 30s count, after combing to the extent of 20% noil, could be spun to 50s and 60s counts.
- Combing studies were continued with several popular varieties of cotton in the early years and the benefits derived from different levels of combing were discussed in research bulletins for the guidance of spinning mills.
- In some miscellaneous trials, interesting results were arrived at. Spraying liquids like Syton on cotton at the card was found to increase yarn strength up to 12% on account of enhanced inter-fibre friction.

4.1.3. Air Jet Spinning of Indian Cotton

The first-ever spinning trials with Indian cottons on air jet spinning system was conducted by CIRCOT with Japanese partnership in the year 1995. Yarns of counts ranging from 30s to 60s using four Indian varieties were spun on both ring (RS) and air-jet spinning systems.

- The CIRCOT study revealed that air-jet spun yarns are lower in strength than RS yarns but possess higher elongation and better evenness.
- More significantly, air-jet yarns were found to have 70% lower imperfections (thick places, thin places and neps) as compared to RS yarns.

4.1.4. Spinning of Naturally Coloured Cottons

Since 1990 there has been interest among breeders to develop coloured cotton using the genetic stock available in the country. CIRCOT had teamed up with breeders to make fabrics out of the material harvested from experimental plots.

- Brown-coloured genotypes of 25 mm staple length, combined with acceptable strength and Micronaire, developed at Dharwar, could be spun to 32s count at CIRCOT. Knitted and woven fabrics made from the yarns served to demonstrate (a) the potential of coloured cotton and (b) the scope for commercial production of such cottons in the country.



Chapter 5

YARN CHARACTERISTICS

In the textile value chain, yarn forms the first conversion product of cotton fibre. The quality attributes of fibre and the processing style used in the spinning mill would determine the properties of the yarn. Principal yarn characteristics that define the technological worth of the yarn and the quality of the cloth woven from the yarn are its linear density (count), twist, strength, extensibility and evenness. Linear density is the weight per unit length of the yarn. Its units are tex for cotton and blended yarns, and denier for man-made fibre yarns. Tex is the weight in grammes of 1,000 metres of the yarn while denier is the weight in grammes of 9,000 meters of the yarn. Both these units of linear density are said to belong to the "direct" system. More popular unit of linear density for cotton and blended yarns is the count which represents the number of hanks, each of 840 yards, which together weigh one pound. Count belongs to the indirect system because higher counts go with lower linear density. A few other measures of linear density representing weights of different lengths were also popular in the 1950s and 60s but these are no more in use today.

5.1. YARN TWIST

Spiral disposition of fibres imparts form, compactness and strength to the yarn. Several physical and mechanical properties of the yarn are also dependent on the twist density referred to as the number twists per inch (tpi). Often two or more yarns are twisted together in a direction opposite to the twist in single yarns to form doubled yarns and plied yarns. The doubling twist of the plied and twist in component single yarns will together shape yarn behavior.

- CIRCOT has carried out researches on standardization of twist test methods such as straightened fibre method and untwist-retwist method for which ready machines are available. Performances of different machines have been critically evaluated at CIRCOT for the benefit of industry.
- Twist measurement on open-end (OE) yarns is challenging because of the peculiar lie of fibres in the body of the yarn characterized by wrapper fibres that make the untwisted state of the strand unidentifiable. A torsional equilibrium method evolved at CIRCOT has been found to be useful for OE yarns for which torsion-free state can be taken as the end point of untwisting.

5.2. YARN STRENGTH AND EXTENSIBILITY

Tensile strength (tenacity) expressed as breaking load per unit linear density is the most important characteristic of a yarn. Grammes per tex and grammes per denier are the common strength indices for single strands. For cotton and blended yarns, count-strength product (CSP) is also used as an index of tenacity. Extensibility of a yarn, otherwise known as breaking extension, expressed as a percentage of the original length, together with tenacity would mainly decide the durability and wear life of textile products.

Tensile tests are performed on single strands as well as on skeins of multiple strands. Testing machines are "Constant rate of traverse" (CRT) type, "Constant rate of loading" (CRL) or "Constant rate of extension" (CRE) type. Impact (ballistic) testers measure the energy (work) required to break the specimen. Important research findings in yarn strength studies at CIROT are listed below.

- Yarn strength increases with increasing twist, reaches a peak and then falls. Fibre slippage dominates at low twists while fibre breakage contributes more to yarn rupture at higher twists.
- When an optimally twisted yarn breaks, only about 60% of fibres would have been broken while the remaining fibres undergo mere slippage. At lower twists fibre breakage is less and yarn records low strength.
- Yarn breaks generally at thin places where the twist angle has the tendency to remain high.
- CIRCOT studies have further shown that twist multiplier (TM) required for maximum yarn strength decreases with increasing fibre length. In other words, longer varieties would demand only lower TM to maximize yarn strength.
- From an in-depth study of the influence of TM on yarn strength it was possible to estimate single strand strength of yarn of any specified count and twist from the known strength of the same count but spun with a different TM. Increase in single strand strength for an increase in TM from 4.00 to 4.25 was found to be 6% for yarns of counts from 16s to 40s. A change in TM from 3.75 to 4.00 increased the single strand strength by 6x(1.5)%; an increase from 3.50 to 3.75 by 6x(1.5)2%, a change from 3.25 to 3.5 by 6x (1.5)3%.
- The above study on single strands was later extended to leas (skeins) in which case too it was found that the percentage change in strength for an increase in TM from 4.00 to 4.25 remained at 6.0 itself. However, the factor whose geometric progression occurs in the relationship was found to be 2.0 instead 1.5.
- Another study on count, twist and yarn strength revealed that single thread CSP and yarn extension for a given TM decreased with increasing count.

- A study of the effect of machine speed variation on yarn quality showed that increase in spindle speed from 8600 rpm to 9950 rpm does not affect yarn quality whereas change in draw frame speed from 320 rpm to 475 rpm could reduce yarn quality.

- Another investigation on mercerization of cotton yarn showed that both slack as well as stretch treatment increased the single strand strength. However, tenacity showed no change with slack treatment on account of contraction of the yarn and the concomitant increase in its tex value. Stretch-mercerized yarn, on the other hand, being lower in tex value thus emerges with higher breaking load as well as tenacity.

5.2.1. Humidity Effects on Yarn Strength

Several studies were performed in early years on the influence of ambient humidity on yarn strength measured on single strands and skeins.

- CIRCOT studies have shown 15%--20% increase in yarn strength, both in single strand and lea tests, when the relative humidity of the room in which the yarn was conditioned and tested was raised from 35% to 85%. The actual increase was found to depend on factors like count, twist, the type of machine used, etc.

- Equations for predicting strength at the standard humidity of 65% RH from the data gathered at any prevailing humidity have been derived on the basis of extensive data by researchers at CIRCOT on many occasions in the past. However, though the findings were significant from a fundamental point of view, the conversion equations derived from these studies are of little value today because laboratories are invariably conducting tests in conditioned atmosphere of 65% RH and 27°C temperature as per standards.

5.2.2. Other Studies in Yarn Strength

- Extensive studies have been conducted on tensile strength and elongation of cotton yarns spun to different counts and twist levels. Also studied was ballistic work of rupture of both single strands and skeins, using commercially available machines subjected to certain modifications. These studies have revealed the complex relationships of tensile properties with structural characteristics like count, twist and humidity levels.

- Studies on the effects of spindle speed on yarn strength showed that lea strength and ballistic work of rupture, much like single strand strength, are not significantly affected by the increase in spindle speed up to 9950 rpm. Similarly, lea strength and ballistic work of rupture do not change with increase in draw frame speed up to 475 rpm.

- With the universal adoption of the metric system, skeins of 100 metre length of the yarn with 100 loops, each of 1 metre length became popular in the 60s of the last century. CIRCOT undertook comparative studies on the strength of leas and metric skeins and established that lea CSP is practically equivalent to yarn strength index (YSI) defined as

the strength of metric skeins in grammes divided by the tex value of the yarn. Of course, YSI was on an average 3% higher than CSP. For better precision in conversion from CSP to YSI, a regression equation had also been evolved.

- In 1966 with the switch-over of test length norm from 12 inch to 500 mm for single thread strength tests, following adoption of metric system, it was necessary to evolve a conversion formula. For this, several varieties of cotton were spun to 20s, 30s and 40s counts and single thread strength determined on the same instruments at the two gauge lengths. The test results were statistically analyzed to evolve regression equations to derive the strength at the gauge length of 500 mm from that obtained at 12 inch gauge length.

- In an effort to minimize the sample size in the skein test, which is destructive in nature, a study was conducted on skeins of different sizes ranging from 10 m to 150 m, including the standard metric skein of 100 m. The study revealed that 50 m skein can be considered satisfactory in respect of accuracy when sample availability is limited, as indeed is the case while evaluating genotypes in early stages of breeding trials.

5.2.3. Further Studies in Skein Strength

Skein strength is widely used in textile industry for quality assessment of yarn. The usual practice is to employ a lea of the yarn wound into 80 turns on a wrap-reel of 1.5 yard perimeter such that during test there are 160 strands of 27 inch length. It is well known that lea strength is less than 160 times the average single thread strength even through there are 160 strands taking part in the test. This is so because all the strands do not break even when maximum load is recorded by the machine. With the rupture of weakest strands, slippage occurs and redistribution of applied load takes place in a continuous manner following breakage of more and more strands. The number of strands actually breaking in a lea test is found to range between 5 and 35.

- A study was made at CIRCOT on the correlation of skein strength with the mean strength of the weakest groups of yarn obtained in single thread test. The means of the weakest 5, 10, 15, 20 and 25 strands as well as the sub-mean and mean in single thread test were correlated with skein test results.

- In the above study, all the means in single strand tests were found to be significantly correlated with skein strength. The mean and sub-mean had the highest correlation with skein strength.

- The breaking strength of skeins increased by as much as 10% as a result of knotting (looping) the skein at the hooks of the machine indicating reduced slippage and better participation of the strands in the rupture of the skein. Knotting of ends also raised the breaking extension of the skein by 20%.

5.2.4. YARN TEST IN BUNDLE FORM

In normal skein tests, about 50-60 specimens are required to be tested for accurate estimate of strength since the CV% is as high as 8% -- 10%. A study at CIRCOT showed that if test is carried out on yarn "bundles", instead of skeins, the variation (CV%) could be rendered negligible. Using a special device for making parallelized yarn bundles and clamps that could be mounted on skein tester, it has been demonstrated that even with 2 tests, accurate value of yarn strength can be obtained.

5.3. YARN EVENNESS

Irregularity in the linear density of the yarn affects both yarn appearance and yarn strength. What strikes the eye most is the irregularity in the thickness of short lengths of the yarn. Periodic irregularity is largely due to "drafting wave" while non-periodic irregularity results from machinery imperfections.

- CIRCOT has standardized a qualitative method to assess yarn evenness from visual observation of "yarn appearance boards" made by winding the yarn on black card board pieces of prescribed size and examining it under proper illumination. Seven degrees of evenness could be identified by comparison with standard appearance boards prepared by CIRCOT. The seven degrees are: Very Even, Very Even to Even, Even, Even to Fairly Even, Fairly Even, Uneven, and Very Uneven.

- Quantitative assessment of yarn irregularity is made by "cutting and weighing method" which, however, is slow and now largely out of use. Modern machine, the Uster Evenness Tester automatically tests long lengths of yarn to give indices like (i) mean deviation percentage of cross-sectional dimension referred to as U% (ii) number of thick and thin places and (iii) neps. The Uster Machine is also usable for testing regularity of sliver and roving.

- After extensive work on comparison of visual (qualitative) and instrumental (Uster) evenness indices, CIRCOT had in 1964 recommended four descriptive grades namely Very Even, Even, Average and Uneven each falling within specified range of U% values, as against the Uster company's suggestion of three grades such as Even, Average and Uneven. Further, the U% values recommended by CIRCOT were higher than the strict norms set by the Company. CIRCOT felt that the high standard of evenness set by Uster might not be maintained by Indian mills, equipped as they were with old spinning machines at that point of time.

- In a study of mixing of two medium staple cottons it was found that the proportion of the inferior component up to 25% did not reduce evenness when the yarn count chosen was within the spinning capacity of the two varieties as judged from yarn strength. On the other hand, when the mixture was spun to a finer count, even 25% proportion of the inferior variety could adversely affect yarn evenness. In case the superior variety forming the major components was much longer than the inferior cotton, yarn evenness

was significantly reduced even when the count was within the spinning capacity of the mixture. These results were seen as valuable findings with potential for use in day-to-day mill practice.

- Extraction of at least 20-25% waste at the comber is essential to spin 40s and 60s yarns of acceptable evenness as shown by a study at CIRCOT. Lower levels of combing would not make the yarn better than carded yarn.
- Yarns spun from double roving with double draft have higher evenness than those spun from single roving with normal draft, as found in another study.
- Neither an increase in draw frame speed from 320 rpm to 475 rpm, nor an increase in spindle speed on ring frame from 8,000 rpm to 10,000 rpm has any adverse effect on yarn evenness, it has been confirmed by trials at CIRCOT.
- Studies have also revealed that irregularity increases slowly at speed frame while marked increase occurs at ring frame.
- Studies on mercerized yarn showed that irregularity (U%) increases on alkali treatment with or without stretch. However, visual method (yarn appearance board) showed the opposite trend. Possible reasons for this divergence have been discussed.
- More irregular yarns have lower strength and higher strength irregularity. Conversely, yarns having more variation in strength are bound to record low levels of evenness.

5.4 FIBRE PROPERTIES AND SPINNING PERFORMANCE

Several studies have been conducted at CIRCOT to assess the dependence of spinnability of cotton on fibre attributes. Mean length and fibre weight per unit length (Micronaire) are found to have strong correlation with HSC while other fibre properties do not have significant influence on spinnability. Regression formulae to predict HSC from mean length and fineness have been worked out for different length groups and for each species of cotton. Some highlights are noted below.

- Many studies have shown that prediction of spinnability is better when regression equations are worked out separately for each cotton species instead of using a single formula for all botanical groups.
- Quite a number of studies on prediction of spinnability from a combination of fibre characteristics such as length, length variability, fineness, strength and maturity have been carried out using several varieties of cotton covering wide ranges of fibre quality levels. Analyses of multiple and partial correlations, however, did not lead to improved accuracy in predicting spinnability from fibre characteristics. Effects of individual fibre properties on yarn strength are extremely complex. For example while fibre maturity is a desirable quality for good yarn strength, it was found to be an asset for only shorter cottons which are inherently coarser too. In many studies, fibre fineness was found to be

more important than length and in some cases fibre strength was also a major factor for assessing spinnability.

- One other study had shown that fibre characteristics like length, fineness, strength, maturity and length irregularity have a greater effect on yarn strength than on the irregularity of yarn strength. This has been so because yarn strength is mainly governed by the presence of thick and think places which are produced by processing and machinery inconsistencies.

- A rigorous statistical analysis in a more elaborate study on as many as 50 cottons spun to 20s and 30s counts had shown that fibre length, fibre weight and fibre strength contributed most to yarn strength. On the other hand, yarn strength irregularity (a parameter defined by CIRCOT researchers) appeared to be influenced by fibre length but not by other fibre properties. This result led to the inference that yarn strength irregularity is more governed by processing conditions than by quality aspects of the fibre.

- From a detailed study of the complex roles of fibres of different length groups in single strand breaking tests, it has been revealed that longer fibres contributed more to yarn strength. Fibres shorter than about 23 mm merely slipped during yarn rupture while longer fibres developed tension and broke, establishing the fact that these longer fibres act as major contributors to yarn strength. The study had also yielded a regression equation to predict single strand CSP of yarn solely in terms of the percentage of fibres above 23 mm.

- Another study in 1964 involving as many as 40 cottons led to prediction formulae for HSC in terms of length and length variation indices from Ball Sorter and Fibrograph besides fibre fineness, each of which was found to be highly correlated with spinnability. Notably, fibre strength was not involved in the prediction formula as it had no significant correlation with spinning potential.

- The influence of fibre properties on yarn evenness has been a subject of detailed studies at CIRCOT. In two such studies involving scores of yarn samples spun to 20s, 30s and 40s it was revealed that length variation indices like CV%, SF% and UR% contribute more to yarn irregularity than do indices of central values of fibre length like mean and 2.5% span length. It is also significant to note that fibre fineness seemed to have no association with yarn irregularity.



Chapter 6

FIBRE STRUCTURE

Extensive researches have been conducted at CIRCOT on the morphological and fine structural characteristics of cotton fibre, right from the early years of the Institute's establishment. Apart from studies of general features of the fibre in the raw state, investigations have also been carried out on the changes in structure occurring during the development period of the fibre inside the boll as well as changes brought about by chemical treatments. The tools in such studies included optical microscopy, electron microscopy (both transmission and scanning types), x-ray diffraction, infrared spectroscopy etc., for all of which the Institute is adequately equipped.

6.1. FIBRE MORPHOLOGY

From early years of inception, CIRCOT has been engaged in the morphological studies on cotton fibres including both growing and fully mature fibres. Highlights of significant research findings are enumerated in this Section.

- While still inside the boll, the cotton fibre is a tubular entity with circular cross section which, on boll opening, turns doughnut shaped as a result of desiccation. Distortion of cross-sectional shape is more in immature fibres which are characteristically thin-walled.

- Circularity C expressed as $C=4\pi A/P^2$ where A is the area and P is the perimeter of cross-section, is found to be the highest in cottons belonging to *G.arboreum* species, followed by those from *G.herbaceum, G.barbadense* and *G.hirsutum,* in that order. Within each group, mature fibres are found to be more circular than immature ones.

- Circularity varies along the length of individual fibres. From basal end to the tip of the fibre, circularity is found to improve.

- Swelling of cotton fibre in alkali (30% NaOH) in slack condition increases the circularity. Stretching during swelling improves the circularity further. Similar improvement is also noticed after swelling treatment in KOH (40%) and EDA (80%) too.

- Twists in cotton fibre, referred to as convolutions, develop all along its length when the turgid fibre dries up after boll opening.

- The number of convolutions per unit length of the fibre depends on the variety, and within each variety, mature fibres have more number of convolutions than immature ones. Varieties belonging to *G.arboreum* and *G.herbaceum* species have fewer convolutions and lower convolution angle while *G.hirsutum* cottons abound in this feature. *G.barbadense* cottons have intermediate values.

- An early study at CIRCOT had shown an overall correlation coefficient of – 0.73 between convolution angle and fibre strength in the case of *G.barbadense* cottons. The relationship, however, was found to be weak in other species.

- Contrary to expectation, it has been proved that the frequency of convolutions does not enhance or reduce the strength of yarn spun from the cotton. Nor does it in any way affect fibre or yarn lustre.

- The convolution angle is negatively correlated with fibre strength in *G.arboreum* and *G.barbadense* cottons. On the other hand, in *G.herbaceum* and *G.hirsutum* cottons, such a correlation is absent, suggesting that factors other than fibrillar orientation have greater influence on fibre strength in these two species.

- Interesting findings have been made on the origin of structural reversals (SR) in cotton which are regions where the spiralling fibrils reverse their direction from S to Z and vice versa. Reversals range in number from 2 to 28 per cm among cottons. Reversals are generally regarded as weak spots where breakage could preferentially occur when the fibre is stressed or stretched. This, however, is not borne out by experimental results. CIRCOT data on several cottons have shown that the number of reversals per unit length is neither correlated with fibre strength nor with the decrease in strength with increasing test length.

- More recent CIRCOT study by electron microscopy has shown that morphological deformities of different types present in cotton fibre are spots where breaks occur, justifying the absence of correlation between reversal frequency and fibre strength.

- An optical microscopic study of fibres removed from unopened bolls without disturbing the zig-zag manner in which they are constrained to remain during development had unfolded interesting facts about convolutions and reversals. The study revealed that during initial drying of the fibre, the points midway between adjacent bends begin to flatten into reversals on either side of which an equal number of convolutions also appear. These convolutions cannot be carried beyond the bend and thus their number on either side of a reversal is the same. Often the bend also is a reversal. These reversals at bends can be weak points because the inner portion of the bend would be necessarily shorter. Such a structural constraint would cause non-uniform distribution of stress when the fibre is loaded or stretched, causing early break.

6.2. X-RAY DIFFRACTION STUDIES

The spirally disposed fibrils in cotton are partly crystalline in places where the molecular chains display 3-dimensional order, and partly amorphous where this order is absent. The crystalline portions cause x-ray diffraction which can be exploited to quantify (a) the degree of orientation of crystallites with respect of the fibre axis and (b) the proportion of crystalline and amorphous celluloses in the fibre. Since molecular chains of cellulose are organized into thread-like entities called fibrils which are helically disposed in the fibre, the angle of helicity (spirality) is synonymous with the angle of orientation of crystallites with respect to the fibre axis. This angle of orientation measured as "40% x-ray angle" in the diffraction pattern of a fibre bundle is an index of fibrillar orientation. The spiral angle ranges from 20 deg to 35 deg in different varieties of cotton. Significant research findings are listed below.

- Early studies at CIRCOT had revealed significant negative correlation between 40% x-ray angle and fibre bundle strength, implying that varieties in which the helical angle is low, the fibre strength is high. In other words, closer alignment of fibrils parallel to the fibre axis makes the fibre strong.

- Like fibre strength, other properties like toughness and stiffness too are negatively correlated with 40% x-ray angle indicating that fibrillar orientation closer to fibre axis enhances toughness and stiffness too.

- An x-ray diffraction study on fibres from two different regions of the seed surface revealed that the chalazal end fibres are poorly oriented as compared to those from side regions. Observed differences in fibre strength between fibres from the two regions could be attributed to the differences in fibrillar orientation.

- In a study of convolutions and x-ray angle in different varieties of Indian cotton, CIRCOT scientists found strong association (correlation coefficient: 0.70) between convolution angle and x-ray angle, similar to the relationship reported on foreign cottons by workers abroad.

- A detailed study at CIRCOT found high negative correlation between x-ray angle on the one hand and single fibre strength and bundle strength indices on the other, large fibrillar inclination resulting in low strength. Unlike in studies by earlier works, a single regression line could be drawn from data on all four species of cotton.

- Single fibre and bundle strength data at short test lengths like zero and 3 mm showed good correlation with x-ray angle while single fibre strength at 10 mm test length was found to be unrelated to the x-ray angle. This result suggested that while at short test lengths, fibrillar orientation may primarily influence fibre strength, at longer test lengths the presence of structural weak links might play dominant role.

- Fibres in a given variety differ in strength depending on the linear density attained by them till the end of the development period. A CIRCOT study on developing fibres

showed that fibre strength increases with wall thickening up to some level and then remains constant during the remaining period of wall thickening. Linear density, on the other hand, keeps rising till the end of the developing period. As a result, tenacity which is the ratio of strength and linear density, first shows a progressive increase, reaches a peak and then declines, leading to the inference that cellulose layers formed in later stages of cell growth simply add to the weight of the fibre without contributing to its strength.

6.3. SPIRALITY OF FIBRILS IN COTTON

By virtue of optical anisotropy, the cotton fibre shows birefringence whereby refractive index for light polarized parallel to the fibre axis (n_e) is higher than the index for light polarized perpendicular to the fibre axis (n_o). The difference (n_e-n_o), referred to as birefringence is a measure of the degree of orientation of molecular chains in both crystalline and amorphous regions of the fibre. The spiral angle of the fibrils can be calculated from the birefringence. CIRCOT has made several studies on the birefringence of cotton fibres. Some results are highlighted here.

- One early study at CIRCOT had shown that if the convolution angle is subtracted from the spiral angle obtained from birefringence, one gets a constant angle of 24° for all cottons. This result led to the inference that all cottons might have the same spiral angle of fibrils in the original un-convoluted state of the fibre in the unopened boll, and that the differences found in the birefringence of normally dried fibres from different varieties are due to the unequal effects of convolutions.

- Tests on developing fibres showed that birefringence increases with wall thickening suggesting that fibrillar inclination tends to diminish in the inner layers (lamellae) of the secondary wall of cotton fibre.

- The above conclusion about decreasing spiral angle in inner layers is also corroborated by x-ray diffraction studies on developing cotton fibres. It was found that diffraction intensity of x-rays from a fibre bundle has a bimodal pattern characteristic of two crossed structures, in the yearly days of fibre development. As the cell thickens, the x-ray pattern gradually tends to be of a single mode. At the same time, the average spiral angle shows a decline, validating the inference that spirality diminishes in the inner layers of the cell wall.

- As mentioned earlier, there is an opinion among scientists that spiral angle could be equal in all varieties of cotton when the fibers are in the never- dried state inside the boll. Differences in x-ray angle found among dried fibers, according to this school of thought, are due to unequal influence of convolutions that form during the initial desiccation following boll opening.

- The above issue was put to test at CIRCOT in a later study made in two ways. In one, the convolutions were removed by swelling and stretching fibers from different varieties in

alkali. Although differences in x-ray angle among varieties diminished after the swelling-stretching treatments, some differences still persisted.

- In the other approach, the formation of convolutions was prevented by drying the fibers from unopened bolls through solvent extraction. Fibers thus dried, like the alkali-treated fibers in the first experiment, had diminished dispersion of x-ray angles, but some differences among varieties still remained.

- Both the trials thus led to the conclusion that some differences do exist in the intrinsic spirality of fibrils in different varieties of cotton even in the original convolution-free state inside the boll.

6.4. SEM STUDIES

Repeated studies have shown that fibre strength is the highest at zero test length and is largely governed by the degree of fibrillar orientation. At longer test lengths, the strength shows progressive fall attributable to the influence of weak places. Some SEM studies have thrown further light into this and related fibre behaviours.

- SEM scans have revealed the presence of eight types of what can be called morphological deformities in cotton fibers. The percentage fall in tenacity from 0 to 3 mm test length has been found to correspond with the number of deformities per unit length of the fibre. This result seemed to suggest that such morphological deformities are presumably weak spots the presence of which can cause rapid fall in strength with increase in test length.

- Another SEM study of fibre bases embedded in seed coat revealed that *G.arboreum* and *G.herbaceum* cottons have broader bases as compared to cottons belonging to *G.hirsutum* and *G.barbadense.* The size of the fibre base would logically influence the effort needed to pull out the fibre and would thus determine the energy required for ginning cotton. The comparative ease of ginning *G.barbedense* cottons could be attributed to the small size of fibre base in these varieties.

- Fibre base study by SEM has also shown that micropylar fibers have larger bases than those in the side and chalazal regions, validating the well- known fact that fibers of the former group are hard to separate from the seed.

- Swelling and stretching treatments using certain chemical reagents cause changes in physical, structural and mechanical properties of cotton. Several studies have been undertaken at CIRCOT with different swelling agents like NaOH, KOH, ZnCl2, EDA, etc.

- Treatments with these reagents at optimal concentrations, temperatures and duration are found to cause increase in tenacity (up to 50% at 3 mm test length), a similar increase in strength uniformity ratio (SUR), diminution in crystallinity and considerable

increase in fibrillar orientation marked by reduced x-ray angle besides improvement in cross-sectional features, lustre, etc., under specific conditions.

- Cotton fibers are made up of micro-fibrils which comprise well-ordered as well as poorly ordered aggregates of cellulose molecular chains. Early SEM studies at CIRCOT had shown that fineness of cotton can be traced down to the micro-fibrillar level. A coarse variety is found to have thick micro-fibrils while a fine variety has fibers with thin micro-fibrils. A quantitative study undertaken later revealed that a coarse variety of cotton of 230 millitex possessed microfibrillar dimensions of 230Å width and 85 Å thickness while a fine variety of 150 millitex was found to have these dimensions as 120Å and 30 Å respectively.

- Another CIRCOT study employing SEM has revealed interesting facts about structural reversals observed after swelling the fibres in zinc chloride. Two types of reversals are found. One type has fibrils of the same fineness on both sides of the reversal while the other type has fibrils of two different sizes (thickness) on the two sides. Abrupt change in fibril thickness could render the latter type of reversal a weak point in the fibre.

- Electron Diffraction technique has been employed at CIRCOT to study lateral order within microfibrils. Various operational parameters of the electron microscope were standardized for ED studies on discrete microfibrils of cotton cellulose. Typical values of structural parameters evaluated from the ED patterns are: Crystallinity – 89%, Crystallite width – 72 Å, Crystallite length – 220 Å. Sharp reflections in the ED patterns have clearly revealed that cellulose microfibrils are highly crystalline and rod-like entities with high intra-fibrillar order.

6.5. MISCELLANEOUS STUDIES

6.5.1. Induced Cystallisation in Never-dried Cotton

Early researches at CIRCOT had demonstrated that never-dried cotton fibres have very high accessibility and reactivity, attributed to protofibrils imperfectly arranged. During the initial drying on boll opening and exposure of fibres to the atmosphere, the protofibrils aggregate and the chemical accessibility is reduced. Researches at CIRCOT have shown that slow drying of never-dried fibres under specified conditions can lead to a cohesive structure with 10%-15% additional crystallization, as confirmed by x-ray studies. Further, the resulting crystallites are highly ordered ones which resist acid hydrolysis. Tenacity and elongation are, however, the same as those of normally dried fibres.

6.5.2. Enzymolysis of Never-dried Cotton

Normally-dried cotton cannot be easily hydrolyzed by enzymes because of its highly crystalline nature. Taking advantage of the high accessibility of never-dried fibres (NDF) in the boll, CIRCOT attempted enzymatic hydrolysis to produce sugars. The study showed that NDF could be almost completely (96%) converted into reducing sugars within 6 hours of enzymatic treatment. Interestingly, 20% of the reducing sugar was glucose.

6.5.3. Strengthening Rayon by Swelling and Stretching

Normal rayon fibres and filaments are known for their low strength (2 g/d), poor wet strength (1.2 g/d), low crystallinity level (35%), high extensibility (20%) and moderate x-ray orientation factor (fx=0.80). All these properties can be improved by a swelling-stretching-neutralizing cycle standardized at CIRCOT for rayon filaments. Up to 55% stretch is found to be possible in this treatment that results in increased strength (2.4 g/d), reduced extension (10%), enhanced crystallinity (57%) and better orientation (fx = 0.89). Strength loss on wetting is significantly reduced.

6.5.4. Standardisation of Fabric Shrinkage Test

The BIS Shrinkage Test Method IS 2977-1964 was time consuming for routine tests as it demanded slow drying of the fabric after wash. After critical studies, CIRCOT recommended that the elaborate BIS method could be shortened as follows.

- The fabric specimen of 60 cm x 60 cm size could be soaked in tap water with a wetting agent for one hour. After soaking and dabbing with blotting paper the specimen could be dried for 3 hours in standard atmospheric condition or alternatively in an oven with air circulation for 30 minutes.

6.5.5. Permanent Pleats in Cotton Fabrics

Normally, cotton skirts do not retain stitched-in pleats after they are washed. A study at CIRCOT demonstrated that pleats can be made permanent by a simple process. The 3-step process comprises soaking in alkali, pressing between plates and neutralization. During wear, the skirt may develop wrinkles and the pleats may turn less sharp; but the pristine elegance will return when the skirt is again soaked in water and drip-dried.

6.5.6. Fabric Handle by Kawabata System

The aesthetic quality of an apparel fabric is known as "handle" traditionally assessed by subjective hand-and-eye methods. The Kawabata system of instruments permits objective estimation of fabric handle from measured values of properties like stiffness, smoothness, softness (compressibility) and stretchability by means of four instruments which together yield as many as 16 parameters from which Primary Hand Value (PHV) is found out with the help of equations specific to each end use such as winter/summer suiting, dress material, inner/outer wear, etc. From the value of PHV, an integrated index called Total Hand Value (THV), representing the overall aesthetic quality of the fabric, which can range from 0 to 5, is arrived at, making use of transformation equations meant for each end use.

- In one early study of fabrics by using the Kawabata system of instruments, it was revealed that summer suitings of more-than-average handle value (THV rating of 2)can be made from cotton by using coarse yarns in warp and weft so as to achieve a cloth cover of 20 or more.

- Another study on polyester-cotton blended fabrics revealed that for optimum realization of hand value, a polyester content of 60-80 % is desirable.

6.5.7. Fabric Comfort

Comfort aspect of clothing is receiving increased attention in textile technology. The efficiency with which air, moisture and heat are transported through fabrics decides the comfort one can attain with the clothing. CIRCOT had initiated some studies in this regard.

- An apparatus was designed many years ago at CIRCOT for measurement of moisture passing across fabrics. Studies showed that moisture transfer through cotton fabrics depends on the packing of fibres in the fabric structure. In polyester fabrics moisture transfer takes place through non-fibre spaces. In polyester-cotton blends, the transfer improves with increase in cotton content.

Chapter 7

CHEMISTRY OF COTTON CELLULOSE

Cellulose is the major constituent of plant matter. Wood and cotton lint are the main sources of cellulose. Cotton fibre is the purest form of natural cellulose containing as much as 94% to 96% of cellulose on dry weight basis. The molecule of cellulose is a linear polymer made up of anhydroglucose or glucopyranose units. Adjacent glucose rings are linked at 1-4 positions through glucosidic bonds. The number of glucose units in a molecule known as the degree of polymerization (DP) ranges from 300 in regenerated cellulose (rayon) to 5000 in cotton.

Properties of cellulose fibres are dependent on the structural modifications to which cotton and cotton textiles are subjected in industrial practice. The response of cotton to various chemical reagents assumes importance when efforts are made to improve the performance of textiles made from this fibre. Right from the early years of inception, CIRCOT has been engaged in researches on the chemical aspects of cotton and cotton textiles. Significant results are reported in this Chapter.

7.1. CHEMICAL CONSTITUENTS IN COTTON

The cotton fibre contains, in addition to cellulose (94%), small quantities of ash (1.3%), protein (1.2%), pectin (0.9%), and wax (0.6%), besides organic acids and sugars (2%). The proportions of the various cellulosic and non-cellulosic constituents show wide variation among different species and among different varieties in each species. Agronomic factors too influence the proportion of the constituents. Some CIRCOT studies on chemical constituents in cotton are highlighted here.

- Researches in 1947 had shown that the cotton grader's estimate of "feel" is in fact related to the wax content which ranges among cottons from 0.03% to 0.6%. A scale for estimating the feel of cotton (very silky, silky, slightly silky, roughish and rough) in terms of wax content was recommended by CIRCOT for the benefit of cotton trade.

- Several Indian cottons were analyzed for the presence of various constituents such as oxides of K, Al, Ca, Mg, Fe, Si and P besides ash content and wax that forms on the surface of the fibre.

- Changes in chemical characteristics of cotton fibre have been followed up during boll development. As cellulose deposition progresses, there is increase in cellulose content, DP and crystallinity alongside improvement in physical properties like maturity and fibre strength.

- Measurement of moisture regain and wax content of several varieties of cotton showed high negative correlation, highlighting the fact that wax acts as a physical surface barrier for the entry of moisture into the fibre.

7.2. CELLULOSE DEGRADATION

Polymeric degradation refers to the decrease in the degree of polymerization (DP) which in the case of cotton cellulose occurs when the material is acted upon by chemical reagents, micro-organisms and high energy radiations. Several studies on cellulose degradation have been conducted at CIRCOT in early years. The most common method of determining DP is the one based on viscosity of the solution of cellulose in cuprammonium hydroxide. Salient results are briefly discussed in this section.

- Experiments at CIRCOT had demonstrated that DP of cellulose in cotton fibres decreases from micropylar to chalazal region, with side region fibres showing intermediate values. Similar trends are also seen in fibre strength, maturity and fibrillar orientation too (matter discussed in Chapter 3).

- Early studies on the degradation effects of kier boiling on the properties of cotton yarn showed that the concentration of caustic soda in a pressure boil is not a critical factor as seen from fluidity measurements. Open boiling with soap and soda ash, on the other hand, causes considerable degradation and fall in yarn strength.

- Kier boiling with caustic soda up to 4% does not cause degradation of cotton, but beyond 4% there is significant degradation though yarn strength is not much affected.

- Bleaching with chlorine always lowers fibre strength and yarn strength.

- Swelling treatments meant to enhance the desirable qualities of cotton also bring about chemical degradation. CIRCOT researches on treatment of cotton with EDA, Ethylamine and aqueous solutions of NaOH, KOH, LiOH, etc. revealed that while improving the chemical accessibility of cotton, these treatments do invariably degrade cellulose and bring down fibre strength.

- High energy radiations have a prominent role in textile finishing which is rendered speedily and is technically much easier. Risk factor, however, is the degradation of the material. Effects of gamma ray irradiation on cotton were put to study at CIRCOT many years ago. Early studies had shown that cotton, raw or mercerized, undergoes rapid degradation and strength loss on gamma ray irradiation beyond 1 Mrad.

- Gamma ray treatment was also found to cause oxidation of cellulose. Oxycelluloses thus produced are oxidized at C-6 position as shown by CIRCOT researches.

- In the manufacture of sterilization products, any increase in radiation resistance would be an advantage. CIRCOT has conducted researches on the effects of chemical treatments on radiation resistance.
- Acetylation of cotton cellulose up to a DS of 1.6 is found to give protection against hydrolytic breakdown, but it increases the oxidative degradation caused by irradiation.
- Allylation of cellulose up to a DS of 1.25 is found to offer protection against oxidative breakdown even at high doses of gamma rays.
- Incorporation of aromatic benzyl and benzoyl groups in cellulose also is found to increase its resistance to radiation damage.
- A good deal of research on microbial degradation of cotton has been carried out at CIRCOT. *Pencillium funiculosum* isolated at CIRCOT can produce an enzyme 'cellulase' capable of rupturing hydrogen bonds in cotton cellulose.

7.3. DYEING OF COTTON

Researches in dyeing of cotton commenced at CIRCOT in the early years after its establishment and has continued till today. Several basic and applied studies have been made and impactful results arrived at by the scientists. The following findings are based on early researches in dyeing. More recent ones are discussed in Part 2 of this book.

- Many decades ago researchers at CIRCOT had designed a colorimeter to measure the residual concentration of the dye left over in the bath after treating the sample of cotton. The dye absorption capacity of the cotton fibre is then judged from the concentration of the leftover dye.
- Dye absorption percentage is found to vary among cottons, fine varieties picking up more dye than coarse ones. In each variety, dye absorption declines with increasing molecular weight of the dye.
- Kier boiling with alkali, under pressure, removes surface impurities of the fibre and opens up the pores, permitting easier access to dye molecules resulting in better uptake.
- Early researchers at CIRCOT had standardized a method to determine fibre maturity from the depth of shade of an acid dye. Mature fibres show lighter shades while immature ones pick up more dye. By comparison with standard reference shades prepared with cottons of known levels of maturity it has been possible to estimate the maturity of any unknown sample of cotton.
- Fraudulent mixing of superior quality with inferior ones for commercial gains is a well acknowledged fact. This practice was more common in olden days than at present. Methods to detect, and if possible quantify the extent of adulteration have been of interest to scientists of CIRCOT. Differences in fibre characters like length, fineness and

maturity were found to be not quite sensitive to detect and quantify the adulteration. On the other hand, dye uptake differences among cottons appeared more promising in as much as colour shades which looked notably different in potential adulterant varieties than in the good quality cottons being sold.

- A dyeing study on the comparative behavior of RS and OE yarns was made with a wide range of direct, vat and reactive dyes. Scoured and bleached yarns subjected to mercerization with and without stretch were included in the study. Dye uptake recorded consistently higher values in the case of OE yarns in all treatments. The comparatively more open structure of OE yarns must be responsible for this difference in dye uptake behavior.

- A study was conducted at CIRCOT to understand the impact of pretreatments on the dyeing behavior of knitted fabrics. Single and double jersey cotton fabrics were subjected to two alternative treatments: (i) direct bleaching (DB) and (ii) scouring and bleaching (SB). On dyeing, the DB fabrics showed higher colour strength values than SB fabrics. A particular enzyme treatment given to the SB fabrics enhanced the colour strength but no such improvement was found in DB fabrics after the enzyme treatment.

- Before the discovery of synthetic dyes natural colours alone were in use in textiles. The current awareness about pollution caused in the manufacture of synthetic dyes and the harmful effects on human health has revived interest in natural dyes. CIRCOT has conducted several studies on colouring of cotton with natural dyes.

- Lac dye known to colour only silk and wool, has been used on cotton by CIRCOT scientists. A violet shade has been shown to be possible if cotton fabric is pretreated with chitosan by a pad-dry-cure process. Wash-fastness could be improved by cross-linking or by mordanting with alum and ferrous sulphate. Mordanting gave different colours as well.

- Cotton could be dyed to a bright yellow colour with Berberin. Pre-treatment with tannic acid followed by tartar emetic was found suitable for restricting the temperature to 60 °C during dyeing. Mordanting with certain reagents could produce different colours and improve wash fastness property of dyed material.

7.4. DURABLE PRESS (DP) FINISHES

Notwithstanding their comfort characteristics, cotton cloths perform poorly in crease recovery, unlike synthetics like polyester and acrylic. Crosslinking cotton cellulose with nitrogenous resins has been an accepted treatment to improve crease recovery and the DP rating of cotton fabrics. The strength and wear life of treated fabrics are, however, considerably reduced. CIRCOT scientists have conducted several studies in DP finishing of cotton fabrics with minimal strength loss. Highlights of results follow.

- In an early study in which several Indian varieties were screened for their suitability for

cross-linking, it was revealed that cottons with high strength and elongation are better candidates for DP finishes, as judged from the superior retention of tensile properties.

- A 2-step poly-set process for crosslinking was standardized at CIRCOT. In this process, the cotton fabric is first treated with any of the chemicals such as DMEU, DMDHEU and MMF in the presence of zinc acetate or magnesium acetate to effect polymer deposition. In the second step, zinc nitrate is used as catalyst to initiate crosslinking. Fabric treated by the 2-step process has better wrinkle recovery and reduced strength loss as compared to those crosslinked by the conventional 1-step process.

- The acidic nature of catalysts used in crosslinking is known to cause considerable strength loss in cotton. To reduce the acidity of catalysts, mixtures of salts of strong acids with weak ones were used at CIRCOT while crosslinking with DMDHEU. Several mixed systems were attempted. The one comprising aluminium sulphate and weak acids like citric acid, glycolic acid and acetic acid of appropriate proportions at a curing temperature of 150 °C was found to produce fabrics with Wrinkle Recovery Angle (WRA) as high as 308°, yet retaining 66% of original strength. The process has been patented.

- Another catalyst system of aluminium sulphate and citric acid at a reduced temperature of 140 °C also gave a WRA of 300° and strength retention of 66%.

- Once awareness about health hazards associated with formaldehyde started growing, search for safer chemicals began. Glyoxal was one choice. CIRCOT carried out detailed study on crosslinking with glyoxal and explored different combinations of catalysts and curing temperatures. Use of aluminum sulphate mixed with aluminium ammonium sulphate was found to impart adequate wash-wear property (WRA: 205°) at low temperature (125 °C) with good fabric strength retention (65%).

7.5. FUNCTIONAL FINISHES

Development of functional finishes for cotton fabrics has been a domain where CIRCOT has done considerable research work. Anti-soiling finish, flame retardant finish and anti-microbial finish are the areas where significant researches have been carried out at CIRCOT.

7.5.1. Anti-soiling Finishes

Soil can get easily deposited in polyester and resin-finished cotton fabrics from which removal of soil is difficult. CIRCOT has developed finishes to retard soiling and enhance soil release during washing.

- In CIRCOT's finishing process, carboxymethyl cellulose is the principal reagent used, along with an N-methylol reagent or a non-formaldehyde crosslinking reagent.

- Certain fixing agents and silicon-containing softeners are also added to the system to ensure (i) durability of the finish against washing and (ii) reduce fabrics stiffness.

- The finish is confirmed to stay even after 25 washes and ensure a WRA of 300°, combined with a strength retention of 70%.

7.5.2. Flame Retardant (FR) Finish

FR technology for textiles advanced considerably during the latter half of the last century. Phosphorus-containing compounds have proved effective in imparting FR properties to cotton textiles. Several organo-phosphorus compounds have been synthesized and are available commercially.

- Many years ago, CIRCOT in association with Textiles Committee developed a cost-effective process that involved phosphorylation of cotton with urea and diammonium hydrogen orthophosphate together with an active polymer "Polysin" by a pad-dry-cure route. The new process appeared to hold potential for use with apparel and furnishing fabrics.

7.5.3. Anti-bacterial Finish

During wear, cotton textiles pick up various micro-organisms and act as substrates for their proliferation. Microbial activity spells health hazard for the user.

- Efforts were made at CIRCOT for evolving durable and safe anti-bacterial chemical finishes. Among them the method based on in-situ synthesis of peroxide complexes with selected cations in the matrix of cotton fibre showed encouraging results.
- The CIRCOT method involved pad-dry-cure treatment of fabric at high temperatures with peroxide compounds.
- Efforts were also made to create peroxide molecules within the matrix using high-energy gamma rays and electrons so as to avoid the direct use of this chemical and the pad-dry-cure step. The trials were successful.

7.6. ABSORBENCY OF COTTON

Many short-stapled and coarse varieties of cotton, unsuitable for textiles find use in the production of absorbent cotton. Figures of merit for absorbent cotton are higher 'water holding capacity' (minimum 23g/g) and low "sinking time" (below 10 sec). Many varieties belonging to *G. arboreum* and *G. herbaceum* species grown in India have potential to be used as absorbent cotton.

- CIRCOT has screened several varieties of cotton for their suitability as absorbent cotton. Suitable ones identified are those with micronaire value of 5-8 units and of staple length below 18 mm.
- Conditions for kier-boiling and bleaching of raw cotton for use as absorbent cotton have been optimized at CIRCOT. Kiering at 0.5% NaOH and bleaching with 0.5g/l of available chlorine would yield absorbent cotton meeting the requirement of British pharmacopoeia.

Chapter 8

BY-PRODUCTS UTILIZATION

Cotton seed and plant residue are byproducts of cotton cultivation with immense potential for commercial exploitation through appropriate technologies. Traditionally, cotton seed is crushed for oil, but wider use of different components of the seed has been awaiting development of newer technologies. CIRCOT researchers in recent years have evolved ways and means of utilizing seed components and plant residues to manufacture a wide range of products. It is to be acknowledged that the foundation for such researches was laid at CIRCOT in the early years of its establishment.

8.1. COTTON SEED COMPONENTS

Oil, linter, seed hull and the solid residue left after oil extraction referred to as "meal" have considerable commercial value in as much as these components can be used to manufacture a wide range of products. While oil can be put to both edible and industrial uses, linter is popular as a raw material for the manufacture of several chemicals including explosives. Hull is a supplementary roughage for cattle while the meal is a source of protein. Highlights of CIRCOT research on cotton seed components are listed out in this section.

- Early studies at CIRCOT had revealed that desi varieties (*G. arboreum* and *G. herbaceum*) have low seed index and kernel content while the new-world cottons (*G. hirsutum* and *G. barbadense*) have much higher ranges for these properties.
- As early as in 1965, scientists at CIRCOT had developed a simple and rapid centrifuge method for estimating oil content in cotton seed. In this method, finely crushed seeds are extracted with a solvent and the latter centrifuged to separate the oil.
- Higher seed weight in each variety of cotton generally goes with higher oil content, as per data gathered in early experiments at CIRCOT.
- Detailed cotton seed analyses at CIRCOT had revealed the presence of high oil content in seeds of *G. hirsutum* and *G. barbadense* cottons (15%-23%) as compared to seeds of *G. arboreum* and *G. herbaceum* cottons (12%-20%).
- Studies on the effects of agronomic treatments on the oil content in cotton seeds have

unfolded the beneficial effects of phosphorus and potash. However no such effect was found with copious addition of nitrogen in the manure.

- Samples of cotton seed oil from several varieties grown in the country have been screened at CIRCOT for their fatty acid composition specifying the quantitative presence of linoleic, palmitic, oleic, palmitoleic, stearic and myristic acids, with their content decreasing in that order, in all the varieties.

- Significant variations could, however, be found in oil content as well as in fatty acid composition of the oil from the same variety grown in different locations.

- During boll development, the oil content of seeds is found to increase gradually up to 40 days and remain almost constant thereafter.

- On storage, oil gets rancid due to oxidation. Studies have been conducted at CIRCOT to estimate the level of oxidation and enhance the shelf life of cotton seed oil with the use of antioxidants. Raw oils were found to have much longer shelf life than refined oils which became rancid in 3-4 months. Superior stability of raw oils is ascribed to the presence of gossypol which acts as an antioxidant. Some chemicals were also identified to prolong the shelf life of cotton seed oil.

- Thermal as well as oxidative stability of cotton seed oil was also studied at CIRCOT. It has been ascertained that oils with higher iodine value and higher percentage of polyunsaturated acids are thermally less stable than those with lower values for these parameters. The presence of natural anti-oxidants improves the stability.

- Linters are short fibres left on the cotton seed even after the removal of spinnable fibres by ginning. The percentage of linters varies between 8% and 12% of the weight of the ginned seed, depending on the variety.

- Linter content widely varies among varieties belonging to different species. *G. hirsutum* varieties have high linter content of up to 11% while *G. arboreum* and *G. herbaceum* cottons have only 4%-8%. *G. barbadense* cottons have naked seeds with practically no linters on ginned seeds.

- Early researchers at CIRCOT had standardized the conditions most suitable for bleaching cotton linters. A bleaching time of 1.5 hours and concentration of 1.5 g/l of available chlorine, at a pH of 8.5 were identified as optimal conditions for bleaching cotton linters.

- For an insight into the working of the Indian delinting industry CIRCOT conducted a survey of all the units in Maharashtra, undivided Andhra Pradesh and Karnataka. The survey served to identify the various constraints from which it was possible to make recommendations for improving the quality of Indian cotton linters.

- Cellulose content/yield is an important quality parameter that determines the market

price of raw linters. CIRCOT has devised a rapid method employing the Shirley Trash Analyser to determine the cellulose yield in raw linters. This method has since been adopted by the Bureau of Indian Standards as one of the accepted methods.

- One of the drawbacks of Indian linters is their high ash content due to the presence of trash comprising burrs, boll rinds, bracts, leaves etc. Among these, dry leaf bits are identified as the chief contributor to the ash from linters.

- The processing performance of linters from different varieties of cotton has been studied at CIRCOT. Parameters such as weight loss on alkali boil, viscosity of bleached linters, drop in DP on bleaching, brightness after bleaching etc. varied among varieties. The study also served to identify the causes of technical problems faced by processors and emphasized the importance of the selection of cotton varieties for extracting linters for different end use.

- Cotton seed meal left-over after oil extraction, contains protein to the extent of 45%-60% with good amino acid profile. At CIRCOT a process for preparation of peptone from cotton seed meal employing enzymatic hydrolysis was standardized by using two proteolytic enzymes, papain and pancreatin, in succession. Both the peptones were found to be on par with commercially available plant and animal peptones in respect of chemical properties. Microbial response to these peptones was found to be excellent. Patent has been obtained for this process.

8.2. COTTON WASTE UTILISATION

Cotton stalk is rich in cellulose and is similar to hard wood in fibre structure. Immense potential exists for its use as raw material for the manufacture of various industrially important products like particle boards, hard boards, paper of different grades, corrugated boxes etc. CIRCOT has conducted extensive researches on the utilization of cotton stalk for industrial uses and has developed viable technologies.

CIRCOT's researches on the pulping of cellulosic materials as early as in 1940s had laid the foundation for more elaborate work on the use of cotton plant residues for manufacture of pulp for different grades of paper. In an early work at CIRCOT in 1948, scientists had standardized the method of kier-boiling, bleaching and pulping cellulosic raw materials like bamboo and bagasse. Pulps from these materials evaluated for alpha cellulose content, ash content, viscosity, copper number, alkali solubility, lustre, etc., were found to compare well with imported pulps, indicating that bamboo and bagasse are promising raw materials for making paper pulp.

8.2.1. Paper from Cotton Stalk

Later studies at CIRCOT have shown that two types of paper pulps can be prepared from cotton stalk, namely soda pulp and kraft pulp.

- For soda pulp, cotton stalk is digested with NaOH (5%-15%) at 130°C for 90 min. The digested material is converted into pulp by mechanical refining and beating to the

required degree of freeness. The pulp can be used for preparing paper of wrapping and packing grades while writing grade paper can be made from bleached pulp.

- For kraft pulp, cotton stalk chips are digested with 15% kraft liquor ($NaOH+Na_2S$) at 20% sulphidity and 170 °C for 90 min. The cooked material after disintegration is beaten to get the pulp of desired freeness. Kraft pulp can be bleached to a brightness level of 80% using 6% available chlorine by a 3-step process comprising chlorination, alkali extraction and hypochlorite treatment. Kraft paper suitable for packaging purposes and superior grade paper for writing and printing can be prepared from this pulp.
- Corrugated boards (3-ply, 5-ply & 7-ply) can be made out of kraft paper prepared from cotton stalk pulp. These boards in turn are usable for making boxes for packaging fruits. The boxes are found to meet all BIS specifications.
- Chemi-mechanical pulp derived from bagasse, despite its merits in terms of higher yield, lacks in certain desirable properties for the improvement of which, about 25% chemical pulp from hardwood is usually mixed with bagasse pulp. Since the pulp from cotton stalk is similar to that of hardwood, the former is ideally suited for blending with bagasse pulp. CIRCOT studies showed marked improvement in the properties of bagasse pulp when it is blended with cotton stalk pulp.
- Preparation of pulp from cellulosic materials involves cooking in pressure digesters in presence of strong chemicals at 140°-160 °C for 2-4 hours. A novel biological anaerobic treatment procedure has been standardized for softening the cellulosic materials. The method demands only low concentrations of chemicals and cooking is restricted to just 30 minutes at 100 °C. Effluents generated are less toxic and hence the method is eco-friendly. The process has ben patented.
- One of the substances widely used in pharmaceutical formulations and in the paint industry is micro-crystalline cellulose (MCC). CIRCOT has standardized a procedure for preparing MCC from different agro-wastes like cotton stalk, bagasse and sisal fibres. Properties of MCC thus made such as particle size, crystallinity and bulk density are similar to those of commercially available MCC prepared from expensive wood pulp and cotton linters.

8.2.2. Hardboard from Cotton Stalk

A process was standardized at CIRCOT to make hardboard from cotton stalk. The process comprises chipping of cotton stalk, conversion into thermo-mechanical pulp, mat formation and pressing in a hydraulic press by a 3-step cycle to get hard boards. The process is ecofriendly as no chemicals are used in either pulping or in the binding process. Lignin present in the raw material acts as the binder. These boards find use in furniture making, room partitioning and panelling.

8.2.3. Particle Board from Cotton Stalk

CIRCOT has also developed the technology for making different types of particle boards from cotton stalk which can substitute timber.

- The process involves chipping of the stalk into particles of appropriate size, drying, mixing with binder, mat formation and pressing of the mat between heated plates of a hydraulic press to get boards. The hot-pressed boards, after cooling, are sanded on both sides to ensure uniform thickness. The boards can be made flame retardant, termite-proof and water resistant by using certain chemicals along with the binder. The boards thus made are of good quality meeting BIS specifications and can find use as table tops, window panel inserts, in wall panelling, making furniture, room partitioning, cupboards, etc.

- Major cost of particle board making is due to the binder. Attempts were made at CIRCOT to replace phenol resin with cheap binders from naturally occurring phenolic compounds from wood and bark extracts, cashew nut shell liquid and lignin products from paper mills. Almost 50% of phenol can be replaced by making use of such natural phenolic compounds.

8.2.4. Mushroom Crop on Cotton Stock

Agro-industrial waste mainly consists of cellulose, hemicellulose and lignin, all of which are collectively referred to as lignocellulosic materials. Mushrooms degrade lignocellulosic substrates through enzyme production and utilize the degraded products to produce their fruiting bodies.

- A method was standardized at CIRCOT to grow oyster mushroom (*Pleurotus* sp.) on cotton stalk. Chipped cotton stalk is wetted for 48 hrs together with identified activators. The material is steam-pasteurized at 70 °C for 8 hrs and spawned after cooling. Before spawn impregnation, the material is enriched with nitrogen by means of certain nutrients. It is possible to harvest about 500 g of fleshy fruiting bodies per kg of the stalk. With Bengal gram flour used for supplementation, the yield could be even doubled.

- An inexpensive pretreatment was also developed for growing Dhingri mushrooms on cotton stalks. The conventional hot water treatment of stalk before spawning is replaced with an inexpensive anaerobic microbial treatment at room temperature.

8.2.5. Fibre and Paper from Linseed Stalk

CIRCOT, under its agro-waste utilization programme has demonstrated the potential of agro-wastes from dual-purpose linseed (flax) crop.

- Parameters for retting of linseed stalk were standardized. The yield of the scutched fibre was around 25%. The study showed that industrial twines and yarns can be spun from flax using the jute spinning system.

- Detailed studies brought out the potential of the dual purpose linseed stalk for pulping and for production of good quality paper for writing, packing, etc.

8.2.6. Biogas from Willow-dust

The production of biogas from willow-dust, a cellulosic textile mill waste, was demonstrated for the first time in this Institute in the early years of 1980s. Use is made of a consortium of micro-organisms isolated by CIRCOT scientists for anaerobic digestion of the biomass. It has been possible to produce about 170 litres of biogas with 55% methane content from 1 kg of willow-dust in 30 days.

- An operational plant was set up in a textile mill in Mumbai to produce biogas from willow-dust in 1984 with a capacity to digest 24 tonnes of the mill waste per month. The plant produced about 250 cubic metres of biogas from 1 tonne of willow-dust in 60 days.
- The process of biogas production from willow-dust was further improved by employing a mixed microbial consortium. It has been possible to produce as much as 600 cubic metres of biogas from 1 tonne of willow dust in 60 days. An outstanding feature of this process is that the microbial culture works efficiently even at temperature as low as 20 °C.
- This process has been patented by CIRCOT.
- The CIRCOT technology could be extended to process press-mud, a waste material available in abundance in sugar factories.

8.2.7. Recycling of Newspaper Waste

De-inking of newspaper waste meant for recycling is generally done by chemical methods. A novel method of de-inking by means of cellulase enzyme was developed at CIRCOT. Cellulase hydrolyses cellulose and releases the ink.

- The enzyme-treated pulp is washed to remove the ink. The de-inked pulp is quite white in colour though slightly inferior in mechanical strength which, however, could be restored by mixing fresh pulp from other cellulosic materials or by adding guar gum.
- This process has also been patented.

8.2.8. Super-absorbent Polymers

A new class of polymers prepared from polyacrylates, referred to as super-absorbent polymers (SAPs), can absorb large quantities of water and retain them in their matrix. SAPs capable of absorbing water up to 300 times the weight of the material have been synthesized by researchers abroad through graft co-polymerisation of acrylonitrite with the polymeric matrices of natural polysaccharides such as those derived from corn, tapioca, jowar etc. At CIRCOT effort was made to use naturally occurring polysaccharides for SAP by a process in which a very low level (0.3 Mrad) of gamma irradiation was employed to initiate polymer reaction, instead of toxic ceric salts used in conventional processes. When employed as soil amendment, CIRCOT's SAP was found to effect manifold increase in water holding capacity of the soil and also modify its drainage characteristics.

Chapter 9

BIOCHEMICAL PROCESSING OF COTTON

Microorganisms are ubiquitous in nature. Their role in both harmful and beneficial aspects with particular reference to cotton and its by-products including waste utilization has been put to study at CIRCOT where a few useful technologies have been developed over the years.

9.1. BIOSYNTHESIS OF CELLULOSE

Even through cellulose is one of the most abundant polymers available in nature, the mechanism of its synthesis is not fully understood. Research at CIRCOT has shown that a single cell system like *Acetobacter xylinum* when grown in a medium containing glucose as substrate could synthesize cellulose, the chemical properties of which are similar to those of native cellulose.

9.2. CONTROL OF COTTON ROOT WILT

Pot culture studies were conducted at CIRCOT to explore the possibility of controlling root wilt caused by fungal phytopathogens in cotton by amending the soil with prawn shell waste containing about 25% chitin expected to promote *in situ* growth of chitinase-producing microorganisms and thereby arrest the proliferation of pathogenic fungi. The study yielded encouraging results in disease control.

9.3. PRODUCTION OF FUNGAL CELLULOSE

A highly active thermostable fungus *Penicillium funiculossum* F4 was studied in detail at CIRCOT. Various cellulosic waste materials were incorporated in the medium as carbon and nitrogen sources. It was found that alkali treated linters, jute stalk pulp, bleached newspaper waste, rice husk, cotton stalk and saw dust gave encouraging results. Ammonium phosphate and tryptone used as nitrogen sources as well as common oil cakes especially their hydrolysates stimulated the production of the enzyme. The method of producing cellulase has been patented by CIRCOT.

9.4. DESIZING OF FABRICS

An enzymatic method was standardized for desizing of fabrics sized with tamarind kernel

powder (TKP) and low viscosity TKP, using cellulase enzyme from *P. funiculosum* F4. Desizing in this manner is found to be more efficient than the soda boiling method used in industry and has no adverse effect on fabric strength. This process too has been patented.

9.5. ANAEROBIC DIGESTION METHOD FOR RUMEN DIGESTIBILITY

The digestibility of cellulosic materials is normally estimated by undertaking actual feeding trials on ruminants. When several research samples are enriched by chemical or biological methods, it becomes difficult to carry out actual feeding trials. CIRCOT has standardized a method that employs anaerobic digester. The advantage is that several small samples can be tested at the same time, and thus reduce cost.

9.6. USE OF CELLULASE IN TEXTILES

Cellulases are extensively used in textile mills for biopolishing of fabrics which is a process in which the enzyme hydrolyses surface fibres on the fabric and brings about improvement in fabric qualities such as reduction of fuzz, pill formation, increase in softness and lustre, etc. Fabrics treated with *P. funiculosum* cellulase produced by CIRCOT method are found to be comparable in properties with those treated with commercially available cellulases.

9.7. AMYLASE FROM BACILLUS SUBTILIS

Amylase finds wide application in de-sizing of textile fabrics prior to finishing treatments.

- Several micro-organisms producing amylase have been isolated at CIRCOT. Among them *Bacillus subtilis* 159 was found to be active at 60°C and at a pH of 6.0.
- Alpha amylase from *B. subtilis* was found to be suitable for the preparation of low viscosity starch for sizing, as well as preparation of adhesives and corn syrups.
- Another CIRCOT study had shown that amylase produced by *B. subtilis* 159 is as effective as commercially available amylases for the removal of starch, and it can be readily accepted by the textile industry. The process is ecofriendly, unlike the traditional acid treatment.

9.8. MICROBIAL CONTROL OF COTTON STICKINESS

Stickiness is one of the problems that affects processing of cotton during ginning and spinning. Stickiness is caused by aphids and whitefly infesting cotton plants resulting in the formation of a mixture of sugary compounds and sugar alcohols. CIRCOT has standardized an inexpensive microbial treatment for controlling the stickiness by spraying a mixture of bacteria recovered from never-dried cotton bolls.

9.9. MILL FEVER SYNDROME : BYSSINOSIS

Textile mill workers exposed to cotton dust often suffer from allergic mill fever syndrome popularly known as Byssinosis, caused by inorganic elements present in this dust. It is reported

that gram-negative bacteria *Enterobacter agglomerans* are the dominant gram-negative flora in cotton dust. CIRCOT study had shown abundant presence of bacteria in all parts of the plant except the lint. Bracts and bottom parts were found to have more bacteria than other parts. Most of the bacteria in the bracts are gram negative such as *Enterobacter, Beijerinckia* and *Methylobacter*. Of these, *Beijerinkia* was the most common. These are free-living nitrogen-fixing bacteria.

9.10. TOXIC ELEMENTS IN LINT AND PLANT PARTS

Cotton lint that reaches a textile mill contains inorganic elements particularly heavy metals, found in foreign matter such as plant parts that stay with the fibre. Some of these metallic elements are known to be hazardous to human health. An elemental analysis of plant parts and lint carried out at CIRCOT by using X-Ray Fluorescence Spectrometry (XRFS) revealed the presence of as many as 26 inorganic elements. Significant observations are the following.

- In general, the concentration of the metallic elements is much lower in lint than in other plant parts. Prominent among these elements include Na, Mg, Si, P, S, K, Co, Zr, Br, Ni, Cd, Ba. The last four elements are known to be the most harmful. These metallic elements come from soil as well as from fertilizers, fungicides and herbicides applied on cotton plant and seed.

- Analysis of processing wastes like cotton dust has indicated that the respirable dust generated in processing zones contains toxic elements in various proportions depending on the mechanical operation.

- Precleaning of kapas prior to ginning reduces particle size of plant parts already present in the cotton fibre, and these pulverized fragments get deposited on the fibre. During subsequent processing, the particles get dislodged and go into wastes and dust fractions, polluting the surrounding air.

- It was concluded that if collection of plant parts along with kapas at the picking stage could be minimized, there would be significant reduction in the concentration of toxic elements in the lint as well as in the respirable dust generated during processing. Clean picking thus assumes significance for a healthy atmosphere for workers in the processing zones besides enhancing yarn quality.

PART 2

Chapter 10

COTTON HARVESTING, GINNING AND BALING

Cotton is harvested worldwide either by hand or by machines, though in India, machine harvesting is still in the experimental stage. The harvested seed cotton has to be ginned before being exploited for various end uses. Quality-wise, Indian cottons are among the best in the world, but the methods employed for the processing have left much to be desired. Despite being harvested manually, Indian cotton has attained notoriety as trashy and contaminated with a wide range of foreign matter. Trash includes leaves, bracts and other plant parts besides dust. With the modernization of ginneries since year 2000 through Government intervention in the form of Technology Mission on Cotton, trash levels have come down but contamination still remains a challenge. Careless methods of transportation of cotton from the farm to the market and to the ginning factory and heaping of cotton in the open yards at both the market and the ginnery, are the obvious reasons for the hefty presence of contaminants in Indian cotton bales.

Keeping in view the importance of precleaning and appropriate ginning practices that would deliver good quality cotton to the textile industry, CIRCOT has carried out pioneering research work in the initial processing of cotton. Reduction of power consumption by ginning machines through replacement of bush bearing with ball-bearings in roller gins and conversion of double-action into single-action mode in single roller gins for improving the processing of long staple varieties, etc. were notable researches undertaken in the early years after the establishment of the Institute. All new varieties evolved in breeding centres across the country were subjected to pre-cleaning and ginning tests for identifying optimal conditions. Technical and economic surveys of ginning factories were conducted from time to time and measures for improvement of ginning in the country were suggested to the textile industry and the Government. Part 1 of this book has already outlined the early research work. Highlights of work carried out in ginning and related areas in recent years are presented in this Chapter. Major part of these researches relate to development of machines needed in pre-ginning and post-ginning domains, and investigative studies on connected issues.

10.1. COTTON HARVESTING AND PRE-GINNING OPERATIONS

10.1.1. Shoulder-mounted Power-driven Cotton Picker

As already stated, cotton is picked in India by hand and, to cope up with the increase in acreage

and production of cotton, coupled with diminishing rural work force, simple harvesting tools are felt absolutely necessary. At GTC of CIRCOT at Nagpur, a shoulder-mounted power-driven cotton picker was developed by assembling various components which were separately fabricated for the purpose and evaluated in the field. The new machine employs two counter-rotating brushes for gathering the kapas as the device is brought near the open bolls. The kapas is sucked into a tube with the aid of a sucking lance (used in sprayers and vacuum cleaners) and deposited at a convenient spot. The cotton picker is undergoing further refinements for improved performance.

In the meantime, a private company in Coimbatore, prompted by SIMA-CDRA, had developed a hand-held mechanical cotton picker based on the same design as the CIRCOT machine. The evaluation of the SIMA-CDRA machine was entrusted to CIRCOT. The efficiency of this machine was found in CIRCOT trials to be limited to 3.5 kg/hr as against manual picking rate of about 4.9 kg/hr. Further work at CIRCOT would aim at raising the efficiency further.

10.1.2. Tractor-operated Cotton Stalk Puller

Cotton stalk left in the field after harvesting can be put to many uses identified through researches at CIRCOT. Gathering the dry stems from the field is, however, a tedious exercise. To reduce the tedium, a simple machine has been designed at GTC. The device performs the combined operation of (a) ploughing, (b) uprooting the cotton plants and (c) conveying the stems towards cutting blades for chopping them into bits of the required size. The machine will be of help to farmers wanting to use cotton stalks for making value-added products.

As an adjunct to the above machine, industry has designed a cotton stalk shredder that chops the cotton stalks a few inches above the ground and cuts them into small pieces which can be loaded on a tractor trolley by means of an attached blower fan.

10.1.3. Cleaner for Machine-harvested Cotton

A cleaner based on sling-off action was developed at GTC for on-field cleaning of machine-stripped cotton that normally abounds in stem fragments and other plant parts. The Cleaner thus designed was integrated with the cotton stripper developed by CIRCOT in collaboration with CICR, and Mahindra & Mahindra Ltd.

Presently, the cotton stripper is being modified for enhanced efficiency and reduced trash collection during machine-harvesting. Appropriate modifications in the on-board cleaner too are contemplated to bring down the trash content.

10.1.4. On-farm Cleaning of Seed Cotton

A single-cylinder cotton pre-cleaner based on axial-flow principle for on-farm use was designed at CIRCOT recently. This cleaning machine consists of a cylinder assembly, grid bar assembly, top cover assembly, feeder assembly, mainframe assembly and power drive assembly, all mounted together on wheels making the machine portable. The appliance is able to effectively remove trash particles like leaves, bracts, kawadi and sand, besides fine dust, the elimination of

which is found to improve colour grade of kapas, without hurting fibre quality. The machine can clean seed cotton at the rate of 5-7 quintals per hour. The trash content in the seed cotton thus cleaned is as low as 1-1.5%.

10.1.5. Mechanization of Cotton Heaping

In order to facilitate easier cotton heaping operation in ginneries, a cotton loading-unloading machine was designed at CIRCOT. This machine consists of a flexible inlet pipe, casing, impeller, perforated flat disc, electric motor, GI flexible pipe and trolley. The impeller of the centrifugal fan was modified by incorporating a perforated flat disc to avert choking with cotton. Perforations of 3 mm were found to be optimum. It was possible to transport 30 quintals of seed cotton per hour. Attachment of a cone at the inlet side of the impeller increased the efficiency of transportation.

The original version of heap maker gave an output of only 25-30 quintals of seed cotton per hour. Modifications were carried out to increase the output by incorporating an open type impeller. A conical perforated disc was used in place of flat disc. With this, the impact forces on the disc got distributed uniformly avoiding heavy loading, and the effective suction area also increased two-fold thereby enhancing the output of the machine. With these modifications the output of seed cotton increased to 50-60 quintals per hour.

The above machine is still at the development stage in the laboratory. The industry is yet to appreciate the new concept. Efforts are on to highlight its merits.

10.1.6. CIRCOT Pre-cleaner

Over a decade ago, CIRCOT had developed an inclined type pre-cleaner for use in ginning factories. The machine has a delivery speed 30 quintals of cleaned cotton to meet the needs of a 24 DR gins set-up. CIRCOT Pre-cleaning machine is manufactured in collaboration with M/s Bajaj Steel Industries and marketed as "CIRCOT-Bajaj Pre-cleaner". Over 700 machines have been sold to ginning factories in India and abroad. The current annual sales rate is over 35 machines.

In order to assess the effect of cylinder type and saw band type pre-cleaners on trash content and lint quality after ginning, experiments were carried out with different varieties of cotton from the long-staple class. On an average, about 1 mm reduction in length was noticed in ginned lint if pre-cleaning was done by saw band type pre-cleaner. The harsh opening of seed cotton by saw bands might be the reason for this reduction in length.

10.1.7. Trials on Bajaj Boll Opener

In India, cotton crop is severely affected by pink boll worm attack, leading to increasing presence of kawadi in seed cotton received at ginneries. The ginning industry has been looking forward to find an efficient solution to process this material. Although research on processing of kawadi cotton is scant with no reported past data, some machines are available in the market for cleaning and opening of kawadi cotton. The machines, however, need to be tested, evaluated and optimized to improve their efficiency.

CIRCOT conducted performance evaluation of Bajaj Boll Opener in the factory premises of BSIL, Nagpur. The capacity of this opener for processing kawadi cotton was about 850 kg/h. Bulk density of raw cotton which was initially 134 kg/m^3 came down by nearly half to 73 kg/m^3 on passing through this Boll Opener, thus achieving adequate opening to make it ginnable. About 40% kawadi could be recovered for ginning, the rest going as losses through different mesh screens, dust and feeder splash-out. The opened kawadi was ginned on DR gin as well as saw gin. The lint recovery from the opened kawadi was marginally higher in saw gin (25%) than in DR gin (22%). Fibre test results from HVI on the lint thus obtained from the two gins, however, showed no significant differences.

10.1.8. CIRCOT Kawadi Cotton Opener

A new opener was designed at CIRCOT for processing kawadi cotton, comprising immature and infested seed-cotton separated in the pre-cleaning systems in cotton ginneries. This equipment is a modified version of Bajaj Boll Opener, and functions in a similar manner but meant to be used on kawadi cotton. In this machine, cotton bolls are opened by air turbulence. Opened and cleaned raw cotton is delivered at the discharge end. It recovers usable raw cotton from what is separated out by pre-cleaner as a waste material, that too without causing any damage to cotton fibres in the process. The machine with overall dimensions of 3.5 m x 1.5 m x 1 m, and weighing 500 kg, is powered by a 5 hp motor and has the capacity to process 6-8 q/h of raw kawadi cotton with a lint recovery of around 25%.

Commercial trials conducted with the Kawadi Opener have shown convincing results, and the ginning industry has evinced considerable interest in the machine. Licence for manufacture will soon be issued.

10.1.9. Performance Evaluation of Contamination Cleaner

A commercial model of seed cotton contamination cleaner was critically evaluated for its performance and potential utility in the Indian ginning industry. The machine has multiple cleaning sections such as foreign matter twinning section, leaf clearing section, and foreign matter separation section. The design features of the machine according to the manufacturer are: capacity-- 15 tonnesof seed cotton per hour; soft trash removing rate and residue film removing rate—over 80%. In the performance study made by CIRCOT, the contamination removal efficiency of the machine was found to be only 42% which is much lower than claimed. Deterioration in fibre quality was perceptible. Longer contaminants like nylon strips, threads, cloth pieces etc. were found to have got separated in the twinning section. Cotton leaf and small-sized foreign particles up to 3-4 mm were removed in the cotton leaf clearing section. Contaminants like plastic wrappers, tiny thread pieces and nylon strips could not be removed at all. Excessive single locking of cotton bolls and wick formation of output seed cotton were frequent. Good quality seed cotton was often found in trash chambers.

In order to improve contamination removal efficiency and avoid wick formation, modifications were carried out in different cleaning sections of the contamination cleaner. Changes in suction

and blower fans were carried out to adjust air pressure. Twinning section rollers were modified. The length of spikes was increased from 50 mm to 75 mm and the spike scheme was changed from zig-zag to straight pattern. Modifications were made in the twinning section and leaf cleaner section to reduce roller speed to 350 rpm from the existing 473 rpm by replacing the 6-pole electric motor with an 8-pole motor. Cleaning trials were carried out after these modifications but no improvement was observed in contamination and trash removal efficiency of this machine that also demanded a hefty 250 HP supply. The machine does not seem to hold promise as a cleaning equipment for ginneries.

10.2. GINNING AND POST-GINNING OPERATIONS

10.2.1. CLOY and Lilliput Gins

Cotton trading centres in the country need machines for ginning small samples of cotton for on-the-spot assessment of ginning percentage and fibre quality. Decades ago CIRCOT had designed what was referred to as Lab Model Gin which has been discussed in Chapter 2 (Part 1) of this book. More recently a newer model, the CLOY gin, with capacity to process as much as 7 to 8 kg of seed cotton per hour was designed. This sturdy machine uses a cast iron stand for housing the motor and the roller, and needs only single-phase electricity supply. From 1998, every year CIRCOT has been selling more than 10 units of this machine which is useful to the farming community, seed companies, cotton co-operatives and traders.

The Lilliput Gin, a tiny version of the CLOY gin, designed at GTC mainly for use by breeders and agricultural scientists, is portable, weighs only 15 kg and can be operated by a 2 HP motor to produce about 1 kg lint per hour. Several pieces of the Lilliput gin are in use in breeding centers in the country.

10.2.2. Digital Ginning Percentage Indicator

A portable digital ginning percentage indicator (DGPI) has been designed at CIRCOT for use in marketing centres. This portable machine is being developed on electrometrical principle for real time determination of ginning percentage of seed cotton.

The major components of DGPI are weight recording system, GOC-PLC set-up, software program, electronic display unit and accessories for integration with a portable cotton gin. Performance of the portable cotton gin with DGPI has been evaluated in terms of its functionality, ginning percentage, ginning output and fibre quality by means of test on several samples of cotton. DGPI was found to display accurate GP digitally on real time during ginning. The results were compared with conventional method of determining GP with portable gin. The new device is bound to accelerate GP-based trading of seed cotton in ginning industries and market yards, and thereby enable farmers to bargain for premium rates for their cotton with higher GP over, say, 34%.

A prototype of the DGPI is kept at GTC for demonstration to stakeholders, keeping in view the commercialization of the device.

10.2.3. HIPRO Laboratory Model DR Gin

This is a small-sized gin with the capacity comparable with that of commercial size DR gins. The machine was developed in collaboration with Visvesvaraya National Institute of Technology, Nagpur. The gin has the advantage of working on a single-phase supply with either a 2 or 3 hp motor, and can process about 50-60 kg of seed cotton/hr. This gin comes handy for evaluation of ginning out-turn, much like the CLOY gin. In addition, the lint thus obtained can be used for fibre quality tests, and the seed can be used for small-scale sowing for germination studies. This technology has been licensed to Precision Tooling Engineers, Nagpur, for commercial exploitation.

10.2.4. Single-locking Feeder for DR Gins

This machine was designed for use with DR Gins for improved ginning efficiency in terms of output and energy consumption, as compared to the conventional auto-feeders fitted in present-day roller gins. The new feeder design is based on the concept of single locking of cotton bolls. It consists of a pair of feed rollers, a pair of spike cylinders and grid bar housed in a feeder hopper and chute for cotton distribution on either side of the beater. Constant feeding rate of individual locules is maintained at the ginning point.

The speed of spike cylinder and the moisture content of kapas were optimized for long and medium staple cottons. Optimum spike cylinder speeds of 307 rpm & 297 rpm and cotton moisture levels of 7.5% & 7.2 % were arrived at for long and medium staple cottons respectively, using multiple regression analysis of data from extensive trials. The use of the new feeder was found to result in 22% & 25 % increase in ginning output and 12% & 13.5 % reduction in specific energy requirement for the two length categories as compared to conventional auto-feeder. Significant improvement in colour grade of cotton was evident while other HVI and AFIS fibre quality parameters remained unchanged. With these advantages the Single-locking Feeder would be a highly useful tool for ginneries. The device is being demonstrated at GTC, Nagpur to manufacturers interested in commercial production.

10.2.5. Optimizing Groove Profile and Roller Diameter in DR Gins

Roller grooving is performed in ginneries by using a marble cutter, once or twice a week, depending on the moisture level in cotton. It takes around 4-7 minutes for an operator to trim up grooves on one roller. The spacing, width and depth of the grooves as well as the number of grooves on each of the rollers should be constant and uniform for efficient ginning. CIRCOT study of ginneries revealed wide variations in the groove profiles with inevitable adverse impact on ginning efficiency and lint quality. The lint output is found to be a function of groove profile as well as roller diameter. By monitoring ginning output it was observed that the rate of wear of leather roller ranged from 0.03 to 0.05 mm/hr. During this interval, the reduction in ginning output varied from 7.3% to 12.8%. On the basis of this study, CIRCOT recommends that rollers in DR gins be replaced after 1000 hours of operation to ensure economic ginning.

10.2.6. Modified DR Gin

The power transmission system in the DR gin was redesigned to allow independent drives for the roller and the beater whereby any desired speed of the two components becomes possible. Through appropriate combination of the two speeds to suit each variety of cotton, it would be possible to maximize ginning efficiency.

In the new design, the crankshaft (also called as the main shaft) is connected to a flywheel having a pulley. Two V-belts provide the necessary transmission of power from electric motor to the machine. The speed of the roller can be varied with change of pulley attached to the crankshaft. The total planetary gearbox present in the existing design of double roller gin is eliminated. This will also preclude the need for grease/oil in the modified gin, thereby averting possible contamination of lint by lubricants.

Further, the hanging weights used for applying pressure on roller against fixed knife are eliminated in the present design by using a spring-loaded system attached to the main frame. This system incorporates a more scientific way of applying pressure evenly on the roller, leading to a more uniform wear profile for rollers. A simple mechanism is provided for dismounting the roller for routine grooving and maintenance tasks. Trials conducted on the modified DR gin have shown that a roller speed of 120 rpm and a beater speed of 1200 oscillations per min, at 7% seed cotton moisture content could give the highest ginning rate of about 89 kg/hr, an improvement of 62 %over the normal DR gin rate of 55 kg/hr.

The modified DR gin has been patented. Prototype machine is kept at GTC for demonstration to interested manufacturers.

10.2.7. Gin Trash Handling System to Control Pink Boll Worm

The pink bollworm (PBW) is a menace to cotton crop and cotton industry, and its eradication is a prime necessity. During ginning process, live worms escape through the gin trash, get dispersed in the neighborhood and find their way back into cotton fields. It is, therefore, necessary to interrupt the life cycle of the pest at the ginnery itself. A gin trash handling system was developed at CIRCOT to crush this material whereby all the boll worms could be destroyed.

The gin trash handling system comprises a blower fan, ducting, cyclone and compactor, and is designed for a capacity to treat 2.5 tonnes of trash per hour. A 20 HP blower fan generates an air flow of 4800 m^3/h and a pressure of 363 WG. The fan impeller has six straight blades rotating at a speed of 3000 rpm. The 1D-3D cyclone separates out air and trash passed through the blower fan. Gin trash compactor with 1 HP,1500 rpm electric motor drives a screw conveyor at a speed of 72 rpm. The ducting of 1 foot diameter provided at the inlet of the blower conveys the trash from blower to cyclone. The machine has been installed at GTC, Nagpur.

Performance of trash handling system has been assessed by testing cyclone fly waste, lint cleaner waste and pre-cleaner waste. The efficiency of the system in destroying bollworms has been confirmed from the 100% mortality of larvae and pupae in these trials. In one trial at CIRCOT,

the ginning performance of pink bollworm-infected cotton showed 17%, 14% and 11% reduction in ginning out-turn, fibre length and tenacity respectively besides significant deterioration in colour grade of lint. CIRCOT has recommended the use of this Gin Trash Handling System for preventing the spread of pink bollworm through cotton ginneries.

10.2.8. Rotary Tubular Drum Dryer

A rotary type tubular drum drier was designed at GTC, Nagpur for quarantining pink bollworm-infested cottonseeds. In this system, cotton seed is indirectly heated to about 65° C - 70° C for 5-6 min using thermic fluid as heating medium. The inlet temperature of thermic fluid can be safely increased to 200° C by controlling the boiler fuel feeding. Wet cotton seed introduced into the upper end of the dryer shell progresses through it by virtue of rotation of tubing system and the dried cotton seed is withdrawn at the lower end of the dryer. The major assemblies of the equipment are: bucket elevator, rotary joint, elliptical shell, tubing system, flights and lifters, moisture transport system, and cotton seed conveying and bagging system.

The dryer thus designed was able to reduce moisture content of the cotton seed by 6 percentage points by increasing its temperature to 65-68° C from an initial temperature of 26° C, which was sufficient to quarantine cotton seed against pink boll worm. However, the effectiveness of the dryer was not up to the mark for cotton seed having 18% moisture content as the maximum temperature attained by it was less than that required for quarantine purpose.

The above dryer machine has been licensed to M/s Bajaj Steel Industries, Nagpur for commercial scale production. At present, three dryer machines are in use.

10.2.9. Pneumatic Loading of Rollers in DR Gins

A pneumatic system was designed for pressing the roller against the fixed knife in DR gins to replace the hanging weights currently in use. The new system is found to reduce the vibration of the machine and at the same time ensure uniform ginning of cotton all along the length of the roller with marked improvement in the brightness of lint and decrease in nep count by 15%.

10.3. MISCELLANEOUS STUDIES

10.3.1. Trials with Rotary Knife Roller Gin

Rotary Knife Roller Gin (RKRG) is generally considered unsuitable for processing Indian cottons because of concerns about fibre neps and seed cuts. A study was made to examine how far these apprehensions are justified. A comparison was made of the performances of a commercial RKRG machine and a DR gin. The capacity of the former (425 kg lint /hr) was about six times that of the Jumbo DR gin (70 kg lint/hr). Other parameters of the RKRG were: rotary knife speed–400 rpm; feeder roller speed—16 rpm; pressure between roller and stationary knife—80 bar). Fibre quality test by HVI showed only marginal decrease in span length of the lint from RKRG, but UR, fineness and strength remained unaffected. AFIS results indicated 46% higher fibre neps (133 cnt/g to 250 cnt/g) and 36% higher seed coat neps (29 to 46 cnt/g) in rotary knife ginning in comparison with DR gin. Cut seed presence was found to be in the range of 2.8%

to 3.8 % and 0.4% – 0.8 % respectively for rotary knife gin and DR gin. The yarns spun from the lint lots, however, were similar in quality. The study thus demonstrated the need for caution while opting to use the rotary knife roller gin.

10.3.2. Database Management System for Ginneries

An efficient Database Management System for running a modernized ginnery was developed at CIRCOT. All the required parameters were identified and an Entity Relationship diagram was generated. Data entry forms were designed by incorporating suitable validations for proper data entry. All the forms have the facilities for clearing, updating, and saving data and raising queries about the data. However, the software needs to be refined further for adoption by potential users.

10.3.3. Bale Manager Software

A cotton bale manager software was developed to help design and generate a bale identification tag and to interface this bale tag with bale database management software so that it would be possible to generate customized labels for each and every individual bale containing factory's name, the press mark number, year of production, bar-coded bale ID and data on fibre attributes. Application of bale manager to generate barcode labels was found to be better than the conventional system of bale marking with ink.

10.3.4. GINERP for Modernized Ginneries

Another software for managing a modern ginnery, namely GINERP, has been developed in association with M/s SSPS, Hyderabad.In this software, the barcoding has been included as a bale management module. The GINERP software was intended to be of help in the management of men, material, machinery and finance in a ginnery. Although licensed to the collaborating firm for its manufacture, adoption by ginning industry has remained tardy.

10.3.5. Bale Tracking with RFID Tag

A bale tracking method was developed by attaching a unique RFID tag with one of the twelve cotton bale straps during the packing operation. Software was developed with features to record the mandatory parameters like Pressmark No., Year of manufacture, Lot Number, Bale Number and Weight and optional quality parameters like Grade, Variety, Fibre Length, Micronaire, Strength, Trash and Moisture.

This technology has not found takers till now. However, as and when the Govt. of India implements its cotton quality control order, insisting on fibre quality and other features of baled cotton in accordance with BIS Specifications (IS: 12171), the RFID Tag is bound to get traction.

10.3.6. Technical Manual for Ginneries

An exhaustive technical manual was prepared for solving trouble-shooting problems that occur during the operation of the entire system of machines in a modernized ginnery. Ways and means to maximize the efficiency and productivity of the machines are also discussed in the

book replete with illustrations.

10.3.7. Enclosure to Curb Dust from Gins

CIRCOT scientists have designed an enclosure system to arrest a major part of the dust generated in ginneries. Preliminary measurements had shown that 90% of the dust in the ginnery originates from the ginning point. The enclosure system developed at the Institute is able to arrest 80% of the dust originating from the ginning point.

10.3.8. Study on Noise in Ginneries

A study of noise levels in ginneries revealed that DR gins are the main contributors to sound pollution which, however, can be partly controlled by minimizing sound transmission and source isolation such as by employing proper enclosures for ginning machines. Based on the study, CIRCOT recommends that noise pollution act be enforced in ginneries for creating safe working condition for the staff. To protect workers from respiratory diseases, the amount of respirable cotton dust in the air must be limited. It is also recommended that those working in areas with high noise or dust levels should be provided with plugs or muffs and breathing aids such as dust masks.

Chapter 11

MECHANICAL PROCESSING OF COTTON AND OTHER FIBRES

The reader may recall that CIRCOT's work on the relationships between the spinning value/yarn quality and important fibre properties of cotton, processing techniques for Indian cottons, evaluation and comparison of new testing instruments, effect of the extent of variation of fibre properties on yarn quality, etc., were some of the important areas of technological research carried out at this Institute in earlier years, as highlighted in Part 1 of this volume. Particularly notable are the standardization of micro-spinning technique, definition of spinnability in terms of what was designated as the Highest Spinnable Count (HSC) and working out of regression equations for predicting spinning value of cotton from its fibre characteristics. All these have helped the cotton breeders to estimate the spinning potential of new strains being evolved by them through a multitude of varietal improvement programmes. The Spinning section of CIRCOT, in the first 75 years after the Institute's establishment, has thus contributed to the development of hundreds of genotypes capable of spinning yarns covering the entire range of counts (12s to 120s) needed by textile industry. This Chapter discusses CIRCOT's researches in the domain of spinning during the last 25 years. The work included studies in the processing of cotton and blends as well as machinery design and fabrication.

11.1. COTTON PROCESSING

11.1.1. Studies in Cotton Processing

The Spinning Division took up several studies to address the problems relating to quality improvement of spun yarns comprising both pure cotton and cotton blends. By the turn of the century the export market started demanding high quality yarns specifying the maximum number of faults permissible in the strand, following the stringent requirements set by sophisticated high-speed looms. The number of yarn faults thus needs to be kept at very low levels to ensure sustenance in the global market.

The mechanism of yarn faults originating from (i) trash (ii) fibre fly and (iii) spinning process was put to detailed study at CIRCOT. Of these, trash and fly together were found to contribute to about 88% of yarn faults. Further, it was found that higher carding rate in combination with higher draft set at spinning stage seems to increase all classes of yarn faults. The role of low-Micronaire and low-maturity cottons in contributing to yarn faults was also investigated. It was

found that faults of all classes including those of objectionable category increase sharply with the fall in fibre Micronaire value.

11.1.2. Low Pressure Splicing of Yarn

CIRCOT scientists have evolved a low pressure splicing technique for the production of better quality joints using commercially available splicing machines about which a mention was made in Part 1 of this book. The quality of a splice is judged by its retained strength as a fraction of the normal yarn strength, and by the visual appearance of the joint. Splice joints prepared by the low pressure technique in yarns of polyester and cotton, blended in the ratio of 50:50, were found to have higher retained strength in comparison with the joints made in yarns of other blends as well as those in pure polyester and cotton yarns. The retained splice strength was also the highest for ring-spun blended yarns as compared to rotor and air-jet spun yarns. For the latter two yarns, strength of splice joints were barely above half the parent yarn strength. Mill trials on the optimized settings at low air-pressure used in this study also proved successful. Spinning mills have been advised to follow this method.

11.1.3. Influence of Cotton Variety on Knitted Fabric Properties

In one study, single jersey fabrics were knitted by using 30s Ne yarns from 10 different varieties of cotton (DCH.32, G. Cot. 19, F-1378, Phule 388, Mech 1, Nav Bharat 151, Vikram, Surabhi, G. Cot. Hy. 6, G. Cot. Hy. 10). The fabrics thus made were tested for various properties so as to assess the comparative knitting performance of the varieties. Air permeability values of the fabrics lay in the narrow range of 101-115 cc/sec/sq.cm which did not appear to indicate any varietal dependence.

In a parallel study of wear comfort of the knitted fabrics, it was found that air permeability of the fabrics increases with increase in loop length. Further, lea CSP of the yarn was found to be highly correlated (r = 0.92) with the bursting strength of the fabric, leading to the following regression equation:

$$\text{Bursting strength } (kg/cm^2) = (1.32 \times 10^{-3} \times \text{CSP}) + 7.35.$$

This equation shows that every 1000 unit rise in yarn CSP improves the fabric bursting strength by just 1.32 units.

The performance of yarn in the knitting machine was judged by the number of defects in the resultant fabric from each variety. It was found that Bunny performed better than all other varieties and the poorest knitting performance was observed in the case of G. Cot. Hy 6. In the latter case, trash particles were found to be left in the fabric in large numbers. The least number of trash particles was found in the fabric made out of Nav Bharat 151 cotton. Interestingly, the correlation between trash percentage in cotton and trash particles in grey knitted fabric was found to be very low (r=0.31, p=0.38) and non-significant.

11.1.4. Computer Program Based on Artificial Neural Network (ANN)

An ANN model was developed for predicting the quality of ring spun cotton yarn from data on

fibre properties. This model is in turn incorporated into a graphical user interface computer program. This computer program can be used to optimize cotton selection by mills leading to reduction in production cost. It can predict yarn properties such as yarn evenness (U%), thin places per kilometre (-50%), thick places per kilometre (+50%), neps per kilometre (200), yarn tenacity (at test speed of 500 metres/minute), yarn hairiness (hairs above 3 mm length), lea CSP and highest standard count. The agreement between prediction and observation has been found to be good. The ANN model was compared with multiple regression model, and in case of lea CSP prediction, the mean absolute error (MAE) is found to be less by 50% for data set consisting of 23 different cotton varieties, fibre properties and 90 yarn characteristics data set.

11.2. BLENDING OF COTTON WITH OTHER FIBRES

Blending fibres of different origins and quality characteristics is a common practice in textile production. Mixing cotton with man-made fibres like rayon and polyester in order to combine the dissimilar qualities of the components, and at the same time make up for the deficiencies in each of them, renders the fabric and apparel more acceptable to consumers. Blending cotton with other natural fibres like ramie, jute, wools, banana stem fibre etc., is interesting from the standpoint of diversifying the utility of these fibres, some of which at present are not fully exploited. CIRCOT has carried out researches in the standardization of the methods of processing some natural and man-made fibres on the cotton spinning system to produce blended yarns of satisfactory levels of quality. Highlights of the work are discussed in this Section.

11.2.1. Cotton-Wool Blends

This study taken up in collaboration with Central Sheep & Wool Research Institute (CSWRI), was intended to ferret out appropriate use for indigenously-developed short wool fibres for textile applications through short staple cotton spinning route. As the indigenously-developed Avivastra wool and Angora rabbit hair are shorter in length and finer, as compared to normal wool, they are not amenable to processing through the long staple woollen and worsted spinning systems. Therefore, blending of cotton with these two variety of wools was attempted at CIRCOT by taking recourse to the cotton spinning system available at the Institute and thereby develop value-added products.

One indigenously developed crossbred wool, Avivastra wool was successfully blended with DCH.32 cotton and spun on both ring and rotor spinning systems. It has been ascertained from these trials that Avivastra wool can be blended up to 40% for production of yarns of 16s and 20s Ne on ring spinning system and up to 30% for production of 16s Ne yarns on rotor spinning system. Full-scale spinning trials of the optimized blends carried out on commercial spinning machines were quite successful. About 150 metres of fabric with a width of 1.3 metres were produced on a power loom. The feasibility of blending Avivastra wool with cotton has been thus demonstrated by the study.

In another parallel study, Angora rabbit hair was blended with Suvin and DCH.32 cottons for spinning 40s yarns suitable for knitting. The rabbit hair blended well with Suvin cotton and

produced yarns of better quality compared to similar yarns produced from blends with DCH.32. The knitting performance of both the blended yarns was satisfactory. The tertiary blend of cotton, rabbit hair and polyester fibres with equal proportions produced knitted fabric of better bursting strength and low shrinkage properties. The study has confirmed the potential of Angora rabbit hair too for blending with cotton.

11.2.2. Cotton-Ramie Blends

Normally, ramie is blended with manmade fibres such as viscose and acrylic, and with natural fibres like jute, silk, muga, tussar, etc., on jute or flax spinning systems. However, blending of ramie with cotton on short staple spinning system is little known about. Such blending would promote the development of textiles with better functional properties by combining positive features of both the fibres. CIRCOT has successfully processed cotton-ramie blends on the cotton system to produce ring spun yarn of 30s Ne with a blend ratio of 65:35, using chemically degummed ramie. Air-permeability of cotton- ramie blended knitted fabric was higher than that of 100% cotton fabric indicating the suitability of cotton-ramie blends for use in apparels. Higher absorbency of blended fabrics also indicates their suitability for use as towelling and other dress materials.

11.2.3. Cotton-Polyester (Micro-denier) Blends :

With the advent of micro-denier fibres (<1.0 denier), the count limit for rotor spinning can be raised appreciably, as there would be more number of fibres in the yarn cross-section. Besides, the problem of harsh feel characteristic of rotor yarns may be reduced by the use of micro-denier fibres, as they are known to produce fabrics with soft and silk-like appearance. An attempt was made at CIRCOT to explore the feasibility of production of finer rotor yarns utilizing micro-denier polyester in blends with cotton (67:33) to produce shirting fabrics. The trials showed that blended rotor yarns as fine as of 12 tex with adequate quality levels could be spun. Fabrics woven from these yarns were tested for low stress mechanical properties on the Kawabata Fabric Evaluation System. The results amply demonstrated the suitability of rotor yarns spun from blends of micro-denier polyester with cotton for making high quality shirting fabrics.

11.2.4. Cotton-Nylon Core Spun Yarn

Bi-component industrial yarns for varied end uses have been developed at CIRCOT by employing the new core spinning technology also known as Friction Spinning. Core-spun yarns, with nylon as core and cotton as sheath, of different counts,were spun by using the friction spinning machine. It was noted that the cotton component in the sheath confers a soft feel to the textile, and ensures very good bonding with rubber compounds when composites are made, thus helping conservation of chemicals required in the process.

11.2.5. Cotton-Polylactic Acid Blends

Cotton and polylactic acid (PLA) fibers were blended to produce yarns of 14.7 tex (40s Ne) with two different blend proportions 65:35 and 80:20 and the yarns thus spun were converted into

knitted fabrics. Blending of PLA fibres with cotton improves the moisture management properties of the resultant fabric. The higher one-way transport capability coupled with higher spreading speed and bottom absorption rate was found to result in higher Overall Moisture Management Capacity (OMMC) value for cotton-PLA 65:35 fabric. With a cotton-PLA blend of 65:35 proportion, improvement in moisture vapor transmission to the extent of 14% has been observed in comparison to pure cotton (100%) fabric. The thermal conductivity, insulation, and warm–cool feel values of blended fabrics ranged evenly between the 100% cotton and 100% PLA fabrics. The cotton-PLA blend proportion of 65:35 seems to be ideal for producing fabrics that require higher moisture transport such as those meant for sportswear.

11.3. MINIATURE COTTON PROCESSING MACHINERY

Textile machinery industry is already at the crest of developments. Modern processing systems including ring, rotor and friction spinning machines, as well as shuttle-less weaving systems like air-jet, water-jet and Rapier looms are ubiquitous in textile industry. There are several manufacturers for these machines worldwide. However, miniature spinning machines that have application in cotton breeding research and village level micro-industries are required to be imported at unaffordable prices. CIRCOT has endeavored to fill this gap by designing miniature machines for processing cotton and banana fibres about which a brief description is made in this Section.

11.3.1. Miniature Spinning System

CIRCOT has designed a miniature spinning system consisting of carding machine, draw frame, ring frame and open-end spinning machine, in collaboration with M/s Trytex, Coimbatore. The project was an effort in import substitution for the quick spin system available abroad. The CIRCOT system is available at about one-fourth the cost of the imported one.

Inverter drive systems have been employed for easy setting of various processing parameters. The advantages of this spinning system are : (i) fibre samples weighing as low as 40g can be processed easily to produce sufficient quantity of yarn for quality evaluation; (ii) the system is particularly handy for mills while optimizing different spinning as well as yarn parameters to be set in subsequent bulk spinning process; (iii) the machines are operator-friendly and the entire spinning process can be completed within an hour; and (iv) the system is suitable for use by cotton trade, textile mills, research laboratories, educational institutions, training centres and agricultural research stations for assessing spinning quality of small fibre samples.

The miniature spinning system has been licensed by CIRCOT to the collaborating firm M/s Trytex for commercial exploitation. Till now this firm has sold as many as 50 units to textile mills and technological institutes/universities.

11.3.2. Low Cost Carding Machine

This machine was designed and fabricated at CIRCOT for use in cottage industries located in rural areas, to equip them to produce better quality yarn. In the absence of such carding

machines the rural industries particularly in the khadi sector find it difficult to procure good quality yarn in a cost-effective manner.

The CIRCOT machine has three detachable units viz., cleaner, carding and winding units. In initial trials on this machine possessing 11 flat segments fixed over the carding cylinder, carding of fibres was found to improve, with significant reduction of neps in the sliver. About 25 cotton samples were processed on this new carding machine and the slivers so produced were spun into yarns of 30s and 40s Ne, using CIRCOT Miniature spinning system described earlier. These yarns when compared with those entirely spun on the CIRCOT Miniature spinning system were found to have better quality. Initially, the machine was fitted with a stationary flat. Later, it was redesigned with a rotating flat system. The machine can be run for 8 hours at a stretch. The sliver produced is uniform and free from neps and imperfections.

The carding machine is not yet commercialized. Efforts are under way. A prototype unit is available at CIRCOT for demonstration to stakeholders.

11.3.3. Lap Forming Machine for Microspinning

This machine was developed to replace the manual opening method followed at CIRCOT for micro-spinning of small samples about which mention was made in this Chapter as well as in Chapter 4 (Part 1) of this book. The lap former is suitable for opening cotton samples weighing 60-100g and the opened sample is then converted into a mini-lap. The machine can produce around 50 laps per day in contrast to just a few by manual means. The lap machine eliminates human drudgery, and its operation does not demand intervention of skilled workers. This machine is kept in the Spinning Section of CIRCOT where it is used for preparing laps for micro-spinning tests.

11.3.4. Banana Fibre Spinning Machine

A spinning machine suitable for making yarns from banana fibres has been designed at CIRCOT. The equipment consists of a fibre softening unit, fibre cutter, carding unit, drawing unit and ring frame. It has been ascertained that yarns of a linear density of 580 tex and having a strength of 10 g/tex can be spun from banana fibres using these machines.

One of the important requirements in machine spinning of banana fibres is the softening of fibres to make them more pliable for spinning. It was observed that the use of rice bran oil (RBO) as softener gives better results as compared to that of jute batch oil (JBO). Also, piling fibres after softening treatment for an extended interval of 72 hours seemed to be better than that of 48 hours.

One complete set of unit is available at CIRCOT for demonstration purposes as well as for yarn production by interested parties.

11.3.5. Pedal-driven CIRCOT–Phoenix Charkha

This machine was developed for spinning yarns, at the cottage industry level, from coarse fibres

such as those extracted from banana pseudo-stem. The traditional Medlari charkha spinning unit is a foot-operated self-winding spinning wheel with a bobbin to collect the spun yarn. The feeding to Medlari Charkha is done directly by hand without the use of any mechanical device. As a result, the fineness of the yarn spun solely depends on the rate of feeding dictated by the skill of the operator, and this introduces considerable uncertainty and non-uniformity in the linear density and twist in the yarn. To synchronize feeding and twisting, a new drive mechanism has been designed at CIRCOT.

In the new design of the charkha, called CIRCOT-Phoenix Charkha, the flyer and the bobbin are driven independently. The differential in the RPM decides the twist per inch (TPI) imparted to the yarn. The TPI of yarn can be altered through appropriate combination of RPMs of the flyer and the bobbin, achievable by changing the wheels in the drive mechanism. This Charkha can produce relatively fine yarn with adequate uniformity from natural fibres which are otherwise difficult to spin. With the use of the new Charkha, it has been possible to spin relatively fine yarns of 3s count with good-enough uniformity for making value-added products at the village level.

Two units of CIRCOT–Phoenix Charkha are kept in the Mechanical Processing Division of CIRCOT to be used for demonstration of banana spinning for the benefit of prospective clients who are interested in making handloom fabrics and handicrafts from banana fibre yarn.

Chapter 12

STUDIES ON QUALITY OF COTTON FIBRES AND FABRICS

CIRCOT has always been viewed as a centre of excellence in fibre science and technology ever since it was founded a hundred years ago. Over the decades, the Institute has made significant contribution to the understanding of the structure of cotton and its influence on physical and chemical properties as well as on its performance as a textile fibre. Every aspect of the various physical properties of cotton fibre and yarn has been put to detailed study at CIRCOT with the use of newer and newer instruments as and when they became available. Detailed studies in the first 70-75 years on this subject have been highlighted in Part 1 of this book. The potential of High Volume Instrument (HVI), and Advanced Fibre Information System (AFIS) in fibre quality evaluation, Kawabata system of fabric quality assessment, etc. have been put to extensive use at CIRCOT in later years to gather newer information on cotton and cotton textiles. This Chapter discusses some of the significant findings in recent researches.

12.1. STUDIES IN FIBRE QUALITY

12.1.1. All-India Co-ordinated Research Project on Cotton (AICRP-Cotton)

This is a mandated programme of the Institute. Every year, thousands of cotton samples are received for quality evaluation from breeding trials conducted by agricultural universities under the AICRP, as indeed highlighted in Part 1 of this book. Genotypes from cotton breeders of various States are systematically screened every year for yield, fibre quality and pest resistance. As part of the process of screening, CIRCOT evaluates fibre quality of several samples before identifying a genotype which is superior to an existing variety. The process is repeated for a few years. Spinning tests are also conducted at the Institute for samples of advanced trials to ensure that the variety when released would be suitable for hassle-free processing.

The results of fibre and spinning tests on samples received under the project are issued as reports to the concerned agricultural scientists. Some of the reports are discussed at the Zonal and All India Workshops and advice is given by CIRCOT Scientists to the breeders on the improvements desired in respect of fibre characteristics. Further, whenever desired, norms are suggested for adoption during selection of the material. CIRCOT has been successful in ensuring that better yielding varieties meeting the expected quality requirements alone are released for commercial

cultivation. Being strategically placed, CIRCOT through mill surveys finds out the projected requirement of cotton and advises the breeders who, in turn, reorient their breeding priorities.

As fibre quality data in the HVI mode are now used internationally, CIRCOT too has adopted the new system with effect from 2015-16.It is significant to note that till the year 2022, as many as 417 new varieties including hybrids have been developed and released for cultivation through the AICRP. Following the arrival of B*t* hybrids developed by private seed companies since 2002, the ambit of AICRP has been widened to include such cottons also.

12.1.2. Quality Assessment of Improved *G. arboreum* Cottons

Of late there has been considerable interest among breeders to refurbish the image of *desi* cottons through genetic improvement in respect of yield and quality. Such initiatives were inspired by the fact that *desi* varieties are inherently pest-resistant and can compete with B*t* hybrids if the yield and properties are accorded a reasonable boost. Many *desi* varieties have thus been subjected to overall improvement by cotton breeders in recent years. At CIRCOT a study was made to compare the quality characteristics of four "improved"*G. arboreum* cultivars namely, PA-255, DLSA-17, MDL-2463 and Jawahar Tapti, with the properties of traditionally grown *G. arboreum* variety RG-8 and *G. hirsutum* cultivars Bikaneri Narma and LRA-5166.

In the study at CIRCOT, *arboreum* cotton PA-255 recorded the highest 2.5% span length (27.6 mm) which was about 70% higher than that of the conventional *arboreum* strain RG-8 (16.4 mm). The improved arboreum varieties showed significant betterment in fibre fineness with mean micronaire values lying in the range of 4.5-4.9, as compared to 7.0 recorded by conventional *arboreum* cotton RG-8. The fibre bundle strength values for improved *G. arboreum* cottons were found to be significantly higher (21.1-23.3 g/tex) than those of the conventional *G. arboreum* cotton RG-8 (16.4 g/tex); the strain PA-255 showed the highest value of 23.3g/tex. In general, the tenacity values for improved *G. arboreum* were found to be at par with those recorded by *G. hirsutum* varieties. Although the improved *G. arboreum* varieties showed lower values for maturity coefficient (0.77-0.81) in comparison to the conventional *G. arboreum* strain RG-8 (0.83), still the values obtained were significantly higher as compared to the *G. hirsutum* genotypes (0.69-0.71).

Wall thickness and ribbon width are the indices of fineness of a cotton fibre and usually regarded as characteristic of the variety. Conventional *arboreum* RG-8 recorded the highest ribbon width (23.4 µm) and is one of the coarsest cultivars grown in India. The area of cross section of improved *arboreum* strains was found to be in the range of 144-158µm^2, though these values are higher than those recorded for *hirsutum* cotton strains (136-139 µm^2). At the same time the values are almost 50% lower than those recorded by conventional arboreum RG-8 (279 µm^2).

The improved *G. arboreum* cotton PA-255 showed the highest value for single fibre breaking load (5.9 gf) which was noticeably higher in comparison with the values obtained for *G.hirsutum* strains (3.6-4.9 gf). The single fibre tenacity values recorded for improved *G. arboreum* varieties are in the range of 25.3–33.5 g/tex, with the strain PA-255 recording highest value (33.5 g/tex). In

the case of conventional *G. hirsutum* strains, the range was 21.3 –30.4 g/tex, whereas the conventional *G. arboreum* cotton (RG-8) recorded the lowest value (19.2g/tex). The comparatively higher single fibre tenacity for improved arboreum varieties is a noteworthy character.

As regards work of rupture, the improved cotton strains record higher values (2.3-3.2 gf-mm) as compared to conventional hirsutum cotton varieties (1.3-2.4 gf-mm). The improved *G. arboreum* strains, except DLSA-17, showed higher Young's modulus in comparison to conventional *G. hirsutum* strains, suggesting that for inducing same amount of strain, fibre from improved *arboreum* needs higher tensile load. In the case of conventional *G. hirsutum* strains, the range was 21.3 –30.4 g/tex, whereas the conventional *G. arboreum* cotton (RG-8) recorded the lowest value (19.2g/tex). The analysis of the data clearly establishes the parity between improved *G. arboreum* and traditionally grown *G. hirsutum* strains.

The most promising improved *G. arboreum* cotton namely PA-255 along with the conventional *G. hirsutum* cotton LRA-5166 were processed to produce 30/2 denim fabrics (shirting)which were analysed for dye uptake and aesthetic properties. The species *G. arboreum* is known to produce fibres with inherently high maturity. Higher values for maturity point to more copious deposition of cellulose in the fibre considered favourable for uniform and increased absorption of chemicals in the fabric finishing process. Dye uptake, determined in terms of K/S values, were significantly higher in the case of the fabric produced from improved *G. arboreum* cotton (9.2 for PA-255 and 8.8 for LRA-5166).

In the Kawabata system of fabric quality evaluation, Total Hand Value (THV) that represents the overall quality of the fabric (discussed in Chapter 6, Part 1 of this book) varies with the end use application. The computation of THV is done from the Primary Hand Values (PHVs), also based on the particular end use. In the present study, fabrics were prepared, keeping inview the end-use as denim shirting. The THV was, therefore, estimated assuming the fabrics to be used as men's summer and winter wear. The fabrics from improved *arboreum* cotton recorded higher value for THV(2.9) as compared to the fabrics made from *hirsutum* cotton (THVof 2.6) for winter wear application. At the same time, when these fabrics were evaluated for end use as summer wear, *hirsutum* cotton fabrics recorded relatively higher THV values (ca. 1.8) as compared to the improved *arboreum* cotton fabrics (ca. 1.4). The data thus show that the overall performance of improved *arboreum* cotton is at par with that of the conventional medium staple *hirsutum* cottons in respect of fabric quality. The improved *arboreum* cottons can thus be seen as viable alternatives to the medium-long staple *hirsutum* cottons particularly for specific end uses like denim and twills.

Analysis of the entire data in this study clearly shows that "improved" *arboreum* cottons led by PA-255 are superior to some of the conventional arboreum cottons like RG-8 and the *hirsutum* varieties like Bikaneri Narma and LRA-5166 in respect of many of the fibre attributes. Fabrics made from the improved *arboreum* cottons too display superior performance. The study thus leads to the conclusion that upgradation efforts through breeding programmes can bring about

a revival of interest in *desi* varieties that can compete with *hirsutum* cottons in properties and performance.

12.1.3. Spatial Fibre Quality Maps

A case study was carried out to design and develop Geographical Information System (GIS) and Geographical Positioning System (GPS) based spatial cotton fibre quality maps for Nagpur district of Vidarbha region of Maharashtra. Spatial database and spatial fibre quality maps for parameters such as 2.5 percent span length, uniformity ratio, fineness, strength, elongation, ginning percentage, short fibre content, reflectance and degree of yellowness were developed. Spatial distribution, classification and characterization of the district based on the fibre quality were carried out to provide site-specific information.

The quality features of cottons grown in Nagpur district were analyzed by visualizing the spatial maps. The cottons produced in this district were found to be of long and extra-long staples, with 2.5 per cent span length ranging between 28.1 mm and 33.9 mm. Cotton grown in the deep clayey soil was found to be extra-long type while in loamy soil, long staple cotton was dominant. At higher elevations, fibre length was lower than in the plains.

Fineness of cottons produced in this region ranged widely between 2.9 and 4.2 mic. In moderately deep to deep clayey soil, fineness was found to be of medium category, spread out within 4.0-4.9 mic. In shallow loamy soils, the fineness observed was in the fine category, ranging between 3.0-3.9 mic. At higher elevations in clayey soil, the fineness of the cotton was found below 3.0 mic. At higher elevations fineness was comparatively lower than in the plains.

Fibre strength of the cottons in this region ranged from 20.2 g/tex to 26.0 g/tex. In moderately deep to deep clayey soil, strength turned out to be moderately high, ranging from 23.1 g/tex to 26.0 g/tex. In shallow loamy soils, the strength was of the average category ranging from 20.1 g/tex to 23.0 g/tex. At higher elevations, strength appeared to be a bit lower than of cottons in the plains. Elongation at break was found to be better in clayey soils than in loamy soils. In clayey soils, it was found to range from 5.0 % to 5.9 % while in loamy soils it was limited to 4.0 % to 4.9 %.

The short fibre content (SF) of cotton produced in this region lay between 4% and 10 %. Cottons in loamy soils were found to have SF of 6.0% to 7.9% while in clayey soils it was lower ,within 4.0 % to 5.9 %.

12.1.4. Lint Opener for Micronaire Testing

Cotton lint samples drawn from densely packed bales are required to be thoroughly opened and cleaned before fibre quality assessment particularly while using modern testing equipment like the HVI system. The importance of proper opening of the lint sample introduced into the porosity chamber for measurement of fibre fineness (micronaire) is well recognized to ensure not only correct micronaire but also tenacity values. This is so because the fibre strength measured by the HVI machine is internally divided by the micronaire value to arrive at fibre tenacity. Incorrect value for the former would be ruinous for the latter too.

At CIRCOT a new device was designed for opening cotton lint samples meant for use in the micronaire test. A prototype of the lint opener was fabricated in partnership with M/s Precision Tooling Engineers, Nagpur. The machine consists of three main assemblies viz., Licker-in Cylinder, Feeder Roller and Suction assembly, mounted on an MS frame provided with safety covers. The lint chamber, equipped with an easily openable air-tight door, can accommodate about 100g of the opened material. An observation window is provided for viewing the accumulation of opened lint in the chamber. Performance of the lint opener is found satisfactory, judging from its speed (40-50 samples per hour) and the specific volume of lint after opening (90-110 cc/g), which is nearly twice that of the unopened sample (40-60 cc/g).

12.2. RELATIONSHIPS AMONG FIBRE PROPERTIES

12.2.1. Relationship between Fibre Properties and Frictional Characteristics

Inter-fibre friction is an important property that impacts yarn and fabric behavior. Not many studies seem to have been reported on this fibre property though a beginning was made at CIRCOT many years ago, as reported in Chapter 3 in Part 1 of this book. Study of the translation of friction from fibre to yarn and from yarn to fabric might provide more useful information in understanding the frictional behaviour of all fibrous assemblies.

In another friction study, an attachment to Instron tensile tester, designed at CIRCOT, was used for measurement of friction. Fibre-to-fibre friction was measured as one fibre pad was moved at a slow speed of 5 mm/min over another pad of the same cotton, under a normal load of 30 g. Frictional force was noted from the load-displacement curve traced by the Instron machine and the frictional coefficient μ was calculated therefrom. Similar procedure was followed for tests on yarn pads too. The study included as many as 19 cotton varieties/hybrids covering a wide range of length and fineness. Fibre property characteristics of all the cotton samples were determined by using the HVI machine.

From the test data gathered in the experiments it was found that frictional coefficient μ has a significant positive correlation with fibre length uniformity ratio (significant at 0.01 level), indicating that better uniformity in fibre length gives higher μ. It was also observed that μ is not influenced by 2.5% span length. The only other property that influences μ, at 0.05 level of significance, is the micronaire. It can be stated that coarser fibres in general have higher μ. The correlation coefficients of μ with maturity and gravimetric fineness are found to be non-significant. Possible reason for lack of relation between μ and maturity could be that the degree of wall thickening does not leave its imprint on the character of the fibre surface.

In case of yarns, a negative correlation ($r = -0.53$) significant at 0.01 level is observed between μ and yarn twist/inch (tpi). Yarns spun from coarser and shorter fibres have lower tpi compared to those spun from longer and finer fibres. As a result the coarser yarns tend to be more compressible when compared to highly twisted finer yarns. Due to this compression, a depression is formed at the place where pressure is applied making it more difficult for the yarn pads to move past each other, resulting in higher μ values found in coarser yarns.

With yarn diameter, μ has a positive correlation (r = 0.46) significant at 0.01 level. With increase in yarn diameter, the area offered for frictional contact becomes more uneven since coarser yarns would not be as compactly aligned in the yarn pad as finer yarns. This, coupled with the fact that coarse yarns have fewer twists and hence are more compressible, leads to increased frictional values.

12.2.2. Grouping of Bales Based on Micronaire

In India, spinning mills are compelled to procure cotton bales that are not individually tagged with their fibre characteristics. This is so because supply of fibre test data is not mandatory for ginneries (of course recently the Ministry of Textiles has issued notification making post-sale supply of fibre quality data mandatory with effect from a future date). Based on random sampling of cotton from some of the bales, the acceptability or otherwise of the entire lot of bales is decided by mills. In the absence of data on fibre properties of individual bales, spinning mills are mixing cotton of different varieties with proximate fibre lengths to spin desired yarn count. No effort is made to take into account the fineness differences among the bales.

The effect of segregation of bales based on fineness of cotton (instead of fibre length) on the quality of yarns spun from them was put to a brief study at CIRCOT. Bales were segregated on the basis of micronaire value and grouped into seven lots: i) 3.2-3.5, ii) 3.6, iii) 3.7-3.8, iv) 3.4-3.8, v) 2.9-3.0, vi) 3.1-3.2,and vii) 2.9-3.2. All groups were spun to 80s Ne yarns. Highest CSP of 3237 was obtained for lot 7 and lowest CSP of 2988 for lot 2. Yarn evenness (U%) ranged from 11.7 to 12.6, thin places/km ranged from 30 to 88, thick places ranged from 84 to 240 and neps/km ranged from 262 to 415. Yarn tenacity was found to be in the range of 19.5 to 20.3 g/tex and elongation between 5.1% to 6.0%. However, no trend could be found on the effect of micronaire on yarn quality characteristics except that, in general, bales grouped low in micronaire gave predictably higher yarn tenacity.

12.2.3. Maturity-Micronaire Relationship

Constancy of cross-sectional perimeter for a given variety leads to a very strong relationship between the micronaire value and the degree of thickening. Varieties having perimeter within a specified range can be pooled to establish the relationship between the micronaire value and the degree of thickening. In one CIRCOT study, cross-sectional perimeter, degree of thickening and micronaire values were estimated for 25 varieties which included RCH (2.4 - 4.5), DCH .32 (2.5 - 3.0), Surabhi (2.6- 3.5), MCH.11 (2.6-4.0), MCU.5 (2.6-4.0), etc., representing a fairly wide range of micronaire values. It was observed that for a given variety, the cross-sectional perimeter remains nearly constant irrespective of the degree of maturation. This leads to a direct relationship between the micronaire value and the degree of thickening which represents the true, botanical, maturity for a given variety. It has also been possible to pool the varieties having perimeter within a specified range and establish the relationship between micronaire value and degree of thickening for each perimeter range. For a perimeter range of 51-55 microns, the cottons studied namely NHH.44, LRA.5166, G.Cot.16 are found to be governed by the equation $\theta = 0.0458$ Mic. + 005137.

12.2.4. Performance Comparison of Lint Openers

Micronaire reading (Mic) indicates the resistance to passage of air through lint specimen compressed to a given volume. If cotton lint samples are tested on modem High Volume Instrument (HVI) as such in the condition in which they are received without any opening and cleaning, possibility of variations in micronaire reading cannot be avoided. However, for increasing the speed of testing, the tendency among machine operators is to use samples as received without any further opening. The Mic value can be considerably higher if samples are tested without opening. Unopened lint would also retain trash particles that are bound to further augment the measured value of micronaire. While opening allows proper air flow and accurate surface area measurement, unopened sample reduces the actual surface exposed to air and offers less resistance to air flow thereby increasing the Mic reading, which in turn, leads to lower tenacity values when the HVI machine is used for the tests as pointed out earlier. Thorough opening of the sample to be introduced into the porosity chamber for micronaire measurement is, therefore, very important. Presently, opening of lint samples for Mic testing is achieved either manually by hand or by using equipment like trash analyzer and opener blender.

The extent of lint opening and the capacity of these methods were studied at CIRCOT using MAG-SITRA Trash Analyser and SDL Opener Blender which are the most popular machines of the day. It was observed that while both machines gave comparable quality of opening, the capacity of the Trash Analyser was nearly double due to its larger size when compared to the Opener Blender. The latter which weighs 43kg and has overall dimensions of 640 mm x 470 mm x 300 mm, is only about half the size of the Trash Analyser and, therefore, has a capacity limited to 15-20 samples per hour. However, the performance of the two machines was at par, judging from the specific volume of lint which was around 100-120 cc/g after opening, in both cases. On the other hand, manual opening could achieve only up to 60-80 cc/g, which was only marginally higher than 40-60 cc/g in case of unopened samples. Opened and unopened mic values were 3.0 & 3.4 for H.6, 3.3 & 3.7 for LRA.5166, 3.6 & 4.0 for H.4, and 3.6 & 4.3 for G.Cot.16. The wide differences in micronaire underscore the importance of sample opening.

12.2.5. Micronaire and Contact Angle

The wettability of a solid is measured by the contact angle between a drop of water and the surface of the solid. Contact angles below 90° correspond to high wettability or hydrophilicity while contact angles above 90° signify low wettability or hydrophobicity. The wettability of cotton fibres from different fineness grades was put to a brief study at CIRCOT through measurement of their contact angles. The goniometer and powder cell method was used for contact angle measurement. Three groups of the cottons widely differing in fineness namely super-fine, fine and coarse were chosen for the study. The first group comprised cottons of micronaire 3.6 or below; the second group had micronaire between 3.7 and 5.0 ; and the third group had micronaire 5.1 and above. Contact angle and general fibre properties were determined on all the selected samples.

The results of measurements showed that the contact angle between water and fibres is not influenced by the span length, UR or tenacity of the fibres. However, finer cottons are found to have higher values for contact angle (79.4° to 84.0°) as compared to coarse cottons (70.5° to 75.7°).These results lead to the conclusion that coarse varieties of cotton wet more easily than fine cottons.

12.3. MISCELLANEOUS STUDIES ON COTTON QUALITY

12.3.1. Survey on the Use of AFIS in Export-oriented Mills

Two instruments that play major roles in cotton selection and process control in mills are the High Volume Instrument (HVI) and Advanced Fibre Information System (AFIS). While the HVI has been in use by export–oriented units (EOUs) in the last many decades, the AFIS entered the Indian textile industry only in the early 1990s. Although AFIS gives a wide range of information about fibre quality in a short time, the parameters exploited by the EOUs for maintaining yarn quality are limited. The survey was conducted in and around Kolhapur of Maharashtra state, where a conglomeration of EOUs could be seen. The study was restricted to EOUs that possessed the latest test equipment including AFIS.

The survey revealed that EOUs conduct test on 20% of their bales for AFIS fibre parameters. The standard number of tests prescribed by the manufacturer of this machine to ensure accuracy is 5 per sample. However, only two out of 6 EOUs are found to be following the standard number of replications while the remaining mills consider four readings as adequate. Five readings of each parameter would involve 15,000 fibres whereas 4 readings would restrict this number to 12,000 fibres and hence the result is bound to be less accurate.

The survey has revealed that upper quartile length (UQL), 5.0% length, short fibre content (SFC)(n), millitex (mtex), immature fibre content (IFC), maturity ratio (MR), neps/g and seed coat neps (SCN/g) are parameters that were put in use daily by EOUs in their routine operations. EOUs use only 8 parameters out of 14 parameters available on this machine. Among these 8 parameters, neps/g is used by all the EOUs while the least used parameters are the 5.0% length and fibre millitex.

Upper Quartile Length (UQL) by weight is the length of the 25% of the longest fibres in a sample. UQL is used for comparing the 2.5% span length obtained from HVI. Four mills use this parameter and, as per their experience, HVI 2.5% span length plus 1 mm will be equal to UQL from AFIS. This is used as a check for HVI and, if this parity is found wanting, the instrument is checked for its calibration.

The 5.0% length by number is the length of the longest 5% of fibres. Out of the 6 EOUs under survey, one uses it for draw frame setting. The 5.0% length of the combed sliver is measured and used for setting purposes. In the case of breaker draw frame, 5% length is kept for the front zone while for the back zone it is fixed at 5% length plus 4 mm. Similarly, in the finisher draw frame, the front zone is kept at 5% length plus 2 mm and the back zone is kept at 5% length plus 6 mm. The remaining EOUs use 2.5% span length plus their own arbitrary allowance for their draw frame setting.

For short fibre content, AFIS gives two values, one based on weight of fibres and the other based on their number. All the surveyed EOUs use only Short Fibre Content by number [SFC (n)]. This is defined as the percentage of fibres shorter than 0.5 inch. SFC(n) is mainly used for deciding the amount of noil to be removed while setting the comber. One EOU cautioned that it should not be used for carding performance study, as the card sliver that comes as output contains fibres with hooks, and as a result, the SFC(n) measured would be misleading.

AFIS gives fibre fineness in millitex. The mill 'E' uses it for cross-checking the micronaire value of cotton obtained from HVI. Fineness measured by AFIS is equivalent to gravimetric fineness and can be different from millitex value derived from micronaire. A CIRCOT study had revealed that within varieties, the relationship between AFIS fineness and micronaire value gave substantially high correlation, with 'r' values ranging from 0.92 - 0.98. However, pooled data for more than 100 samples, which comprised different varieties as well, showed a relatively low 'r' value. But the correlation still remained significant at 1% level. This of course affects the predictability of micronaire from AFIS fineness or vice versa. This is understandable as AFIS fineness would depend only on wall-thickness while micronaire value would depend both on perimeter and wall-thickness. So long as the former remains the same, (true for a given variety) a higher correlation can be expected between micronaire and AFIS fineness.

Immature Fibre Content (IFC) is the percentage of fibres possessing less than 0.25 degree of thickening. This value is mainly used by EOUs in deciding the mixing of cottons in the production of yarns meant for knitting. According to one mill 'B', two cotton varieties differing by more than 10% in IFC should not be mixed. This is done to avoid dyeing defects in knitted fabrics. IFC is also used to check the comber performance and it is expected that comber should preferably remove undeveloped fibres and bring about reduction in IFC by at least 25%.

Maturity Ratio (MR) is the ratio of the number of fibres with degree of thickening of 0.5 or more to that of fibres with degree of thickening of 0.25 or less. Like IFC, this parameter is also used by the EOUs for choosing cottons for the production of hosiery yarns. Mills 'B' and 'C' insist on a minimum MR of 0.8, while mill 'E' would not buy cotton if the MR is below 0.86. Such measures are taken mainly to avoid stripping effect known as 'barre' in finished fabrics.

Neps per gram indicates the number of neps present in one gram of cotton. This is the parameter most extensively used by all the EOUs to study the performance of blow room, card and comber. One EOU uses this parameter for cotton selection as well. As per the norms adopted by these mills, for roller-ginned cotton, the neps per gram should be less than 180 and for saw-ginned cotton it may be permitted up to 250. Higher neps are allowed for saw ginned cottons, as the treatment in saw gin is harsh and produces more neps than roller gin. All the EOUs agree to the point that neps per gram in blow room lap should not be more than double that of raw cotton. The card and the comber should work with a nep removal efficiency of at least 75% and 55% respectively.

Seed coat neps (SCNs) are fibres entangled with seed coat fragments that remain in baled lint. One EOU insists on a condition in its contract that a consignment will be accepted only if the

SCN is less than 25 per gram in the cotton. Normal neps are easily removable during carding unlike SCNs which are difficult to remove at the card as they break into small fragments. The SCNs that remain after carding and combing create yarn faults, finally resulting in defective fabric.

12.3.2. Status of Trash Content in Indian Cottons

The Bureau of Indian Standards (BIS) has laid down specific norms for maximum trash allowable in baled cotton. They are: 3% for extra long staple, 4% for long and medium long staples, and 5% for medium and short staples. It is often told by industry that Indian cottons are highly trashy and many cotton varieties have trash content exceeding these levels largely because pre-cleaning is not practised at many ginneries. Added problem with our cotton is the presence of foreign matter referred to as contamination resulting from improper kapas handling practices at the farms, market yards and ginneries. A solution to these problems was the modernization of cotton markets and ginneries through Technology Mission on Cotton (TMC) during the eleven-year period between 2000 and 2011. CIRCOT had interacted with the Ministry of Textiles in the implementation of the modernization programme. The Institute had trained hundreds of gin technicians, ginnery owners, market personnel and farmers in best practices that can help reduce trash and contamination in cotton bales. A study of the impact of TMC on the quality of Indian cotton was made at CIRCOT by testing a large number of cotton samples in the six-year period between 1997 and 2002.

Cotton samples were collected from all cotton major trading centers of India and were measured for trash content. The total number of samples collected over six year period and tested was 12414. Variety wise and year wise analysis was carried out wherever a minimum of 10 measurements were made per variety per year. Similarly, for centre-wise discussion of results, a minimum of 100 samples were kept per centre over the six-year period.

Trash content over the years seemed to have dropped down to 3.0 from 4.1 in the above six-year period. The percentage of drop over six-year period is 37. From 1997 to 1999, no noticeable trend was seen for trash levels. However, the average trash content continued to drop from 2000. In case of minimum trash percentage, it remained almost the same for all years whereas the maximum had dropped down to 8.3 from 16.0.

Irrespective of the year, 60% to 77% of the samples belonged to the group of 2% – 3.9 % trash level. It was often reported that Indian cottons are having trash levels of about 6%. This study did not validate that observation as it could be seen for year 2002 in which only 0.7% of the total samples had trash levels above 6% trash. Variety-wise distribution of trash for medium and long staple cotton over a six-year period revealed the well-known fact that long staple cotton tends to gather less trash than medium and short staple cottons.

The lowest trash level of 1.6% was observed for MCU.5 in the year 2002. The highest trash level of 12.1% was observed for V.797 in the year 2000. This variety is a closed boll type cotton. The bolls are picked and beaten to separate the kapas and in this process, they tend to retain more

trash than other varieties. In case of long staple cotton category, as far as trash levels are concerned, MCU.5 has always performed better than DCH.32. For DCH.32 variety, which is already having other problems like low maturity and micronaire, the presence of high levels of trash further reduces its market value and quality.

In the center-wise distribution of trash levels, Kothagud, Adoni and Errupalam were found to have the least average trash of 2.5% among the centers chosen for the study. Minimum trash levels observed were as low as 0.6 in some centers and as high as 2.1 in some others. Kothagud center of Andhra Pradesh performed better in all statistical parameters calculated, with a mean of 2.5% and minimum and maximum at 0.6% and 4.7% respectively. The maximum trash levels of 24.9 and 25.8 were observed in centers Janakhandi and Warangal. A close observation of these two centers had revealed that the values of trash above 20% are only six pertaining to JKHY.1 variety for the year 1998 and hence cannot be considered as significant. The overall trash level of Indian cottons had dropped down to 3.0 in the year 2002 from 4.1 in 1997. All major varieties showed a downward trend for average trash content from 2000 onwards.

12.4. STUDIES ON FABRICS

12.4.1. Single-Jersey Knitted Fabrics from Fine Count Rotor Yarns

Mechanical properties are of critical importance in the determination of quality, appearance and performance of fabrics used for making garments. Kawabata system of instruments is used to measure low stress mechanical characteristics to arrive at what is known as "total hand "value"(THV), an integrated index of the aesthetic value of the fabric. A brief description of the Kawabata instruments and the procedure to arrive at THV was made in Chapter 6 of Part 1 of this book. Results of an early study were also discussed.

In a recent study at CIRCOT the Kawabata system of machines was used to assess a set of single-jersey fabrics knitted by using three rotor-spun 50s yarns from (a) 100% cotton, (b) 67/33 polyester/cotton blend and (c) 100% polyester. These yarns were converted into two-yarn parallel-wound packages and used for knitting. A 10 inch diameter single-jersey knitting machine was used with a gauge of 24. All the four Kawabata instruments (KES-FB series) were used for measuring the 16 mechanical characteristics needed for fabric evaluation.

Test results from Kawabata system were put to critical study. Pure cotton fabric was found to have tensile test parameters suggestive of high extensibility essential for superior wear comfort as compared to pure polyester and blended fabrics. At the same time, parameters representing shear property were low, indicative of better softness of cotton fabric. Further, the surface property indicators revealed the superior smoothness of the cotton fabric as compared to the blended and pure polyester fabrics. Similar trends were found in the compressional property parameters as well as indices of bending behavior. Almost all the 16 Kawabata quality markers pointed to the unequivocal superiority of cotton fabric in respect of tactile comfort properties.

12.4.2. Wear Comfort Indices for Cotton Fabrics Based on Kawabata Tests

The Kawabata system of instruments for fabric evaluation offers a wide range of measures

representing tactile and thermo-physiological comfort derivable from clothings used in different situations. It may be noted that Kawabata system also includes an instrument for determining thermal, moisture and air permeability of fabrics which together decide the thermo-physiological comfort. CIRCOT scientists have used the complete Kawabata system to study the comfort aspects of fabrics and have proposed two wear comfort indices, one for winter wear and the other for summer wear.

Winter Wear Comfort Index: In the case of winter wear fabrics, tactile comfort and thermal-wet comfort are perceived to have equal importance in deciding the overall rating. Winter wear fabrics should have high thermal insulation property (thermal resistance); at the same time they should be permeable to moisture as otherwise, condensation of vapour in the fabric structure can lead to erosion of thermal insulation. The third factor is air permeability which should be kept low to ensure that thermal insulation property remains intact.

On the basis of the above considerations, Thermo-physiological Comfort Index for winter clothing (TPCI w) has been defined as:

$TPCIw = (TR \times MTR \times AR)$

where TR is the thermal resistance value (Tog), MTR the moisture transport rate (g/sq.m/hr) and AR the air resistance (KPa/sq.m.).

Since TPCI w and THV are, as stated earlier, equally important for winter clothing, we can define the Total Wear Comfort Index for winter clothing as:

$TWCIw = (TPCIw) \times 0.5 + (THV) \times 0.5$

Summer Wear Comfort Index: In the case of summer clothing, thermo-physiological comfort should be viewed as more important than tactile comfort. Summer wear fabrics should be highly permeable to both air and moisture and, at the same time, should have low thermal resistance. Hence, Thermo-physiological Comfort Index for summer clothing (TPCIs) has been defined as:

$TPCI\ s = (MTR \times AR)/TR.$

As TPCI s is more important than THV for summer clothing, we can define Total Wear Comfort Index for summer clothing, by giving arbitrary but meaningful weightages to THV and TPCI s thus:.

$TWCI\ s = (TPCIs) \times 0.7 + (THV) \times 0.3.$

Cotton fabrics of both plain and twill weave construction ranging in weight from 100 to 190 gsm were woven from yarns that varied in count from 20s Ne to 80 Ne spun by using two different twist levels for each count. Yarns of a given count were spun from cottons that varied in fibre attributes predominantly in fibre micronaire. The fabrics were assessed for low-stress mechanical properties by using the Kawabata Evaluation System (KES-FB). Both Primary Hand Value (PHV) and Total Hand Value (THV) were arrived at by prescribed procedures. Air

permeability was measured by using KES-FB AP18 while the moisture transfer properties were measured with Thermolabo II, both belonging to the Kawabata system.

When considered as summer wear fabrics, both plain weave and twill gave higher values for TWCIs showing the suitability of these fabrics as summer wear. Fabrics woven from finer yarns (80s count) gave higher value for TWCIs, due to higher heat, moisture and air permeability of these fabrics, as compared to the ones woven from 50s count yarns. When fabrics woven from 50s or 80s count yarns were considered separately, it was found that those made from coarser (high micronaire) fibers gave the higher value for TWCIs. This was so because, such fabrics were permeable to air, heat and moisture, an important feature needed for summer wear fabrics. The use of very light fabric (from 80s yarn) would be ideal for summer clothings as there will be more evaporation of sweat and loss of heat to the environment in addition to improved air permeability values.

When examined for application as winter wear materials, all the cotton fabrics under study showed TWCI w less than 5, establishing their striking unsuitability for this end-use. When the fabrics were considered for women's suiting, THV showed higher rating for fabrics woven from 50s yarn, by virtue of their higher smoothness and softness, compared to those from 20s yarn. However, TPCI w showed higher value for fabrics from 20s yarn as compared to those woven from 50s yarn due to higher thermal insulation value and moisture permeability. The combined Total Wear Comfort Index (TWCI w) showed that fabrics woven from coarser count yarns are better suited as winter wear suiting fabric.

12.4.3. Inverse Relaxation in Fabrics

If a strained specimen (fibre/yarn) is allowed to recover a part of its strain and is constrained to remain at this reduced strain, then the stress in the specimen starts increasing. The increase in stress is initially fast but slows down with time, eventually reaching a constant value. This phenomenon, referred to as inverse relaxation (IR), was reported first by researchers at CIRCOT in the late 1990s. Inverse relaxation index (IR index) has been defined as the quantum of this stress increase expressed as a percentage of the stress at the maximum initial extension. Stress relaxation was discovered and its nature studied first in the case of cotton fibre specimens. Considerable information on the nature of this phenomenon had been gathered at CIRCOT in the years before 2000.

In a recent study to understand and demonstrate this phenomenon in fabrics, five different commercially available cloths were chosen. Of these, three were of 100% cotton, one was of 100% polyester, and one was of 80/20 polyester/cotton blend. The IR indices of 100% cotton fabrics were found to be in the range of 2.9 to 33.2 and for 100% polyester it was in range of 0 to 18.6. From these data it could be seen that stress build up due to the phenomenon of inverse relaxation could be as high as 2 kg in a one-inch strip, in either direction, warp or weft. For a fabric of 48 inch width used in mercerization, dyeing, etc., where it undergoes stresses and strains, there can be an increase in load of the order of 100 kg across the width of the fabric. Such a high increase in load can cause the fabric to slip through the drawing rollers. This may affect the ultimate results

of processing. The phenomenon can also cause periodic variation in the width of the fabric during both weaving and chemical processing. These observations highlight the need for appropriate measures to prevent manifestation of the effects of inverse relaxation phenomenon.

12.4.4. Warm-Cool Feeling of Denim Fabrics

The warm-cool feeling associated with clothing materials has been recognized by the Chinese since historical times and they found that cotton, linen and silk fabrics are good for summer clothing due to the cool feeling associated with these materials.

An attempt was made at CIRCOT to understand the fabric properties influencing the warm-cool feeling of denim fabrics. Four greige denim fabrics differing in weight per unit area were chosen for the study. The fabrics were subjected to five different finishing treatments and the structural as well as thermal properties of treated fabrics were determined to assess their influence on warm-cool feeling of the fabric in terms of "q-max" parameter measured by using the Thermolabo II which is part of the Kawabata system.

Thermolabo II consists of (i) a guarded hot plate (BT-Box) with 5 cm × 5 cm area, (ii) T-Box which is essentially a copper plate with known thermal capacity, insulated on all sides except front face, and (iii) water box which can be maintained at any temperature by circulating water through it. The index q-max can be measured under both insulated as well as constant temperature conditions. The present study employed insulated condition for measuring q-max. The T-Box was heated to about 35 °C by keeping it over hot BT-Box. The former was then quickly placed over the fabric that was kept over a block of insulating material. The maximum of the heat flux flowing between the T-Box and the fabric surface was detected by the electronics of the instrument.

The measured parameter q-max is generally higher for a finer fabric (241 gsm) than a coarser fabric (544 gsm). Finer fabric, by virtue of the finer yarn that goes into its making and the higher number of ends and picks per inch, has a smoother surface profile that leads to better thermal contact between the fabric surface and the skin. Washing treatments given to the fabrics appeared to have strong influence on the q-max values. It was seen that, in general, except for Hard Wash, finishing treatments improved the cool feeling of the fabric (q-max) from 1.06 to 1.12. Hard Wash caused fall in q-max irrespective of the weight category to which the fabric belonged.

Structural parameters like fabric thickness, bulk density and cover factor were found to influence the warm-cool feeling. The q-max values of all the fabrics other than Hard Wash showed a negative correlation with thickness of fabric (r^2=0.93). Cover factor also seemed to have a negative correlation with q-max (r^2=0.79). This observation may be attributed to the existence of correlation between cover factor and thickness of fabrics. Thicker fabrics, in general, have better cover factor and they also have a relatively uneven surface profile. The relationship between q-max and bulk density of fabric was also found to be negative. While q-max showed an increasing trend with picks per inch (PPI), dependence of q-max on ends per inch (EPI) was

not significant. Denims, being twill weave fabrics, have filling yarns floating across the warp whereby a higher pick density would lead to more number of floating yarns on the fabric surface. While these weft yarns help to impart better thermal contact between the skin and the fabric surface, the influence of warp yarns that do not come in contact with the skin, is minimal. Hence, weft yarns appear to predominantly influence the heat exchange between skin and the fabric.

Chapter 13

TECHNICAL TEXTILES AND COMPOSITES

13.1. TECHNICAL TEXTILES

Technical textiles are engineered products manufactured for non-aesthetic purposes, but meant to perform specific functions in different realms of human activity. Examples of technical textiles include geotextiles, medical textiles, automotive add-ons, agro-textiles, protective clothings, etc. They are manufactured from natural as well as man-made fibres that have one or more of the functional properties such as high tenacity, elasticity, thermal resistance, electrical conductivity/insulation property, antimicrobial attributes, etc. With the advent of a plethora of synthetic textile materials and the ever-increasing need for special functional accessories, technical textiles have thrown open a vast area for research and development. CIRCOT with its experience and expertise in textiles has ventured into the domain of technical textiles and has developed many technologies. A brief discussion follows.

13.1.1. Protective Cover for Pesticide Spraying Operators

The use of personal protective equipment (PPE) minimizes pesticide exposure and reduces the risk of associated health hazards. CIRCOT has developed a pesticide-protective cloth for use by agricultural pesticide spraying operators. Here, use is made of a water-repellent fluorocarbon-based chemical TG581 (Fluorotex FCN) along with a cross-linking agent (Melamine formaldehyde) applied on fabrics made of pure cotton as well as cotton polyester blends. Protective garments resembling rain coat covering head and face, were made out of the fabrics. The cloth is found to possess adequate wash fastness up to 25 wash cycle. The efficacy of the treatment has been ensured by tests which showed that the fabric meets level 2 of protection criteria in pesticide protective clothing standard, indicative of <5% pesticide penetration. The results are indicative of good pesticide protection offered to the wearer .

13.1.2. High-Performance Cut-Resistant Fabrics

Worker safety is the first essential requirement for any kind of activity. The most common safety device needed by workers is the hand glove. The material to be used for making the glove warrants judicious selection. The nature of operations must be considered while selecting the type of gloves to be worn by workers. Where the work involves cutting and slashing operations, "cut-resistant" fabrics will have to be used for making gloves.

Under CIRCOT's technical textile product development programme, multilayer fabrics were developed with two different fabric structures, namely, plain and twill. The fabrics were produced by using three layers of warp yarns namely, Dyneema (420 D) on the top layer, polyester (420 D) on the middle and bottom layers. Four different types of weft have been used in the fabric namely, core-spun cotton/nylon, core-spun cotton/steel, Dyneema, and polyester multi-filaments. The fabrics thus developed were able to meet EN 388 standards, with level 2 performance for cut resistance, abrasion resistance, and puncture resistance, and with level 5 performance for tear strength. CIRCOT has recommended this fabric for making hand gloves for workers exposed to risks mentioned above.

13.1.3. Cotton Pads for Wound Dressing

Wound dressing is classified into primary and secondary dressing. Both play vital roles in treatment of the wound by absorbing the exudates seeping out from the spot, protecting it against bacterial infection, and providing adequate moisture for quick healing of the gash. Cotton, a natural fibre and an acknowledged hypoallergenic, is best suited for wound dressing applications. A cotton-based high-performance wound dressing pad with high absorbency and anti-microbial property has been developed at CIRCOT. Nanosilver-based wound dressing thus developed showed excellent performance with over 99% reduction of both Gram-negative and Gram-positive bacteria as per measurements made by AATCC TM 100: 2019, Standard test method. This novel processing technology is also found to enhance the absorbency of the pad by as much as 33%. The pad helps the wound to remain moist with exudates but at the same time without causing maceration, keeps it free from infection, and improves the wound dressing duration, with evident cost-effectiveness.

13.1.4. E-textiles

“Electronic” textiles, also referred to as E-textiles, are fabrics that enable electronic components like batteries, light bulbs, sensors, etc., to be embedded in them. An example is a glove made of conductive yarn woven into a fabric that can bring thermal comfort to the wearer. E-textiles require flexible but mechanically stable conducting materials to ensure electronic capabilities in the apparels made therefrom.

CIRCOT has developed an electrically conductive yarn that can function on various DC power supplies. Using this conductive yarn, it has been possible to develop heating gloves, winter garments, knee pads, warming mouse pads, warming shoe pads, and heat-generating seat covers. The systems thus developed require 5V-12V power banks and rechargeable batteries. These products have the ability to generate temperatures from 40 °C to 70 °C as per the requirement and availability of the power source.

13.1.5. Cooling Belt for PPE Suits

Medical protective over-clothes are usually made of synthetic fibers, taking advantage of their superior liquid barrier properties. Nonwovens are more popular than woven fabrics as the former are known to be relatively easy to manufacture, that too at low cost, and are able to retain

high levels of sterility needed for infection control. However, such protective garments are inherently low in wearing comfort on account of poor thermal and moisture transmission capacity. CIRCOT has developed an air cooling and circulating system for augmenting the thermal comfort of impermeable apparels. It helps in improving the performance efficiency of the wearer during long working hours.

The air cooling belt developed at CIRCOT makes use of the well-known Peltier effect that causes heating and cooling of the junctions between two dissimilar metals when a current is passed. The "coolness" generated at one of the junctions is transferred to an aluminium heat sink where the surface area is augmented. The relatively cooler air is circulated by means of fans to bring thermal relief to the wearer. A drop in temperature of 2-3 °C can be effected within an impermeable apparel worn by the worker. The complete system makes use of a 5 V, 2A power bank. The same cooling belt can also be used for outer air circulation by bike riders during the summer season when the temperature can be reduced by 4-5 °C below the ambient temperature.

An electrically conductive paste was developed at CIRCOT, for application on conductive textiles including anti-static textiles, for electromagnetic shielding, and on mobile phone radiation protective clothing. The fabrics thus coated have a resistance of 20-30 ohms/cm, and can be used to make mobile pouches, electrical appliance covers and emf-protective garments.

13.1.6. Filter Fabric for Indoor Decontamination

Indoor air pollution is a complex issue involving a wide diversity of pollutants that can imperil human health. Most common air pollutants that are produced by industrial activity include formaldehyde, particulate matter, sulphur dioxide, carbon monoxide, nitrogen oxides, and several volatile organic compounds. Exposure to these pollutants is associated with numerous effects on human health, including increased respiratory symptoms, hospitalization for heart or lung diseases, and even premature death.

Tackling the problem of atmospheric pollution requires an air sifting system that employs a filter fabric. The efficiency of the fabric to filter out various pollutants is critical to any air purifying system. At CIRCOT, an equipment has been designed for testing the efficacy of filter fabric to block hazardous substances like particulate matter, volatile organic compounds (VOCs), carbon dioxide, and formaldehyde. This equipment uses different sensors for measurement of PM 2.5 and PM 10, VOCs, CO_2, and formaldehyde content.

Polyester-cotton (PC) blended fabric with a weight of 300 gsm was used for the study. Activated charcoal application at 3.5% level was found to give a maximum add-on of 12.4% at 25 minutes of exhaustion time. Filtration efficiency of charcoal-treated PC fabric was higher by as much as 11.5% for PM2.5, 13.9% for PM10, 11.9% for CO_2 and 15.4% for VOCs as compared to corresponding figures for the untreated fabric. CIRCOT has recommended this fabric for indoor decontamination devices.

Also attempted at CIRCOT was the assembling of a three-layer fabric with cotton cloth for inner and outer layers, and activated charcoal-treated polyester-cotton blended fabric for the middle

layer. The particle filtration efficiency of the fabric assembly was at par with the air-purifying window curtains available in the market.

13.1.7. Activated Carbon from Cotton Stalk

Activated carbons are known to work as very effective adsorbents by virtue of their highly developed porosity, large surface area, surface active sites, and chemical reactivity. However, as these are commercially produced from coal, they are more expensive than other adsorbents. Bio-resources, despite their lower carbon content as compared to coal, should be preferred because they are renewable and easily available. The cost of activated carbon made from these sources would be very low when compared to that of commercially available material.

To bring down the production cost of activated carbon, an attempt was made at CIRCOT to use cotton stalk, a bio-waste material, by converting it into activated carbon by a combination of procedures. The activated carbon produced by the method mapped out at CIRCOT has a high surface area of 1010 m^2/g, which is an impressive figure, together with an yield of 48%. It has been confirmed by trials that the cotton stalk-based activated carbon can be used for various applications such as air filtration, water purification, medical uses and dye removal from textile effluents.

13.1.8. Activated Carbon-incorporated Cotton Face Mask

As already stated in the last Section, activated carbons (ACs) are very effective adsorbents by virtue of their exceptional porosity, large surface area, variable characteristics of surface chemistry, and high degree of surface reactivity. In order to develop an AC-based face mask, woven cotton fabrics of different GSMs were coated with activated carbon using appropriate adhesives and a binder. The surface morphology of the control and the coated fabrics were examined by SEM to ascertain the uniformity of distribution of activated carbon over the substrate. Porosity measurements were made on activated carbon, uncoated fabrics and AC-coated fabrics. While mesoporosity was estimated by methylene blue adsorption test, micro-porosity was evaluated by iodine adsorption method. For measuring surface area, use was made of BET Surface Area Analyzer. The tests showed that the surface area of the fabric made a 3-fold increase from from 296 m^2/g (control cotton fabric) to 842 m^2/g, (AC-coated fabric) as a result of the treatment. The microbial resistance of activated carbon-coated fabrics was 52% higher than that of the control fabrics. The results thus showed that AC-incorporated cotton fabrics are evidently suitable for use in face masks.

13.2. DEVELOPMENT OF COMPOSITES

In material science, the term "composite" stands for a combination of two materials with different physical and chemical properties firmly bonded together to form a new substance capable of performing specific functions which either of them will not be able to accomplish alone. A synergistic combination of the properties of components enhances the utility and performance of the combined substance. Simplest examples of composites are cement concrete and fibre-reinforced plastics which are ubiquitous in today's world.

With the use of a wide range of newer components now available, scores of composites are being manufactured and used in fields as varied as automotive industry, aerospace engineering, medical/surgical aids, sports equipment, etc., with limitless prospects in every field. In the last few years, CIRCOT has carried out impactful researches in the domain of composites involving cotton and its by-products together with other materials. Highlights of the work are briefly discussed here.

13.2.1. Rubber-Textile Fabric Composite for Check Dams

Flexible check dams also known as rubber dams, are a special group of geo-system made from technical textiles. Rubber dam is an inflatable structure built across a stream for water conservation, flood control and regulating flow of water in the stream. When the structure is inflated, it serves as a check dam and when it is deflated it functions as a flood mitigation device and a tool to aid sediment flushing. The rubber dam mainly consists of the following parts: (i) a concrete foundation with head wall extension, side wall and wing wall of a normal check dam; (ii) the head wall replaced by rubberized fabric dam body; (iii) anchoring system (anchoring of rubber sheet with bottom and side of the check dam); (iv) inflation-deflation system (an inlet/outlet piping system for inflation and deflation by water); and (v) a pump for filling water for inflation.

In our country, there is lack of know-how in the design and fabrication of suitable rubber-textile composite for making a flexible dam. Initial studies conducted at CIRCOT had revealed that nylon 6 fabric with 450 gsm and nylon 66 fabric with 550 gsm, both of mock leno weave, are eminently suitable as reinforcing materials for the rubber composite to be used in flexi dams. In order to improve the adhesion between fabric substrate and rubber matrix, commercially available Resorcinol Formaldehyde Latex (RFL) was applied on the fabric before it was rubberized. In the composites thus made, nylon 6 was found to have an RFL add-on of 22.4% while in case of nylon 66, the add-on was 19.1%. Warp breaking strength of 8821 N was observed in nylon 6 fabric and 11425 N in nylon 66 fabric. Breaking elongation was recorded in the range of 35.9% to 45.0% for nylon 6 fabric and 31.6% to 35.6 % for nylon 66 fabric. Nylon 6 had a maximum flexural rigidity of 78144 mg.cm and peel strength of 170.7 N/cm. A sandwiched fabric of both nylon 6 and nylon 66 was used in the development of flexi dam.

With the above technology, five flexi check dams were set up in Odisha in different locations. The quality of textile-rubber composite used and the anchoring mechanism for the dams were optimized. The functioning of the check dams was critically evaluated by experts from IIT, Mumbai.

13.2.2. Waste Paper Composite

Waste newspaper can be an effective and cheap source of biodegradable reinforcing material for making a composite, in combination with a polyester resin. Three types of composites have been fabricated with different fibre (paper) contents starting from 25% to 48%. It has been found that at 25% fibre content, the composite material shows a tensile strength of 44.5 MPa and modulus of

4.24 GPa along the fibre direction. As far as the tensile properties of the composite material are concerned, tensile strength and the tensile modulus also increase by 54% and 40% respectively along the fibre direction. The composite thus made can be an adequate and low-cost alternative for the lamination of wooden panels used as table tops, false ceiling boards, door panels etc.

13.2.3. Coconut Fibre-reinforced Epoxy Composites

The reinforcing potential of mechanically-fibrillated coconut fibre to be used in an epoxy matrix was put to thorough study at CIRCOT. The coconut fibre was fibrillated by means of a conical refiner for different durations (10 to 40 min) and subjected to chemical composition analysis, size distribution by microscopy and crystallinity by XRD. The fibrillated coconut fibre (FCF) was used to reinforce epoxy resin by the well-known casting process. Properties of the products were estimated by standard methods. The melting temperature of the epoxy composites, as measured by Differential Scanning Calorimetry (DSC), was found to increase from 295 °C for epoxy alone to 339 °C for the composite reinforced with raw coconut fibre (RCF), and to a maximum of 353 °C for the sheet reinforced with fibrillated coconut fibre (FCF) processed for 20 minutes in the refiner. The surface resistivity of epoxy sheet increased from 1.32 e^{10} Ω to 22.6 e^{10} Ω after reinforcing with control coconut fibre. But, the fibrillation process reduced the surface resistivity due to the uniform distribution of FCF in the epoxy matrix averting the formation of air voids. A similar trend was observed in volume resistivity also. The damage force and tensile load increased significantly for the FCF-reinforced composites, by 61 % and 12 %, respectively, when compared to the RCF-reinforced composites. All these tend to suggest that fibrillation of coconut fibre, as an alternative to conventional alkali treatment, could significantly improve the performance of epoxy composites reinforced with this material.

Chapter 14

NANOTECHNOLOGY FOR TEXTILE AND AGRICULTURAL APPLICATIONS

Nanotechnology deals with the manipulation of atoms, molecules or molecular clusters to create functional materials and devices with enriched characteristics. The first hint of the concept of nanotechnology could be traced to Richard Feynman's lecture in 1959 entitled "There's Plenty of Room at the Bottom", wherein he had predicted that in future we will be making things at the atomic level. Nanotechnology has grown in size and scope over the decades with limitless applications in various fields. CIRCOT has done pioneering work in nanotechnology in the last twenty years and has gained experience and expertise in the synthesis and characterization of nanomaterials and their application in textile finishing, fertilizer manufacture, development of nanocomposites, and paper industry. It is significant to note that in 2015, CIRCOT established India's first nanocellulose pilot plant. Outstanding nanotechnology applications identified by this Institute in the domains of textiles and agriculture are highlighted in this Chapter.

14.1. NANOTECHNOLOGY IN COTTON TEXTILES

14.1.1. Antibacterial Cotton Textiles

Nanomaterials are used in textile finishing to impart novel functional properties and to reduce the quantitative requirement of finishing materials. This in turn will bring down the effluent load and also reduce the carbon footprint in textile finishing technologies. CIRCOT ventured into the field of nanomaterial application in cotton textiles to impart antibacterial property way back in the year 2004. Nanosilver, being an established material for imparting antibacterial property, was prepared by altogether new microbial and biochemical methods by CIRCOT scientists who demonstrated its efficacy in conferring antibacterial attribute to cotton fabrics. Nanosilver particles when applied on the surface of cotton textiles, imparted excellent protection against two representative bacteria, *Staphylococcus aureus* and *Klebsiella pneumoniae*. In addition to antibacterial property, nanosilver was also found to impart colour, evidently due to its inherent surface plasmon resonance property. Later, to improve the wash fastness of nanofinished cotton fabrics, a novel *in situ* process of nanosilver synthesis in the fabrics was evolved and demonstrated to various stakeholders. The treated fabrics are found to possess very good potential for use as medical textiles.

14.1.2. UV-protective Cotton Textiles

Ultraviolet (UV) protection is an essential attribute of clothings to avert incidence of sunburn on human body. Semi-conductor materials are known to be very effective in absorbing the UV rays by virtue of their ideal band gap. At CIRCOT, nanozinc oxide and nanotitania were synthesized and applied onto the surface of cotton textiles to impart UV protection property. Among the two materials developed for UV protection, the use of nanozinc oxide on cotton textiles could be demonstrated on a commercial scale to various stakeholders with spotlight on the ease of handling and scaling up of the process. The nanozinc oxide finishing was performed by the novel *in situ* technique resulting in both UV protection efficiency and antibacterial property. This technology of nanozinc oxide production was entrusted to M/s. Anabond Chemicals, Chennai in the year 2007 for commercial exploitation.

The *in situ* synthesis protocol established for the production of nanozinc oxide on cotton fabrics eliminates the use of binders. In this process, a methanolic solution of zinc nitrate and sodium hydroxide was used as precursor for the synthesis, and pad-dry-cure route was employed for the application. SEM scans revealed that the nanozinc oxide particles formed during the *in situ* process have the size range of 80-130 nm. Treated cotton textiles were evaluated for antimicrobial property using AATCC 100 method and for UV protection property using AATCC 183 method. These fabrics recorded excellent UPF rating of 50+ and 100% inhibition against *S. aureas* and *K. pneumoniae.*

14.1.3. Self-cleaning Cotton Textiles

Finishes for imparting self-cleaning property to fabrics are highly desirable for home textiles and apparels. CIRCOT scientists have recently conducted exploratory studies on the application of nanotechnology to confer self-cleaning property on cotton fabrics. Two different types of nano-finishes were attempted. Using nanotitania, the oxidation of the stains on the surface of the cotton fabrics was demonstrated. This finish has the potential to oxidize the organic stains on the surface of cotton fabrics in the presence of light. Another process was meant to impart super-hydrophobicity to cotton fabrics using nanosilica. In this method, nanosilica was applied on the surface of cotton fabrics using a hydrophobic binder whereby the fabric could develop super hydrophobicity (contact angle: over 150 deg). The cloth would thus display high water repellency through what is generally known as the lotus effect. This property will serve to avert the formation of stains as the spillages carrying dirt would just roll down the cloth without being absorbed by the constituent fibres.

14.1.4. Flame Retardant Cotton Fabrics

Cotton textiles being cellulosic in nature are highly inflammable. Nanoparticles of antimony oxide (Sb_2O_3) synthesized at CIRCOT and applied on cotton textiles have been found to impart flame retardant property to the cloth. The synthesized nanoparticle and the treated fabric were characterized by employing XRD, FTIR, TEM, TGA and particles size analyzer. After the application of Sb_2O_3 nanoparticles on cotton textile, the fabric showed excellent protection from

flame. The limiting oxygen index (LOI) value was found to increase significantly from 18 in the untreated sample to 24 in the nanoparticle-treated fabric.

14.1.5. Moisture Management Cotton Textiles

A "moisture management" cotton fabric was developed by electro-spraying a hydrophobic polymer on the inner surface of the fabric/garment close to the wearer's skin. The Janus sheet architecture, in which one surface is ultra-hydrophobic while the other turns hydrophilic, was established in a 100% cotton fabric. The generation of nano-scale surface roughness by electro-spraying fluorocarbon resulted in ultra-hydrophobicity (contact angle more than 140 degrees) on the inner surface of the cotton fabric while retaining the hydrophilicity (contact angle less than 90 degrees) on the outer surface, thereby imparting moisture management feature due to one-directional water/sweat transport. The overall (liquid) moisture management capability of the cotton fabric could be significantly improved from 2.5 to 4.0, on a scale of 0 to 5. The protocol thus developed is eco-friendly and commercially scalable owing to its minimal chemical demand and zero effluent discharge.

14.2. NANOTECHNOLOGY FOR AGRICULTURE

14.2.1. Nanofertilizers

With two decades of experience in the field of nanomaterial production and characterization, CIRCOT scientists ventured into the field of nanofertilizers for the benefit of the farming community. Nanofertilizers are known to possess enhanced fertilizer use efficacy in comparison with the other forms of fertilizers. The nanozinc oxide production technology standardized at CIRCOT was transferred to M/s. Rashtriya Chemicals and Fertilizers Limited, Mumbai, in the year 2019. With the continued research focussed on the development of newer nanozinc formulations, CIRCOT succeeded in making a new stable nanozinc suspension formulation and this technology was handed over to M/s. Biofac Inputs Private Limited, Hyderabad, in 2022. To diversify the scope, now efforts are going on for to developing nanosulphur formulation for use as fertilizer and fungicide in field crops.

14.2.2. Nanocellulose Edible Coating for Fruits

Edible coating on fresh fruits and vegetables prolongs their shelf life by retarding quality changes and quantity losses through modification and control of the internal atmosphere of individual products. Edible coatings are thin layers of fit-to-eat substances applied on the surface of food by dipping, spraying, or brushing, in addition to or as a replacement for natural protective waxy coatings. Further, edible coatings can carry active ingredients such as anti-browning agents, colorants, flavours, nutrients, spices, and antimicrobial compounds that can extend product shelf life and reduce the risk of pathogen growth on food surface.

Nanocellulose-alginate based composite edible coating was formulated at CIRCOT for coating over pear fruits. The untreated as well as coated fruits were stored under refrigerated conditions for a period of 30 days. Pears coated with NC-alginate emulsion retained better quality with subdued ripening and weight loss as compared to uncoated fruits.

14.2.3. Nanofibre Sensor for Fruit Ripening Application

Electrospinning is a process of creating nanofibers from a polymer solution or melt by applying an electric field. The process involves the use of a high voltage to create an electrically charged jet of the polymer solution which is then gathered on a grounded collector, resulting in a fine, continuous fibre. The process of electrospinning has a wide range of applications in fields such as biomedical engineering, power production, environmental science and textiles. The fibers thus produced can be used in drug delivery systems, tissue engineering scaffolds, filters, sensors, and protective clothing. Electrospinning is an efficient and cost-effective method for producing nanofibers with high surface area-to-volume ratio. Two types of electrospinning are under development, viz., needle spinning and needleless spinning. Multi-needle spinning is also called as multi-phase spinning. A multi-phase electrospinning machine was designed and fabricated for production of nanofibre mat and to overcome some of the existing problems.

In order to sense the phase of ripening of mangoes, an electrospun nanofibre-based colorimetric sensor was developed by using a combination of ammonium molybdate and palladium sulphate in an optimized proportion to monitor the ripening of mangoes. This sensing chemical-embedded matrix targets the alkene-based volatile organic compounds released from mango during ripening to change its colour from off-white to blue when the mango is fully ripened. The colour strength of sensor changes with the concentration of ethylene gas. The change in colour occurs due to structural change in sensing chemical after reaction with ethylene.

14.3. MISCELLANEOUS STUDIES

14.3.1. Surface Coating for Paper

The technology for the production of nanozinc oxide discussed earlier was extended for its use as coating on the surface of paper. On storage, paper is prone to suffer fungal attack. Incorporating antifungal property is, therefore, very essential. The nanozinc oxide prepared at CIRCOT was coated on the surface of paper, and its properties were studied. Pilot scale coating trial and characterization of the treated paper were carried out at Central Pulp and Paper Research Institute, Saharanpur. The coated paper showed excellent anti-fungal property. Additionally, significant improvement in glossiness, smoothness and print uniformity was also observed in the nanozinc oxide-coated paper.

Further, nanozinc oxide-coated paper was found to possess higher print density as compared to that of the control paper coated with commercial bulk zinc oxide. It was noted that nanozinc oxide-coated paper displays higher print density than bulk zinc oxide-coated paper. Significantly, nanozinc oxide-coated paper showed no fungal growth unlike the paper coated with bulk zinc oxide. Further, about 55% reduction on material (zinc) consumption was observed when zinc oxide was used in nano form. The technology of nanozinc oxide coating is expected to have a sigificant impact in paper industry.

14.3.2. Nanotechnology in Composites

Nanomaterials, owing to their high surface area-to-volume ratio, are the ideal candidates for use as fillers in composites. Bionanomaterials offer a further advantage in terms of eco-friendliness.

CIRCOT started its research in nanocellulose from the year 2008 with financial support from the World Bank through National Agricultural Innovation Project (NAIP) of ICAR. In the work under this project, nanocellulose was prepared from cotton linters and evaluated for its potential application as filler in starch films. Nanocellulose is found to enhance the tensile strength and reduce the water vapour permeability of starch films. Due to restrictions on the use of plastic bags, nanocellulose-reinforced starch film assumes significance. Based on the outcome of this project and keeping in view the requirement in large quantities of nanocellulose by various industries, a nanocellulose pilot plant was set up at CIRCOT in the year 2015. The plant caters to the needs of various stakeholders. This is the first in India and the only one of its kind in the world to produce nanocellulose form cotton linters on a pilot scale with a capacity of 10 kg per shift of 8 hours. CIRCOT is now exploring the potential applications of nanocellulose in cement concrete, paper coating, reinforced rubber, fruits coating and as fillers in biodegradable films.

Nanocomposites were prepared by using nanoparticles of ZnO stabilized by soluble starch as filler in polypropylene by the melt mixing process. Mechanical properties of nanopolypropylene were found to marginally improve while dielectric strength recorded a notable increase. By monitoring the evolution of the carbonyl absorption bands from FTIR analysis, the efficacy of nanozinc oxide in the reduction of photo-degradation due to UV irradiation could be demonstrated. The excellent antibacterial activity (>99 %) exhibited by nanozinc oxide-impregnated PP against two human pathogenic bacteria, *Staphylococcus aureus* and *Klebsiella pneumoniae*, makes it a suitable candidate for food packaging applications.

14.3.3. Nanofibre Cartridge Insert for Face Mask

Face mask is one of the most effective means to slow down the spread of viruses. During the Covid-19 pandemic, face masks were part of the infection control strategy to eliminate cross contamination. But the masks were made of synthetic fibres known to pollute the environment on disposal. To address this issue, CIRCOT developed an engineered cotton fabric face mask which is re-usable and with qualities like high filtration capacity and improved breathability.

The CIRCOT mask is made of engineered cotton fabric with two different structures in a single repeat. Of the two, one is a highly fluted structure with excellent air permeability while the other has a compact structure with enhanced air resistance. Due to the simultaneous presence of compact and open structures in two layers, the air movement is diverted and transferred through the open structure. The required permeability is thus maintained. Electrospun nanofibre-based replaceable cartridge is also developed for use in the cotton fabric face mask. The cartridge is made with biodegradable polymeric electrospun nanofibres with a diameter of 100-300 nm. Due to such fine fibre diameter and increased surface area, filtration of the most penetrating aerosol particles is made possible, thus enhancing the breathability. About 95% particle filtration efficiency could be achieved by using the face mask inserted with nanofibre cartridge.

Chapter 15

BIO-PROCESSING OF COTTON AND COTTON TEXTILES

Bio-processing is to be understood as the means to make value-added products with the involvement of microbes like bacteria and fungi as well as bio-catalysts like enzymes. Bio-processing is widely used in food, pharmaceutical and chemical industries. It has the potential for applications in textiles too, but this domain remains largely unexplored. Most of the processes in textiles are chemical-based and are hence considered environmentally hostile. Bio-processes, on the other hand, make use of renewable sources like plant material, agricultural wastes, etc., and entail only low production costs particularly because energy requirements are minimal. CIRCOT scientists have been working in the realm of bio-processing in the last few years and have developed many technologies of interest to textile manufacturers. CIRCOT researches are briefly discussed in this Chapter.

15.1. ENZYMATIC BIO-SCOURING

Some preliminary studies at CIRCOT had demonstrated the efficacy of the enzyme pectinase as a bio-scouring agent to remove the impurities present in cotton. Subsequent bleaching process would eliminate the remaining impurities too, besides imparting whiteness to the cloth. Knitted fabrics bio-scoured with pectinase at 55 °C for 30 min followed by bleaching with a commercial bleaching agent (Ranipal) for 30 min could result in a whiteness index as high as 93%. In large scale trials, terry towels made from 20s and 30s yarns were scoured with pectinase and bleached with hydrogen peroxide by the same procedure. The towels showed whiteness as well as water holding capacity matching with similar towels made from yarns processed by the conventional chemical method. The trials have conclusively shown that bio-scouring of cotton goods with pectinase is a satisfactory ecofriendly alternative to conventional scouring. The process has been patented by CIRCOT.

15.2. ENERGY-EFFICIENT PROCESS FOR ABSORBENT COTTON

The unorganized textile sector has limited research support relating to scouring and bleaching that are critical processes in the manufacture of absorbent cotton. The Central and State governments have prescribed pollution norms for strict compliance by the industry. It was felt that an energy-efficient and sustainable scouring and bleaching technique for making absorbent cotton would be of interest to this hapless sector.

Several experiments were attempted at CIRCOT with various enzymes and bleach formulations for scouring to remove impurities in the fibre. A low-temperature (55 °C) treatment using the enzyme pectinase, in combination with an appropriate bleach recipe employing hydrogen peroxide, was found to give satisfactory levels of absorbency and whiteness. The fibre thus treated is found to possess reduced oxycellulose content and minimal change in crystalline-amorphous ratio as compared to the fibre subjected to conventional chemical scouring which also makes high energy demand. Cotton fabrics treated by the new method could meet IP standards in respect of whiteness and absorbency. Interestingly, a process to reduce Chemical Oxygen Demand (COD) of the effluent from absorbent cotton process could also be developed by using activated sludge. Cotton subjected to the new treatment by employing recycled water was found to have the same whiteness and absorbency values as when normal water was used. The process is thus proved to be eco-friendly and energy-saving,with minimal change in fibre morphology.

In a parallel study in pursuit of energy saving in the preparation of absorbent cotton, a single-stage scouring-bleaching method was standardized for use on short staple fibre waste from mills. In this method, a low concentration of 0.5% (W/W) is used for NaOH as the kiering liquor. The bleaching agent hydrogen peroxide (1:30) is added in the same kier for simultaneous whitening. In this process, there is significant energy saving. The left-over liquor can be reused after adjusting the concentrations of chemicals. The process too has been patented.

15.3. AN ECO-FRIENDLY PROCESS FOR ABSORBENT COTTON

An ecofriendly process was developed for preparing absorbent cotton from non-spinnable short staple cotton. Crude enzyme extract obtained from solid-state fermentation actuated by the fungal strain *P. flabellatus* on a 3-component substrate of banana pseudo-stem, cotton seed hulls and cotton seed meal in the proportion 60:30:10, for a period of five days was used for scouring cotton under optimized conditions. The crude enzyme had a good amount of cellulase (37 FPU) and pectinase (128 U/ml) activity. The single-bath enzymatic scouring and bleaching process was optimized thus: cotton fibre-to-enzyme extract ratio 1:12; temperature 60 °C; time for treatment 40 min; pH 9.0 and wetting agent 0.1%. With these optimal conditions, it has been possible to ensure high absorbency marked by a sinking time of 3 sec and a CIE whiteness index of 31.5. The pectinase and laccase activity in the enzyme extract was 25 and 7 units/ml respectively. Results of scale-up trial made under the optimal conditions also gave encouraging results.

15.4. PRODUCTION OF PIGMENT FROM COOKED RICE THROUGH MICROBES

Large-scale production of pigments by gram negative bacteria *Serratia marcescens* was tried on steam-cooked rice used as substrate, enriched with 0.1% yeast extract and 0.1% urea. The 24 hr-old mother culture was added to this substrate and kept for incubation. Pigment production was noticed after 24 hr. The pigment was extracted by using acetone/hexane as the solvent. For quantification, the extracted pigment was concentrated and a known part of it was serially diluted with the same solvent and a standard curve was prepared. During the first 24 hr of

incubation, the pigment with maximum absorbance at 540 nm dominated while further incubation for another 24 hr led to the formation of a new compound with maximum absorbance at 470 nm. The pigments were red coloured after 24 hr whereas the colour turned to orange after 48 hr of incubation. On an average, about 130 g of the pigment per kg of rice could be produced by this method. The pigment was stable under refrigerated conditions.

Aqueous extract of pigment was found to dye nylon and cotton to pink colour with >50% exhaustion. When the same pigment dyeing process was performed on cotton fabric, darker and uniform shade was obtained. Dyed samples had moderate fastness to washing but light fastness was very poor. Treatment with dye-fixing agent did not have much effect on fastness properties.

15.5. ANAEROBIC BACTERIA TO PRODUCE PIGMENT

Anaerobic bacteria, isolated from CIRCOT's microbial consortium, producing red pigment, were grown in tap water enriched with 0.1% urea and 0.1% yeast extract in direct sunlight. Production of red pigment was noticed after one week. As the pigment could not be extracted by chemical and biochemical methods, a mechanical method (grinding) was used to disrupt the cell wall to release the pigment in acetone. The visible spectrum indicated that this pigment is a mixture of at least three types exhibiting absorption maxima at 475 nm, 575 nm and 770 nm. It could turn mordanted cotton into brownish yellow colour. Dye bath exhaustion was low and the same bath could be re-used to dye a lighter shade on another sample of cotton.

A bacterium producing pink coloured pigment was isolated from the inoculums maintained at CIRCOT. This was grown in nutrient broth for 24 hr after which it was centrifuged for 10 min at 10,000 rpm. The supernatant liquid containing the pigment was used for dyeing trials on cotton and other textile materials. It dyed mordanted cotton, wool and nylon quite well. Some coloration was obtained on acrylic, polyester, bleached unmercerised cotton and secondary cellulose acetate also. Washfastness was good for mordanted cotton but lightfastness was not satisfactory. Lightfastness on other substrates also was poor.

Aqueous extract of a fungal culture *Monascus* was yellow coloured but it could not dye any textile material. Methanolic extract was red coloured and it could dye wool, nylon and mordanted cotton to brownish orange colour. Dye bath exhaustion and colour obtained were better for wool. Fastness to washing was satisfactory but light fastness was poor.

15.6. CHITOSAN AS ANTI-BACTERIAL AGENT

The anti-bacterial property of chitosan, a polysaccharide obtainable from shrimp shells after treatment with alkali, was put to test in a study at CIRCOT. Cotton fabrics were treated with pectinase, hydrogen peroxide, and chitosan to achieve bio-scouring, bleaching, and antibacterial effects respectively. The treated samples were found to display excellent resistance to *Staphylococcus aureus*, a common pathogen, both before and after dyeing with berberine, a natural dye. The durability of the chitosan treatment was tested by washing the fabrics for 50 cycles and measuring the bacterial count. The results showed that the fabric maintained 100% anti-bacterial activity up to 35 wash cycles and 80% activity after 40 wash cycles.

15.7. PLANT EXTRACTS FOR FUNCTIONAL PROPERTIES

In one study at CIRCOT, as many as 15 plant materials, including dried fruits, flowers and leaves of familiar plants were tested for the anti-bacterial activity of water and methanol extracts of these plant parts against *Staphylococus aureus* and *Klebsiella pneumoniae*. The extracts of harda and pomegranate rinds and flowers were found to have good antibacterial activity against both the bacteria, presumably due to the high tannin content (above 35%). Cotton fabrics were treated with water-based solutions of harda fruits, pomegranate rinds and flowers, and then fixed with alum resulting in yellow colour with good colourfastness characters. It was concluded that these materials can be used as natural dyes for cotton. The same fabrics when dyed with manjistha, a red natural mordant dye, assumed a good orange colour with satisfactory fastness properties. This showed that these materials can also act as natural tannin mordants for other natural dyes. The UV-visible spectra of these solutions showed good absorption in the UV region, suggesting that they can provide UV protection to textiles. The fabric treated with these solutions and dyed with manjistha had excellent UV protection, as their ultraviolet protection factor (UPF) was 50, while the control fabric had a rating of only UPF 5, which is very poor. The UV protection of the treated fabrics was wash-durable, as there was no change in UPF after washing by ISO 2 test method.

15.8. BANANA PSEUDO-STEM SAP AS FLAME RETARDANT

The use of the sap from banana pseudo-stem as an eco-friendly alternative to hazardous and non-degradable synthetic chemicals for the development of fire-retardant cellulosic fabric was explored at CIRCOT. The extracted sap was made alkaline and applied to the pre-mordanted, bleached and mercerized cotton fabrics. Tannic acid (5%) and alum (10%) were used as mordants. The fire-retardant properties of control as well as treated fabrics were analyzed in terms of limiting oxygen index (LOI) as well as vertical and horizontal flammability. The LOI of treated cotton fabric improved 1.6 times to that of the control fabric. In case of horizontal flammability, the treated fabric did not show any flame, with propagation rate (7.5 mm/min) almost 10 times lower than that of untreated control. The structural characterization of the fabrics with ATR, EDAX and SEM confirmed the presence of the nitrogenous and phosphoric substances and minerals passing from the pseudo-stem sap onto the fabric to form uniform coating throughout the network structure conferring flame retardancy. Thermogravimetric (TG) analysis of treated and control samples showed that pyrolysis of the treated fabric started at a much lower temperature of ~240° (~ 320° for the control sample) and at a slower rate.

15.9. NATURAL FIBRE POUCH FOR FRAGRANT OILS

A novel natural fibre-based fragrance packet was developed at CIRCOT using a combination of non-woven fabric of cotton and paper made from banana pseudo-stem fibre. The packet containing a natural essential oil citronella, delivers pleasant smell while at the same time repelling mosquitoes. The cotton nonwoven layer acts as reservoir and barrier for the oil while the banana paper layer controls the porosity of the packet and the diffusion rate of the fragrance. The optimal size of the packet is 15cm x 9cm and the optimal amount of oil is 4 ml. The packet can

release fragrance for up to seven days over an area of 25-30 sq ft and repel mosquitoes for up to four days.

15.10. PROPIONIC ACID TO PREVENT FUNGUS GROWTH ON COTTON SEED

Cotton seed quality can deteriorate during storage due to microbial growth, especially in high humidity conditions. This can make the cotton seed meal unfit for use if aflatoxins are produced by the fungus *Aspergillus flavus*. The permitted aflatoxin limit varies across countries, with the US having stricter standards than India. The USDA has prescribed an aflatoxin tolerance limit of 6 ppb for feed and 4 ppb for food while in India they are 1000 ppb for feed and 30 ppb for food. To study the effect of propionic acid and yeast culture on *A. flavus* growth and cotton seed quality, seeds were treated separately with these agents and incubated for different durations. Samples were then stored and analyzed for *A. flavus* growth, oil content, protein content and acid value. The results showed that propionic acid @ 0.75% prevented growth of this fungus for two months without significantly affecting the oil, protein and acid value. Large scale trials have also confirmed the absence of this fungus in the treated cotton seeds even after three months.

15.11. PEPTONE FROM COTTON SEED MEAL

Process conditions have been standardized at CIRCOT for preparing peptone out of cotton seed meal left behind after oil extraction from decorticated seed. Cottonseed meal is a rich source of protein that can be hydrolyzed by enzymes to obtain peptone. The hydrolysis involves two steps: first, the cotton seed meal is treated with alkali and pancreatin, and then with papain. The optimal conditions for this process, arrived at from CIRCOT research, are 0.06% alkali, 0.2-0.5% pancreatin, 0.2-0.5% papain, 50 °C temperature, and 18 h duration. The degree of hydrolysis achieved is 28%, which means that the peptone has a high solubility and a protein content of 60%. The yield of peptone is 65% based on laboratory experiments using commercial cotton seed meal.

15.12. BIO-BLEACHING OF PAPER PULP

Paper pulp from cotton stalk and fibre from banana pseudo-stem were treated with enzyme xylanase for bio-bleaching. The xylanase was produced from cotton seed hull substrate by a cost-effective process. The enzyme is thermostable and alkali tolerant, and suitable for reducing the use of bleaching chemicals and thus curbing environmental pollution which is characteristic of pulp and paper industry. Conditions optimized for the bleaching treatment were: enzyme dose 100%; incubation time 120 min; temperature 50°C; pulp consistency 9 % w/v; and material-to-liquor ratio 1:10. The treatment with xylanase was found to increase the brightness level by about 5 % in case of cotton stalk pulp and 15 % in case of banana stem pulp.

15.13. SAFFLOWER AS NATURAL DYE AND FOOD ADDITIVE

One of the potential applications of safflower petals is their use as an additive to enhance the nutritive and medicinal values of food products. In this context, a detailed elemental analysis carried out using Atomic Adsorption Spectroscopy (AAS) on ten varieties of safflower

suggested the total absence of toxic elements As and Hg in all the varieties. Metallic elements like Cd, Cr, Ni and Pb were present in quantities well within the prescribed limit for food preparations. The elements Cu and Zn which are beneficial in herbal medicines were present in all the varieties studied. Cu was in the range of 5-40ppm and Zn was in the range of 7-37ppm. This knowledge of elemental profile was useful in ascertaining the use of safflower petals as food additives and healthcare products.

Study of the stability of safflower pigments showed that the storage stability of 1% and 0.1% of yellow dye solutions containing permitted quantities of preservatives under ambient conditions over 60 days period was satisfactory with the 1% dye solution retaining 90% of the original colour under ambient conditions. Similar trend was noted in case of yellow dye in solid form. Further study of red and yellow pigments showed that carthamine red degraded in aqueous solution even at room temperature and showed 30% degradation at room temperature and 60% at 100 °C. Yellow pigment showed around 20% degradation in 12 h at 60 °C.

Recipes for incorporation of safflower petals in food items were standardized. The interest in herbal tea formulation developed from safflower petals was shown by many small-scale food industries. Two business establishments in Parbhani and Jalna agreed to produce and market the herbal tea formulations. The anti-inflammatory properties of the safflower petals were studied intensively in animals. The extract fed through intra-peritoneal route showed an improvement of 63% as against an improvement of 79% by standard drug. At the dosage levels tried, the extract fed through oral route showed an improvement of about 30%.

15.14. SECURITY PAPER FROM COTTON LINTER

CIRCOT has developed a high-grade blended pulp for making security paper using pulps from cotton linter and banana fibre mixed in the ratio 90:10. This novel paper pulp technology was launched in July, 2017, and tested on a small scale at two industrial sites namely Security Paper Mill at Hoshangabad and Bank Note Paper Mill (BNPM) in Mysuru.

For the industrial trial of banana fibre pulp manufacture, six tonnes of banana pseudo-stem fibre were sourced from the Jalgoan region of Maharashtra, and the pulping was done at M/s.Bindlas Duplux Ltd., Muzaffarnagar. For making banana fibre pulp, a novel enzymatic process was adopted to speed up the pulping operation and to minimize energy demand. Cotton linter available at the industry was used for blending with the banana fibre pulp. In the blended pulp, a nano-material was introduced such that it can be detected in the security paper by a specially designed optical reader. This technology was developed at CIRCOT to enable the Government to identify counterfeit papers. Upscaling trials in the preparation of pulp and making of security paper will be attempted in coming years.

Chapter 16

CHEMICAL PROCESSING OF COTTON AND BLENDS

Readers may recall that Part 1 of this book, under Chapter 7, had dealt with CIRCOT researches relating to the Chemistry of cotton cellulose. The work reported therein pertained largely to basic studies to understand cotton cellulose and its response to chemical reagents, leading to path-breaking discoveries in the potential uses of cotton and its several by-products besides utilization of the biomass left in the farm after harvest. These researches had opened up path-ways for development of technologies that could utilize these materials for making a wide range of products. In later years, some of the researches were continued to explore wider use for these materials and sharpen some of the technologies already developed. The work in the latter period (1998-2002) is, therefore, largely of an applied nature, with emphasis on transfer of technologies wherever possible.

16.1. PLASMA TREATMENT IN PROCESSING TECHNOLOGY

Atmospheric pressure plasma is being increasingly used in the development of water-free, environment-friendly and cost-effective textile chemical processing technologies to develop value-added products. CIRCOT had, as early as in 2002, initiated research in the use of plasma on cotton for modifying its response to water. The potential of plasma treatment in augmenting the dyeability of fabrics has also been put to study. Highlights of the work are given in this Section.

16.1.1. Plasma for Water Repellency

CIRCOT scientists had designed atmospheric pressure plasma reactors of three different sizes, with and without cooling system, supported by advanced plasma characterization systems such as mass flow controllers, digital oscilloscope with voltage and current probes, optical emission spectroscopy (OES) and gas chromatography-mass spectroscopy (GC-MS). The plasma was generated by use of high voltage (2-15 kV) and high frequency (0-25 kHz) AC supply. The size of the reactor body was 24 cm x 14 cm x 18 cm. Two mass flow controllers were attached with the plasma reactor for precise control over the gas flow. Atmospheric pressure cold plasma was generated in the reactors in the presence of helium (He) alone, (He+air), (He+nitrogen), (He+oxygen), and (He+fluorocarbon gases).

Plasmas generated in the above reactors were used to alter the hydrophilic and hydrophobic characters of various natural as well as synthetic textiles. Particularly mentionable was the effort to use the plasma route to impart a high degree of hydrophobicity to cotton textiles. Treatment of cotton fabric with plasma from ammonia, dimethyl siloxane and their mixtures for varying time periods ranging from 5 to 150 minutes could considerably reduce the water absorbency of the fabric. More detailed study of atmospheric pressure cold plasma generated in the presence of helium and fluorocarbon gas showed that it is possible to effect surface modification of cotton textiles to impart a high level of hydrophobic functionality. Plasma-treated cotton fabric did not absorb water droplets even after 3600 sec in contrast to 5 sec in case of untreated sample. Surface modification of cotton fabric using plasma increased the water contact angle from 0° to 142°. Analysis of the surface chemistry of the plasma-treated sample using secondary ion mass spectrometer revealed a strong peak of F^- at 19 amu which established the plasma reaction of fluorocarbon gas with the cellulosic textile.

16.1.2. Plasma for Improved Dyeing

CIRCOT has used plasma technology also for improving the dyeability of cotton fabrics. In some experiments in 2000-01, cotton fabrics subjected to plasma treatment under different conditions were found with improved dye up-take, without any damage to wash fastness, light fastness and DP when compared to dyed untreated fabrics. In a later work, oxygen and ammonia plasmas were used to treat grey and bleached cotton fabrics which emerged with improved dyeability. In 2013-14, different types of dyes such as reactive dyes (Procion red brilliant MX-5B, dichlorotriazine), Berberin (natural dye), Methylene blue (basic dye) and a yellow direct dye were used to colour plasma-treated cotton fabric samples. Treatment of cotton fabric with helium + oxygen plasma raised the K/S value from 2.49 to 2.73 in 2 to 4 min duration of plasma treatment with 9.6% improvement over untreated fabric subjected to similar dyeing. However, the improvement in color was more promising in case of non-cellulosic fabrics such as silk where K/S value increased from 2.29 in untreated sample to 5.22 in sample treated with (He + Nitrogen) plasma. More significantly, with this technology, the dyeing temperature could be reduced from 90 °C to 60 °C and the dyeing time from 45 min to 5 min. Plasma-based technology for textile processing is an eco-friendly and water-less or low-water-based alternative to processing of textiles with reduced effluent generation.

16.2. SYNTHESIS OF SAFE AZO DYES

CIRCOT had developed a technology to synthesize azo dyes from non-carcinogenic aromatic amines during 1998-99. Twenty non-carcinogenic dyes were prepared by employing three newly identified safe aromatic amines and a series of safe coupling agents in an effort to synthesize eco-friendly azo dyes. From one such amine, aniline 2,5-disulphonic acid procured from dye intermediates manufacturing units and several coupling agents, seven different azo dyes were synthesized. Most of the new dyes showed good colorfastness characteristics and imparted bright red, orange, and yellow colors on wool and nylon. The rubbing fastness of the dyes was also good. A few of these dyes were further chemically modified and new reactive dyes of cold brand type were synthesized. All the unmodified dyes were acidic and hence were

able to dye only wool and nylon with good fastness characteristics. The modified dyes were scaled up in the laboratory itself and yield was satisfactory.

16.3. USE OF NATURAL DYES

It has been stated in Chapter 7 (Part 1) of this book that increasing concern over health hazards associated with the manufacture and use of synthetic dyes has revived interest in natural dyes which alone were used in textiles in bygone centuries. Although natural colourants of plant origin are many and ubiquitous, extraction of the pigments, mode of their application on fabrics and ensuring their durability in the substrates are challenging tasks for the technologist. A few decades ago CIRCOT had initiated studies on the application of natural dyes on cotton and the pursuits have continued to the present day with several useful findings to the Institute's credit.

16.3.1. Dyeing with Lac, Berberine and Manjistha

During the years from 1995 to 1998, methods for colouring cotton and blended fabrics with three natural dyes, Lac, Berberine, and Manjistha were developed at CIRCOT under a consultancy project with National Handloom Development Corporation (NHDC), Lucknow. Apart from ascertaining the fastness properties of these dyes applied on fabrics, it has been possible to impart various color shades from the same dye by using different eco-friendly dye-fixing agents and mordants. Pre-treatment of cotton fabric with tannic acid, tartar and alum before dyeing with Berberin and Manjistha dye produced bright yellow color and bright red shade on the cotton fabric which otherwise had very little affinity for these dyes. The technical feasibility of the process was established by conducting large-scale trials in a mill. Purified dye from Manjistha roots and commercial lac dye were obtained with 7% and 30% yields respectively.

Crude lac dye derived as a by-product from lac processing industry was used as such to dye cotton fabric pretreated with chitosan and amino compounds. Pretreatment of the cotton fabric with mordants and dye fixing agents for lac dyeing was optimized. Dyed samples showed good rubbing and perspiration fastness.

More recently, the dye from Manjistha was used on unmercerized and mercerized fabrics with different blend ratios of polyester and cotton, mordanted with tannic acid and alum. Fabrics dyed with Manjistha on a large scale produced beautiful ruby pink color. Manjistha-dyed fabrics showed good wash and rubbing fastness while perspiration fastness ranged from moderate to good.

16.3.2. Turmeric for Dyeing

Another natural product attempted for dyeing cotton was powdered turmeric, a substantive dye. Dyeing procedure was standardized with a view to assess the efficiency of mordants and their application methods. Three metallic mordants namely, alum, ferrous sulphate and copper sulphate applied on scoured and bleached cotton by pre-mordanting technique were found to increase the color strength, with the iron mordant showing the best result. However, dyed fabric displayed poor light fastness property which failed to improve with the use of either Glauber's

salt or without any fixing agent. Processing conditions for dyeing of polyester-cotton blended fabrics with turmeric were also optimized.

16.3.3. Dyeing with Five Varieties of Safflower

Ecofriendly colours were isolated from five varieties of Safflower and studied for their dyeing characteristics, elemental profiles and stability against natural agents. Colour strength (K/S values) varied from 1.3 to 7.3 in normal varieties of safflower while in non-spiny varieties it ranged from 5.2 to 7.3. Detailed elemental analysis employing Atomic Absorption Spectroscopy on ten other important varieties of safflower showed total absence of As and Hg in all of them. Storage of 1% and 0.1% solutions of yellow dye containing permitted quantities of a preservative under ambient conditions showed satisfactory stability of color for a period of over 60 days whereas red and yellow pigments of carthamine in aqueous solution were thermolabile even at room temperature.

16.3.4. Use of other Flowers

Extracts of Aster and Chrysanthemum flowers were used on cotton fabrics which, when dyed with these colours, showed excellent fastness to light and rubbing, medium-to-good fastness to washing and to alkaline perspiration, but only poor-to-fair fastness to acidic perspiration.

16.3.5. Tender Cocount Husk as Natural Dye

Cotton textiles mordanted with tannic acid and alum were successfully dyed with the extract obtained from tender coconut husk at an alkaline pH to reddish pink shade. The tender coconut husk extract contained about 3600 ppm tannin and hence served as a mordant-cum-dye for cotton fabrics. It produced a good colour but the shade obtained was lighter compared to that obtained with commercial tannic acid as mordant. Different colour shades could be produced when inorganic salts, such as copper sulphate and ferrous sulphate were used as secondary mordants. Fastness properties of most of the dyed samples were very good but some samples showed a colour shift towards darker side upon exposure to perspiration and some staining on adjacent fabrics was observed in case of copper mordanting. Scale-up trials were performed in a laboratory rope dyeing machine as well as Rotary Pressure Vessel. Although the samples were uniformly dyed in rope dyeing machine, the shades were lighter compared to the lab-scale trials conducted in a launderometer. Samples dyed in Rotary Pressure Vessel showed bright and dark colours. Dyed fabrics were also found to have the UPF value of 50+ indicating excellent protection from ultraviolet light.

16.3.6. Colouring of P-C Blends with Natural Dyes

The natural dyeing of polyester-cotton (P-C) blended fabric with manjistha was found to be influenced by the type and method of mordanting. Five mordants, namely alum, copper sulphate, ferrous sulphate, stannus chloride and harda, were applied either before or after dyeing. The fabric was dyed to 20% and 40% shades using two stages of dyeing. The first stage involved treatment at 80 °C and neutral pH, while the second stage involved dyeing at 130 °C

and acidic pH. The dye uptake of the fabric was measured after each stage of dyeing. The results showed that the dye uptake ranged from 62% to 72% for 20% shade and from 65% to 71% for 40% shade at 80 °C. The dye uptake decreased to 51% to 65% for 40% shade at 130 °C.

The optimal conditions for extracting turmeric dye were identified as 100 °C temperature and 60 min. duration. The dyeing process of P-C blended fabrics with turmeric depended on the blend composition. Polyester needed 120 °C, pH 5.0 and 50 min. for best results while cotton required 80 °C, pH 5.0 and 95 min. The fabrics were pre-treated with different mordants (alum, copper, iron and tin) and dyed by the one-step or two-step method. The colour quality and fastness properties of the dyed fabrics were assessed. The pre-mordanting increased the colour strength and most of the fastness properties were acceptable, except for light fastness which was very low, and could not be improved by adding Glauber's salt or dye fixing agent. For manjistha-dyed fabrics, the washfastness and rubbing fastness were very good, the perspiration fastness ranged from moderate-to-good and the light fastness varied from moderate-to-good. However, tin-mordanted fabrics displayed very low light fastness.

16.3.7. Further Studies in Mordanting for Colouring with Natural Dyes

The role of mordants in cotton dyeing with natural dyes is crucial because this fibre has low affinity for most natural dyes. Mordanting is the most important process of preparing fibres to accept the colours. Most of the natural dyes require the use of mordants to achieve durable, long-lasting colour. The mode of application of the mordant (such as pre-, simultaneous or post-mordenting) would affect the extent of dye pickup as well as the fastness properties. Miscellaneous studies have also revealed the efficacy of certain biological materials as mordants for dyeing. These studies are briefy discussed in this section.

Sequencing of Mordanting

The effect of alum, ferrous sulphate and copper sulphate as metallic mordants on colour parameters and colourfastness properties of turmeric (a substantive dye) and manjistha (a mordant dye) was investigated. The mordants were applied by pre, post and simultaneous mordanting techniques. The results showed that cotton absorbed more metal at 60 °C than at room temperature. The metal uptake was reduced by the addition of cream of tartar or citric acid in the mordanting bath. Pre-mordanting increased the colour strength values of turmeric dyed fabrics by 11% - 61 % for alum, 81% - 125% for iron and 6% - 52% for copper and made them darker. Iron-mordanted samples were the darkest but less yellow. Simultaneous mordanting decreased the colour strength and yellowness values for alum and iron mordants but increased them by 70% - 105% for copper. Post mordanting with alum and copper had little effect on colour strength but tannic acid-ferrous sulphate combination enhanced the colour strength and darkness but reduced the yellowness. Turmeric dyed samples without mordant had moderate fastness to washing, excellent-to-very good fastness to dry and wet rubbing but very poor fastness to light. Rubbing fastness was not affected by mordanting. Alum and iron mordants lowered the wash-fastness but iron mordant improved the light-fastness to some extent. Copper improved the light-fastness significantly and even extractable copper levels below 50 ppm (eco - limit) improved the light-fastness.

The dye uptake of manjistha was very low in post mordanting and simultaneous mordanting. Only pre-mordanting was effective. The alum pre-mordanted samples had aluminium levels from 14 to 1506 ppm, depending on various factors such as temperature, additives, and tannic acid pretreatment. These samples showed red hues after dyeing. The colour strength increased from 1.16 to 7.63 with higher aluminium levels. The ferrous sulphate pre-mordanted samples had iron levels from 420 to 816 ppm, depending on the mordanting conditions. These samples showed violet hues after dyeing and were less red than the alum samples. The copper sulphate pre-mordanted samples had copper levels from 195 to 843 ppm, depending on the mordanting conditions. Unlike turmeric, these samples had low colour strength values (0.76 to 1.99) after dyeing with manjistha. The extractable copper levels of these samples were also low and within the eco-limits. The manjistha dyed samples had fair to moderate wash-fastness, moderate to good light-fastness, and very good rub-fastness. The colour-fastness properties did not change much with different mordants, except for some improvement in wash-fastness with copper and iron mordants.

Banana Pseudo-stem Sap as Mordant

The sap of banana pseudo-stem, which is rich in poly-phenols and minerals and is discarded after extracting fibres, was used as a low-cost and eco-friendly mordant in natural dyeing. The sap has a low tannin content of 67 ppm, but it carries copper and iron, which can enhance the light-fastness of the dyed fabrics. In CIRCOT studies, the sap was applied to cotton fabrics before and after dyeing with berberin and turmeric, which are natural dyes with poor light-fastness. The sap improved the colour properties and fastness of the dyed fabrics in different ways. The sap made the berberin-dyed fabrics darker and less yellow, while it made the turmeric-dyed fabrics more yellow and brighter. The sap also improved the fastness to alkaline perspiration of the turmeric-dyed fabrics, and increased the light-fastness of some of the dyed fabrics.

Arecanut as Mordant

Chemical analysis of the arecanut indicated the presence of tannins measured in terms of (+) catechin to be around 10%; hence it was used as replacement to tannic acid for mordanting cotton. Finely powdered arecanut was extracted with water (at M:L ratio of 1:30 at room temperature for 30-60 min) and the decanted liquid was used to mordant cotton fabric. The initial weight of the arecanut was so adjusted as to yield 10% and 20% tannin content in the extract. Commercial tannic acid (10% and 20% level) was also used for comparison. Arecanut and tannic acid treated fabrics were further mordanted with alum (10%) and dyed with manjistha to 10% shade. Samples dyed using commercial tannic acid were reddish in colour whereas samples dyed using arecanut-derived tannin were reddish orange and also had higher colour strength. It showed the suitability of tannins extracted from arecanut for dyeing of cotton with natural dyes.

16.3.8. Miscellaneous Trials

In one CIRCOT study, the pigment obtained from oven-dried florets of Marigold and Chrysanthemum was used to dye fabric with simultaneous evaluation of effluents generated at

each step. Pigment from anaerobic pigment-producing bacteria, *Serratia marcescens*, isolated from CIRCOT's microbial consortium,was characterized for potential use in dyeing textiles.

In a later work, dyeing process of cotton with Marigold and Chrysanthemum flower extracts was scaled up. Application of natural dyes reduced the Total Organic Carbon (TOC), Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) values of effluents. Cotton fabric was dyed with extract from Marigold flowers using eco-friendly mordants to obtain six different shades with uniform dyeing in the jigger dyeing trials. The process has been patented.

Under an NATP project, natural dye was isolated from Safflower petals and powdered extract of the dye was obtained by spray drying. The powdered pigment was used to colour a 5-metre long fabric employing a laboratory model Winch Dyeing machine.

Some years ago, CIRCOT scientists had developed a method for spectroscopic and chromatographic characterization of natural dyes obtained from aerial stems, running stems and roots of *Rubia cordifolia* and stem of *Rubia sikkimensis*. All the extracts showed maximum absorbance in the visible region at 400 nm. One gram mordanted cotton sample was dyed with these extracts and the K/S values of dyed samples were noted to be in accordance with the absorbance. Aqueous extracts of orange and yellow Marigold, white and yellow Chrysanthemum and purple Aster flowers containing flavonoid type of pigments were prepared and their UV-VIS spectra were recorded. Suitable solvent systems for separating these extracts into various constituents by HPTLC were developed. Later, dyes extracted from cultivated *Rubia cordifolia* and *Rubia sikkinensis* were characterized through spectroscopic and chromatographic techniques. HPTLC fingerprints of various natural dyes were also developed to establish the purity of natural dyes available in the market. For improving the color fastness of natural dyes, sap from banana pseudo-stem was used as mordant for simultaneous and post-mordanting of cotton fabric while dyeing with Berberin and Turmeric dyes. Simultaneous mordanting of cotton fabric with banana sap enhanced the darkness and brightness of the dyes. Also used was tannin-rich extract from coconut husk for dyeing of cotton textiles mordanted with tannic acid and alum.

Development of a simple process for eco-friendly dyeing and durable UV-protective finishing of cotton textiles using plant extracts of dried fruits of Harda (*Terminalia chebula*), Beheda (*Terminalia bellerica*) and rinds of Pomegranate (*Punica granatum*) was yet another initiative by CIRCOT researchers. The treated fabrics showed excellent dye fastness and UV-protection (UPF rating 50+) property even after 10 wash cycles. The K/S value of treated samples remained singularly unchanged after the washes.

16.4. CROSS LINKING COTTON WITH POLYCARBOXYLIC ACID

Although DMDHEU serves as a cost-effective finishing chemical to impart dimensional stability, wrinkle resistance and crease recovery properties to cotton fabrics, the continued presence of this chemical in garments even after their life cycle is over, hampers dissolution of cotton cellulose needed for the manufacture of regenerated cellulose from rags. Moreover,

health and environmental problems associated with formaldehyde release remain a major concern over its continued use in textile finishing. In order to overcome the potential effects of methylol-based easy-care finishes, a number of alternative zero-formaldehyde finishes based on polycarboxylic acids (PCA) have been investigated and their relative performance demonstrated at CIRCOT.

Strength retention and durability of fabrics are major challenges in the use of any finishing chemical. A technology was developed at CIRCOT for improving the strength retention and crease recovery of cotton and polyester-cotton blended fabrics treated with polycarboxylic acid mixtures. To augment strength retention, magnesium salts as well as sodium hydrogen orthophosphate were tried as catalysts. Treated fabrics showed better strength retention without much loss in crease recovery angle (CRA) and smoothness properties.

In a more detailed study, crosslinking was carried out on polyester-cotton blends of different proportions. Treated fabrics were dried at 85° C for 5 min. and cured at 180° C for 3 min. using air draft oven. Add-on was found to be very low in case of polyester whereas blends had reasonably good add-on and satisfactory SA as compared to pure polyester fabric. Polyester fabric exhibited better strength retention than control. There was not much difference in SA, CRA and strength retention when the pH of mixture was changed from 3.5 to 4.5.

In another experiment, a system containing a mixture of citric acid and butanetetracarboxylc acid was identified for imparting easy-care properties to cotton fabrics which, after treatment, recorded dry and wet crease recovery angles of 268° and 233°, respectively. The durable press rating of this fabric was 5.0.

16.5. MICRO- AND NANO-LIGNO CELLULOSE

CIRCOT had developed a technology during the year 2016-17 for the isolation of nano form of lignocellulose (NLC) from cotton stalks and coconut fibers by chemo-mechanical and bio-mechanical processes for its potential applications in improving the mechanical, electrical and permeability properties of composites made from these materials. The processes for preparation of NLC from the two materials were optimized. NLC from coconut fibers was produced by a two-stage process of refining and pressure homogenization, and from cotton stalks by a three-stage process comprising pulverization, refining and high pressure homogenization. NLC possessing a mean size of about 375 nm and zeta potential of -27 mV produced by the optimized methodology was used as filler in epoxy resin composites. Due to partial hydrophobicity of lignin, NLC could get uniformly dispersed in the epoxy resin during composite preparation. Addition of fibrillated coconut fibers significantly increased the impact strength (60%) while the tensile strength and ductility index declined, indicating an increase in brittleness and Young's modulus. Also, the thermal stability of composites impregnated with coconut fibers was better as indicated by their increased melting temperature. Surface resistivity of composites demonstrated better phase mixing of nano-fillers in composites.

In a later study, nano composites were prepared by using a 50:50 blend of NLC from cotton

stalks and coconut fibers. The impact strength and tensile strength of these composites were higher than those of composites made with only one of the two NLCs. Blue and brown pigments were added in the composites to enhance the aesthetic value of the composites.

For applications of the NLC-based nanocomposites, various alternatives were explored. One among them was the use as nursery seedling trays which are a better alternative to plastic trays. Large trays using cotton stalk-reinforced polyester matrix were prepared for trials in nurseries. These trays were supplied to ICAR-DFR, Pune, for field evaluation through a study of plant growth in these trays filled with media of different water holding capacities. The plant growth was found to be satisfactory and the trays were stable for more than 8 weeks. Other areas of application of nano-composites identified at CIRCOT include their use in panelling, moulds, master moulds, laminates, castings, fixtures, components for aircraft, high-performance boats and automotives, filament-wound pipe for oil industry, windmill blades and sports equipment.

16.6. NON-METAMERIC COLOUR MATCHING IN TEXTILES

CIRCOT scientists have developed a technology for non-metameric color matching to address the issue of metamerism occurring in the CIE method of color matching. A database was prepared by dyeing cotton fabrics with various concentrations of reactive dyes which were subsequently used to calculate the dye recipe to match any colour shade. Reactive HE dyes (15 different colors) were applied on cotton fabric samples with 10 different concentrations (0.1 to 0.4%). Total 150 samples at different ranges of shades were obtained for each reactive dye. The reflectance values of the dyed samples were measured by using spectrophotometer, and their alpha values were used as inputs for a software program (database) which was developed using 'BASIC' language so as to predict the dye recipe for non-metameric color matching.

Chapter 17

COTTON BY-PRODUCTS UTILIZATION

Cotton crop yields various by-products after harvesting and ginning, such as seeds, linters, hulls, meal, oil, and stalks. These by-products are often neglected, even though cotton seed oil is a significant source of domestic oil and cotton seed and cotton seed cake are used as animal feed. CIRCOT scientists have developed ways to use the by-products of cotton crop in different industrial processes and add value to them. This Chapter presents a brief overview of CIRCOT's research on the diverse applications of cotton by-products. Research in byproduct utilization started at CIRCOT in the 80s of the last century, and a few technologies had been evolved in the early years. An account of these researches is given in Chapter 8 (Part 1) of this book. The work has continued and a report on later work forms the subject of this Chapter.

17.1. COTTTON SEED OIL

17.1.1. Novel Methods of Oil Extraction from Cotton Seeds

A comparative study was made of the methods of cotton seed oil extraction with solvents like hexane and isopropanol, as well by the centrifuging method, in order to evaluate their relative merits. Hexane extraction at 66°-70 °C for 1-5 hours with a material-to-liquid ratio of 1:5 was found to give the highest oil yield of 93% after 5 hours. Isopropanol extraction at 85 °C for 1-4 hours with a material-to-liquid ratio of 1:4 gave a lower oil yield of 53% after 2 hours, and no further improvement could be found with longer duration. Use of isopropanol had the merit of being less toxic, reduced presence of free gossypol in the oil and meal, and superior protein quality. Centrifuge extraction with petroleum ether for 1-9 minutes at different speeds gave the maximum oil yield of 26% in 5 minutes and 2600 rpm. Centrifuge extraction was simple and fast, and produced oil with a deep color. Hexane extraction was the most efficient method, but isopropanol and centrifuge extraction had some advantages in terms of quality and simplicity.

Supercritical carbon dioxide (SC-CO_2) is a green solvent that can extract oil from cotton seed without leaving any harmful residues. This method was tried at ICT, Mumbai, and it was found that oil yield increased with higher pressure and temperature. The maximum yield was 43% at 550 bar and 80 °C for 2 hours. The oil had a golden yellow color and a low gossypol level of

0.022%, which met the FDA standard of 0.45%. This oil can be used for food purposes with minimal refining. Higher pressure equipment may further enhance the oil extraction efficiency.

17.1.2. Frying Performance of Cotton Seed Oil

Oil quality deteriorates when it is heated at 180 °C or 200 °C for long periods of time. Heating causes changes in the oil's chemical and physical properties, such as viscosity, acid value, peroxide value, p-anisidine value, iodine value, etc. The oil becomes foamy and unhealthy for frying and intake. To prevent such deterioration, dimethyl polysiloxane can be added to the oil as an antifoaming agent which forms a film on the oil surface and reduces oxygen uptake from the atmosphere. This helps to preserve the oil quality for a longer time. Different concentrations of dimethyl polysiloxane were tested on cotton seed oil by frying continuously or intermittently. The results showed that this antifoaming agent at 10 ppm concentration lowers the viscosity, acid value, peroxide value, iodine value and p-anisidine value, all highlighting the stability and quality of the oil.

17.1.3. Purifying Polymerized Oil

Polymerized cotton seed oil was procured from a fast food outlet in an attempt to make it usable again after appropriate means. The much-used oil when tested by standard methods showed high levels of peroxide, p-anisidine, and free fatty acids (FFA), besides being high in viscosity and colour, all highlighting its unsuitability for consumption. In order to purify the oil, 13 different combinations of adsorbents like silica gel, activated charcoal and aluminium oxide were attempted. The best results for peroxide, p-anisidine, FFA and viscosity were achieved with silica gel and 4% activated charcoal, but the colour was slightly lower than the oil purified by 1% activated charcoal with silica gel and aluminium oxide. The combination of silica gel + aluminium oxide with 1, 1.5 and 2% activated charcoal also improved the three parameters (FFA, colour and peroxide) to the levels close to those obtained from 4% activated charcoal with silica gel. The highest reduction in FFA was obtained with 1% activated charcoal with silica gel.

17.1.4. Blending of Cotton Seed Oil with other Oils

Cotton seed oil is edible after removing gossypol, but it has a lot of omega 6 fats. To make it healthier and more stable, it can be mixed with other oils. Cotton seed oil (CSO), palm olein (PO) and some cold pressed oils like groundnut oil (GO), sesame oil (SO), and coconut oil (CO) were purchased from the market. These oils had no antioxidants added. Physical and chemical properties of these oils were tested in the laboratory. Coconut oil was the lightest in color and sesame oil was the darkest. Palm oil was the thickest (50.48 cps) and CSO was the thinnest (30.67 cps). Mixing CSO with other oils made them less thick.

An experiment was conducted to ascertain how these oils and their blends with CSO changed when stored at 60 °C for 28 days. The peroxide value (PV) and p-anisidine value (p-AV) were determined on all samples every 7 days to estimate their total oxidation or Totox value (TV). The PV shows how much the oil has oxidized, p-AV shows how many byproducts are formed, and TV shows the total oxidation level. In our measurements, all these values were found to increase

over time. PV increased faster in the first 14 days and then slowed down, while p-AV increased faster after 14 days. This meant that the oil was breaking down more in the later stage. Sesame oil was different, as its PV increased slower in the first 14 days and faster thereafter.

CSO was the least stable oil in terms of oxidation, while CO showed the highest stability. Mixing CSO with other oils enhanced its stability as the proportion of the other oil increased.

Rose-mary extract (RE), a natural antioxidant, was used to improve the oxidative and thermal stability of CSO. Dry RE made in the lab was added to cotton seed oil at 0.1% concentration of 1.00 mg/kg (0.1%) and it improved the oxidative stability of cotton seed oil significantly. The PV and FFA of oil with RE increased much less when heated intermittently at 150°C for 6 h/day for 5 days.

The frying stability of these oils and their 50:50 blends with CSO was tested by frying potato slices 10 times. Chemical parameters of the oil were measured after the first frying as well as after the tenth. CSO had the lowest frying stability and CO had the highest after one and ten fryings, as indicated by the TV values. The 50:50 blends of CSO with other oils had better frying stability than CSO after one frying, with SO blend being the best. CSO and SO blend had better frying stability than the individual oils after ten fryings, showing a synergistic effect, but other blends had worse performance than the individual oils. The colour of CSO did not change much after ten fryings, while CO and GO became darker and SO and PO became lighter.

17.1.5. Peptone from Cotton Seed Meal

Cotton seed meal is a rich source of protein that can be hydrolyzed by proteolytic enzymes to produce peptone. Early work on the identification of a method to prepare peptone from cotton seed meal using the two enzymes papain and pancreatin was mentioned in Chapter 8 (Part 1) of this book. In a later work, the conditions for using the two enzymes to hydrolyze cotton seed meal were subjected to further optimization. The cotton seed meal was pre-treated with alkali (0.06%) before being subjected to sequential hydrolysis with pancreatin and papain. The optimal enzyme concentrations were 0.2% and 0.5%, respectively, and the optimal temperature and time were 50 °C and 18 hours. The resulting peptone had a desirable degree of hydrolysis of 28%.

17.1.6. Microbial Elimination of Gossypol

Cotton seed is a valuable source of oil and protein, but its use as animal feed is limited by the presence of gossypol, a toxic compound that affects non-ruminants and humans. To overcome this problem, a novel and eco-friendly process for detoxification of gossypol in cotton seed cake was developed by using two microbial cultures (*C. tropicalis* and *S. cerevisiae*). The process involved mass multiplication of these cultures from petri-plate/slant to flask and to drum, and adding them to the cotton seed meal, UD cake and DOC with 70% initial moisture content. The mixture was then incubated for 36 to 48 hours for solid state fermentation, followed by drying for 3 to 4 hours at 70 °C to achieve around 10% moisture. The final product was packed in PP bags.

The solid state fermentation technique reduced the free gossypol by 70-80% and the bound gossypol by 50-60%. It also increased the protein content by 10-15%. The gossypol level in the fermented cake met the standards of FDA and protein advisory group, USA and the product can be used as feed for non-ruminants (poultry and fisheries). The performance evaluation of the fermented cotton seed cake in broilers showed that the cultures are safe and have improved feed conversion ratio (FCR). It was found that up to 40% of soybean meal can be replaced with fermented cotton seed cake in the diet of both broilers and layers. The process is environment friendly as it does not produce any effluent. It has been patented and licensed to a company for manufacture.

17.1.7. Gossypol Reduction through Solvent Extraction

As discussed earlier in other contexts, gossypol which is a toxic compound, limits the use of cotton seed meal as a food ingredient. One way to reduce gossypol levels is to ferment the meal, but this results in a dark-coloured, unappealing product. Another way is to extract gossypol with solvents, such as acetone. Acetone extraction leaves the meal white in colour with low levels of free and total gossypol content levels. A combination of acetone and water can further lower the gossypol levels, but it may also affect the protein and lysine content of the meal.

The initial gossypol content of the cotton seed kernel also influences the final product quality. Commercially available cotton seed meal that has been de-oiled with hexane can also be de-gossypolised with acetone, using different methods such as Soxhlet extraction, sonicator extraction or overnight soaking. These methods vary in their efficiency and impact on the nutritional value of the meal. The gossypol levels in commercial kernel flakes were reduced by acetone extraction. The Soxhlet extraction method gave the lowest total and free gossypol (0.82% and 0.08%), followed by the sonicator extraction (1.32% and 0.3%) and the overnight soaking (1.24% and 0.22%). The protein content of the flakes was 51%. The commercial solvent de-gossypolised meal had higher gossypol levels (2.21% and 0.39%) and protein content (59.6%).

A new method for extracting cotton seed flakes without colour loss was developed using water and acetone at room temperature. The method yields about 100g of light yellow material with high protein content (63.2% crude, 39% alkali soluble) and low gossypol levels (1.26% total, 0.14% free). This material can be mixed with cereal flours to enhance their protein value. The extraction liquid can be distilled to recover up to 95% of the acetone, leaving the crude gossypol in the distillation flask.

17.1.8. Cotton Seed Milk

The process of making Paruthi Pal, a traditional drink from Tamil Nadu, was investigated and compared with a laboratory experiment using delinted cotton seeds. The aim was to measure the amount of nutrients and gossypol that are extracted from the seeds into the drink. The seeds were cleaned, soaked, ground with water and filtered to obtain a white milky liquid. The analysis showed that 45% of the seed solids, including protein, oil and gossypol, were transferred to the liquid. The seeds had 23.55% protein, 22% oil, 1.82% total gossypol and 0.785%

free gossypol. The residue had 17.7% protein, 9% oil, 0.5% total gossypol and 0.04% free gossypol. The freeze-dried liquid had 38% protein, 17% oil, 3% total gossypol and 0.5% free gossypol. The gossypol level was higher than the safe limit for human consumption; so this drink should be consumed only sparingly.

17.1.9. Protein Extraction from CSM Using Alkali

An efficient method to extract protein from cotton seed meal (CSM) making use of an alkali was identified at CIRCOT. This method was found to reduce the gossypol content in the protein and increase the protein recovery rate. The protein has good structural properties, making it suitable for various applications. The amino-acid profile of the cotton seed protein isolate (CSPI) was analyzed to check its nutritional quality. It was found that that CSPI has all the essential amino-acids required for animal nutrition, meeting established standards. It was concluded that protein extracted from CSM by this method can be a safer and more nutritious food supplement for mono-gastric animals.

Further process of optimization in the extraction and purification of proteins from de-oiled CSM was carried out resulting in an impressive protein recovery rate of 93.6% and a low level of free gossypol. The isolated protein was found to possess optimal functional properties for potential use in food product development.

17.2. COTTON STALK UTILIZATION

Cotton stalk is the biomass that remains in the field after the seed cotton is harvested. It is often considered as a waste material, although in some rural households it is used as domestic fuel. The bulk of the cotton stalk is, however, burned in the field itself after cotton picking is complete. Cotton stalk has high content of holo-cellulose (67 to 70 %), lignin (24 to 28 %) and ash (6 to 8 %). Taking advantage of the fact that cotton stalk is similar to hard wood in fibrous structure, CIRCOT scientists had explored its use as raw material for making industrially important products like particle boards, hard boards and different grades of paper, etc., and had developed various technologies for their manufacture. Chapter 8 (Part 1) of this book has discussed the early researches on the utilization of cotton stalks. Some recent studies and their outcome are highlighted in this Section.

17.2.1. Cotton Stalk Pulp in Blends

Blending is the means to combine the positive qualities of components in the mix. As mentioned earlier, cotton stalk pulp has been found from CIRCOT studies to be eminently suitable for making different grades of paper. Pulps from rice straw and wheat straw are of inferior quality for this application. For enhancing the quality of straw pulps, attempts were made to blend them with cotton stalk pulp. Chemi-mechanical pulps from rice straw and wheat straw were mixed with chemical pulp from cotton stalk in different blend ratios ranging from 10% to 40%. The paper sheets made from the blended pulps showed a wide range of quality grades. Significant enhancement in the properties of paper from wheat and rice straw pulps was noticeable when blended with chemical pulp of cotton stalk. The optimum blend composition for good quality

paper was found to be 40% cotton stalk pulp and 60% straw pulps. For wrapping and packing paper, the 20:80 blend composition was suitable, while for writing and printing paper, the 30:70 and 40:60 blends were preferable.

17.2.2. Preparation of Cellulose Powder

A new method of preparing cellulose powder was attempted in which cotton stalk was subjected to a biological softening process followed by bleaching and acid hydrolysis. The final product is good quality cellulose. The purified and bleached pulp was hydrolyzed in 2.5 N hydrochloric acid to obtain cellulose powder. This contrasts with the behavior of pulps obtained by the chemical process which upon acid hydrolysis yield microcrystalline cellulose (MCC). The hydrolyzed product was characterized by X-ray diffraction technique, which indicated slightly lower degree of crystallinity. Therefore, this can be utilized as cellulose powder for various end uses. Its suitability as carbon source for the production of cellulase enzyme was also ascertained. The chemical constitution of cellulose powder obtained from cotton plant stalk had a cellulose content of 79% (commercial product-- 99%) and amorphous content of 46.0% (commercial product–46.0%). Enzyme activity was 2325 RS/µg/ml compared to 1320 RS/µg/ml of commercial product.

17.2.3. Hardboard from Cotton Stalk – Large-scale Trial

CIRCOT had, some years ago, developed a process for the preparation of hardboards (binderless boards) from cotton stalk. It comprises chipping of stalk, preparation of thermo-mechanical pulp, and mat formation, followed by pressing of the mat in a steam-heated hydraulic press. The process needs no chemical binder; the lignin present in the material acts as the binder. Standardisation of the process parameters was done through a series of laboratory trials already discussed in Chapter 8 (Part 1) of this book.

A large-scale trial employing the standardised values of process parameters was conducted at a particle board factory in Maharashtra, using about 20 tonnes of cotton stalk chips. Good quality binderless boards were prepared from 100% cotton stalks. Trials were also undertaken with blends of cotton stalks pulp with bagasse pulp to prepare boards. Good quality boards could be made with the pulps blended in the ratio 1:1. The trial clearly showed that the process of preparing binderless boards from cotton stalks was technically feasible on a commercial plant. There were no difficulties encountered in the commercial plant except for the fact that the feeding funnel used to get clogged due to presence of bark in cotton stalk. A slight modification was, therefore, made in the feeding mechanism to overcome the problem. Mechanical strength of the board (59.2 Mpa) was far above the BIS norm (30 Mpa). Water absorption was slightly higher (50%) compared to BIS norms (40%) which may be due to the presence of bark covering of the cotton stalk.

17.2.4. Softboard from Cotton Stalk

Thermo-mechanical pulps from bagasse and wood material are generally used together in the preparation of softboards. Since cotton stalk produces good quality thermo-mechanical pulp, it

was decided to use it in the preparation of softboards. Trials were undertaken in a particle board factory in Maharashtra where thermo-mechanical pulp of cotton stalk was blended with bagasse pulp in the ratio 20:80 and softboards of 11 mm, 16 mm and 25 mm thicknesses were made. The boards were found to be of good quality as evidenced by the modulus of rupture (MOR) value of 22 kg/cm^2 which was better than that of 100% bagasse boards (18 kg/cm^2). The study indicated that depending upon the requirement of MOR, cotton stalks could be blended with bagasse to produce softboards of desired quality. These boards find application as insulating material.

17.3. TECHNO-ECONOMIC STUDY OF PARTICLE BOARD FROM COTTON STALK

In order to popularise the CIRCOT technology for making particle boards from cotton stalk and thus encourage entrepreneurs to set up manufacturing units, it was felt necessary to make an in-depth study of the whole process, with emphasis on the supply chain logistics of the raw material. The study jointly sponsored by CFC, Netherlands and ICAC, Washington, was intended to examine the techno-economic feasibility of the entire range of activities needed to manufacture particle board from cotton stalk. The study amply demonstrated that the processes for making particle board from cotton stalk developed at CIRCOT is technically feasible and is endowed with the potential for commercial exploitation. This technology holds promise as an alternative means to circumvent the raw material crunch faced by the board industry in the wake of depleting forest resources and spiralling cost of bagasse which is the only material so far used as an alternative to natural wood. Utilization of cotton stalk would also help augment farm income through sale of stalks to the board industry. Work done under the CFC project is summarised in this Section.

17.3.1. Cotton Stalk Availability

A survey was conducted to assess the availability of cotton stalk in different regions of India. Data based on response to questionnaire despatched to several farmers in five States in the country indicated that the yield of cotton stalks per hectare varies from 1 to 5 tonnes/ha depending on the variety, plant type, growing conditions, soil type and agro-climatic factors. The survey also revealed that the use and price of cotton stalks differed across the States. In the northern States of Punjab and Haryana, most of the cotton stalks are used as domestic fuel, but farmers are willing to sell half of them for Rs. 400 to 500 per tonne. In Gujarat, most of the cotton stalks are burnt in the field. In Maharashtra and Karnataka, the stalks are used as fuel or exchanged for farm yard manure, but farmers are willing to sell them for Rs. 300 to 500 per tonne.

17.3.2. Stalk Collection and Cleaning

Collection, chipping and transportation of cotton stalks from the farms to the factories, as well as their storage in different forms, are important aspects of raw material logistics on which a study was conducted for three seasons in Nagpur, where cotton is grown under rain-fed conditions. The farmers were informed about the benefits of using cotton stalks. The stalks were easier to uproot right after the harvest, as the soil was still moist. A metal tool helped to uproot the stalks

without much effort, unlike manual pulling. The tool is recommended for uprooting the stalks. Dried in the sun for 4 to 5 days to facilitate easy removal of leaves and rinds, the stalks were cleaned and then chipped to appropriate size at a nearby centre.

Three following methods of collecting and transporting cotton stalks from Nagpur farms to a factory were tried:

- Direct transport of stalks from fields to factory;
- Farmer chipping stalks and transporting them to factories;
- Farmer transports stalks to chipping centre, entrepreneur chips and transports the material to the factory.

The results led to the following conclusions :

- Rainfed farms produced only 1.3 tonnes of chips per hectare while irrigated farms yielded 5 tonnes per hectare.
- The most economical method was to uproot, store, clean and chip the stalks at the chipping centre within 5 km from the field, and then transport the chips by truck to the factory within 50 km.
- Transporting stalks more than 5 km before chipping, or more than 50 km after chipping, was found to be uneconomical.

The average cost of delivering cleaned and chipped stalks with 10% moisture at the factory gate was Rs.1500-2000 per tonne.

17.3.3. Compacting of Cotton Stalks

CIRCOT designed and fabricated various compacting machines, such as hand-operated, power operated and hydraulic ones, and tested their efficiency to compact cotton stalk. The machines showed significant differences in their performance. The hydraulic machine was the best, but it could only compact 4 tonnes of cotton stalk in 6 hours. Compacting cotton stalks was found to be costly and inefficient. Therefore, the stalks were transported without compaction to the chipping machine location.

17.3.4. Transporting Cotton Stalks

Three modes of transportation were attempted for the transfer of cotton stalk from collection centres to GTC, Nagpur: Bullock carts (capacity: 325 kg), tractor-trolleys (575 kg) and lorries (1500 kg). It was found that transporting stalks over distances more than 5 km was not cost-effective. The study, therefore, recommended setting up of chipping centres every 10 km so that the maximum distance for transporting stalks would be limited to 5 km. The study also suggested different modes of transportation depending on the distance: bullock carts for up to 3 km, tractor-trolleys for 3 to 10 km, and lorries for 10 to 50 km.

17.3.5. Cotton Stalk Chipping

The experiments used two kinds of electric chippers: chaff cutter and drum chipper. The chip

quality was measured by the fractions separated with sieves of different mesh sizes. Waste chips smaller than 0.5 mm were to be filtered out and those bigger than 3.5 mm had to be re-chipped. The drum chipper and a modified chipper produced good chips for the board industry. But the villages had no power for the electric drum chipper. So, the modified chipper attached to tractor or power tiller was judged as the best option for chipping cotton stalks. Experiments led to the following conclusions:

- Mobile chippers with tractor are ideal for chipping cotton stalks.
- A 22 HP tractor chipper could make 7-8 tonnes of chips in 8 hr.
- The chips could be directly loaded in a lorry or filled in bags and loaded in a lorry.
- One lorry could carry about 6 tonnes of chips.

17.3.6. Cotton Stalk Cleaning System

In order to remove unwanted components from the stalks before chipping, a cotton stalk cleaning system was designed. The system consisted of four main components:

- A scratching system (peeler) that separates cotton bolls, boll rinds and small branches from the stalks using rollers
- A conveyor system that moves the material from one stage to the next
- An air blowing chamber that removes soil particles, leaves, cotton lint and other impurities from the cotton stalk after it passes through the scratching system
- An air suction chamber that extracts residual loose materials such as leaf bits, fibres and dust particles, leaving the cotton stalk clean and ready for chipping

17.3.7. Particle Board Pilot Plant

A one-tonne-per-day (1 TPD) pilot plant for preparation of particle boards was set up at GTC, Nagpur. The pilot plant comprised an array of several machines as listed below:

Hammer Mill
Drum Chipper
Re-chipper
Rotary Dryer
Glue Blender
Mat Former
Pre- Press (cold)
Hydraulic Hot Press
Cutting Machine
Sanding Machine

After commissioning of the plant, the process parameters were standardized. Concentration of UF resin (7%-8%), temperature (1300-1400 °C), pressing time (3 min) at high Pressure (200 kg/cm^2) + second pressing (8 min) at low Pressure (100 kg/cm^2) were found to give good quality particle boards from cotton stalks. The boards were found to meet BIS specifications in respect of

quality, namely thickness (18mm), Density (671 kg/m^3), Modulus of Rupture (14.6 N/mm^2), Internal Bond Strength (0.6 N/mm^2), Screw /Nail Withdrawal (Newton) at 2118 and water absorption % at 2 h at 28.

17.3.8. Commercial Trials with Particle Board Making

CIRCOT's particle board technology subjected to refinement on the pilot plant was tried on an industrial scale in large board manufacturing units. In the first instance, about 30 tonnes of ready-to-use cotton stalk chips were supplied to M/s Ecoboard Industries Ltd. at Velapur near Pandharpur in central India followed by a second lot of 50 tonnes at the same factory. The chips were delivered from Nagpur, and boards of 13.5' x 6' size were prepared with different thicknesses (9 mm, 12 mm & 18 mm) and multiple surface finishes. Laminated boards thus manufactured were used for making different furniture items and also for panelling some rooms in CIRCOT, Mumbai, GTC of CIRCOT, Nagpur, DOCD, Mumbai and ICAR Headquarters, New Delhi. Tests results showed that it is possible to prepare good quality boards in an existing industrial unit without any modifications.

17.4 MISCELLANEOUS EXPERIMENTS WITH BIO-WASTES

17.4.1. Cotton Stalk Briquettes

The physical properties of briquettes made from cotton stalks were investigated in a commercial plant. The briquettes were made with different sizes and moisture levels of the raw material. The results indicated that higher moisture levels reduced the quality of the briquettes. No briquettes could be formed with moisture levels above 14%. The best products were obtained from material that was ground in a hammer mill, sieved through a 1 mm mesh and had a moisture level of 10%. A pelleting system with a capacity of 150 kg/hr was set up at GTC, Nagpur to convert biomass, especially cotton stalks, into pellets of 6, 8 and 10 mm diameter. The system was used to optimize the pelleting parameters and to demonstrate the process to farmers and entrepreneurs.

17.4.2. Cotton Stalk Pellets

Torrefaction is a thermochemical process that decreases the water and volatile components from biomass thus enhancing some of its properties for energy and heating applications. The process involves heating the biomass in an oxygen-free environment at moderate temperatures, resulting in a product that has higher energy density, lower moisture content, better grindability and compressibility, and lower oxygen-to-carbon ratio. In the present study, cotton stalks were processed into 10-12 mm chips using a tractor-mounted chipper, and then ground to 3 mm fragments using a hammer mill. The ground biomass was then torrefied at 280°C and normal atmospheric pressure for 30 minutes in a Pyrolysis Pilot Plant facility in a factory in Nagpur. The torrefied biomass was characterized for its physical and chemical properties.

The torrefaction process was found to improve the quality of the cotton stalk pellets in terms of bulk density, heating value and ash content. The bulk density (BD) and high heating value

(HHV) of the torrefied pellets were 650 kg/m^3 and 4500 kcal/kg, respectively, while the un-torrefied pellets had 580 kg/m^3 and 3800 kcal/kg, respectively. The ash content of the torrefied pellets was reduced to 4.5% from 7.4% of the untorrefied pellets, due to the evaporation of volatile matters during the process. The torrefied pellets met most of the criteria for the highest quality class of non-woody biomass pellets, such as BD (>600 kg/m^3), durability (>97.5%), ash content (5%) and HHV (>4200 kcal/kg). The merit of this technology employing cotton stalk was put to test at a restaurant in Nagpur for three months and the product was found to be wholly acceptable.

17.4.3. Boards from Safflower Stalks

Safflower stalk is a cellulose-rich raw material with properties similar to wood, as shown by chemical analysis. Early laboratory trials for making particle board and fibre board from safflower stalk were quite promising. Procedure chosen was similar to that employed for cotton stalk. The boards were found to meet all the specifications of relevant Indian standards. The hardboard, made by wet process, did not need any resin as indeed was the case with hardboard from cotton stalk. Safflower stalk can thus be seen as an alternative source of lignocellulosic material for pulp and board industry.

A room in CIRCOT was panelled with particle boards of 18 mm and 12 mm thicknesses, made from 1.5 tonne safflower stalk at an industrial unit in Nagpur. The boards had the same quality as those made from other agro-waste materials.

17.4.4. Banana Pseudo-stem for Value-added Products

Banana cultivation in India covers a large area and produces about 500 lakh tonnes of pseudo-stem every year. This biomass can provide more than 3.40 lakh tonnes of fibres worth Rs. 1500 crores. The fibre extraction process also generates a lot of sap (liquid) that contains 4% Potassium on dry weight basis . This Potassium can be valued at about Rs. 46 crores. Moreover, the fibre and scutching waste can be used for making paper and board. The scutching waste can also be converted into enriched vermicompost. Furthermore, the central core, the tender part of banana pseudostem, can be used for making a range of edible products. A project was undertaken under NAIP to explore the various products from banana and especially the fibre, with Navsari Agricultural University as the Project Leader and CIRCOT as partner.

A Raspador machine was installed at Navsari Agricultural University and the machine parameters were standardized for extraction of banana fibres. A microbial retting method was employed for easy extraction of the fibres from the sheaths and for softening the extracted fibres. A method was also optimized for making cellulose powder from the fibres on a laboratory scale.

Twenty-five varieties of banana fibre samples received from Navsari and eight samples from NRCB, Tiruchirapalli were tested for tensile properties. The chemical composition of fibres from all varieties was also evaluated.

The banana fibres were softened by anaerobic retting as well as by using different softening

agents. Yarns were spun on the jute spinning system as well as by using the Medlari Charkha. The machine- made yarn had higher tenacity than the hand-spun yarn. The hand-spun yarn was finer (about 500 tex) than the machine-made yarn (580 tex). The sap was used as mordant for dyeing trials at CIRCOT labs. All these experiments served to demonstrate the potential of banana stem components for various applications and highlight the scope for intensive research on this putative waste material.

17.4.5. Dense Paper from Banana Pseudo-stem Fibre

The paper industry has been witnessing progressive rise in demand for dense paper, which is used for packaging fatty foods and baked goods. Dense paper is made from wood pulp, but is not a sustainable or abundant source of fibre. A possible alternative is banana pseudo-stem, which is usually discarded as waste. Banana pseudo-stem fibres have high cellulose content and good strength, making them suitable for paper production. In this study, use was made of banana pseudo-stem fibre for making high density paper.

Banana pseudo-stem was cut into small pieces and subjected to digestion by kraft pulping method. Digestion parameters such as temperature, time, alkali concentration and liquor ratio were optimised to obtain the required pulp quality. The pulp was washed, bleached and refined to achieve the desired freeness. Hand-made sheets (400 GSM) prepared from the pulp were allowed to dry naturally. The sheets were tested for mechanical and barrier properties. Tensile index (22.4 ± 3.12 Nm/g), bursting strength (1.6 ± 0.07 kg/cm^2) and air resistance (10.4 ± 0.24 s/100 mL), were all satisfactory. However, it failed in the turpentine oil test for grease resistance. To overcome this deficiency, the paper was given a coating of natural and biodegradable polymers such as carboxymethyl cellulose (CMC) and sodium alginate (SA). The coated paper was tested for mechanical and barrier properties again and was found to have improved in all respects.

Chapter 18

MISCELLANEOUS ACTIVITIES

As already stated in different contexts, CIRCOT began as a testing laboratory to provide quality data on cotton fibre and thus help breeders in varietal improvement research. Over the decades, CIRCOT's interests expanded into newer domains covering the entire cotton value chain. The rudimentary, self-effacing testing laboratory steadily morphed into a research institute with its orientation turned to newer activities like basic knowledge creation, technology development, research collaborations, dissemination of information through training, academic pursuits, resource generation, etc. The earlier Chapters in this book have summarized the research findings and technologies developed at CIRCOT in a multiplicity of knowledge domains, while these final pages are devoted to enlisting some of the other accomplishments of the Institute.

18.1. INTELLECTUAL PROPERTY MANAGEMENT

CIRCOT is a premier institute that conducts research contributing to the innovation processes in agriculture, especially cotton. The Institute acknowledges the fact that its R&D efforts should not only aim at increasing the productivity, but should also target development of strategies to enhance agricultural diversification and value addition of agricultural products through appropriate intellectual property (IP) management. The ICAR has evolved comprehensive guidelines for intellectual property management and technology transfer/commercialization as early as in 2006. These guidelines provide the researchers in ICAR institutes with information on the procedures for operationalization and management of intellectual properties. CIRCOT is one of the trailblazers in the adoption of IP portfolio management in the ICAR system.

Intellectual Property & Technology Management (IP & TM) Unit established at the ICAR headquarters functions as the central facilitating and decision-making body that provides the necessary guidance and support to every institute in its domain. All matters of policy concerning IPR portfolio management and technology transfer/commercialization is decided by the IP & TM Unit in consultation with the concerned SMDs and approval of Director General, ICAR. CIRCOT applied for and secured the first patent in 1977 for a process for de-sizing fabrics sized with tamarind kernel powder using the enzyme cellulase. As on today, applications have been filed by CIRCOT for a total of 78 patents of which 17 have been already granted. The list of granted patents is given below:

1. Process for de-sizing fabrics sized with tamarind kernel powder using cellulase enzyme (1977)
2. A process for the preparation of semi-chemical pulp for production of paper from cotton plant stalks (1988)
3. A new resin finishing process using mixed catalyst system for the production of durable press fabrics (1991)
4. A process for the preparation of paper-grade pulp from cotton plant stalk by anaerobic digestion (1996)
5. Variable speed cotton ginning machine (2003)
6. A process for the preparation of peptone from cotton seed meal by enzymatic hydrolysis (2004)
7. An inexpensive assembly for the isolation of anaerobic microorganisms (2006)
8. A new single stage process for the preparation of absorbent cotton from short staple fibre waste (2006)
9. Machine for compacting cotton stalk using hydraulic system (2007)
10. Double roller gin with improved power transmission mechanism for roller and beater (2007)
11. Miniature spraying system for cotton seeds (2007)
12. Microbial system for de-inking newspaper waste (2007)
13. Hand-cum-power operated cotton stalks compacting machine (2007)
14. Biochemical scouring process for grey cotton goods (2008)
15. A process for production of silver nanoparticles using the fungus *pleurotus sajor caju* (2010)
16. Biological softening of lignocellulostic material for preparing binderless board (2017)
17. Process for dyeing of textiles using solvent-extracted marigold flower waste (2023)

18.2. AGRIBUSINESS INCUBATION

The National Agricultural Innovation Project (NAIP) was a joint initiative of the ICAR and the World Bank, launched in 2006. The project was intended to align with the goals of the Government of India and the National Policy on Agriculture (NPA), which emphasized the generation and dissemination of agricultural technologies and reforms in the technology management system. One of the key components of the NAIP was the establishment of Zonal Technology Management and Business Planning and Development Units (ZTM & BPD) under ICAR institutes, to act as catalysts for these changes. CIRCOT was one of the few institutes entrusted with the task of guiding other ICAR institutes in the West Zone of the country on technology management issues. The West Zone comprises 18 ICAR institutes working on various sectors of agriculture, such as field crops, horticultural crops, farming equipment, soil science, fisheries, weeds and crop processing. Thus, the first ZTM & BPD unit in India was inaugurated at CIRCOT in November, 2008.

Encouraged by the success of ZTM & BPD in the promotion of entrepreneurship in the agricultural sector, ICAR established 52 Agribusiness Incubation Centres (ABI Centres) in its research institutes between 2015 and 2017. The aim of these Centres is to encourage, nurture

and support innovative agribusiness ideas and turn them into sound commercial ventures by forming technology-led and knowledge-driven enterprises, thereby strengthening the agricultural supply chain.

One such ABI Centre was established at CIRCOT in 2016 to nurture cotton stake holders and support their business endeavours. The Centre at CIRCOT facilitates incubation of new enterprises for innovations in technologies by providing them with physical, technical and networking support and services. The Centre also provides facilities and need-based business support to startups and entrepreneurs to test their ideas and concepts before setting up their own enterprise. So far, the CIRCOT ABI Centre has admitted as many as 16 entrepreneurs, graduated seven incubatees, accelerated the development and commercialization of nine innovative products, facilitated funding for incubated entrepreneurs and effectively created opportunities for employment through a range of business- related activities.

18.3. TECHNOLOGY INCUBATION- RAFTAAR

The agriculture and allied sector has seen a surge in entrepreneurship development since the introduction of a new component called "Remunerative Approaches for Agriculture and Allied Sector Rejuvenation" in 2018-19 under the revised Rashtriya Krishi Vikas Yojana (RKVY-RAFTAAR) scheme of the Govt. of India. RAFTAAR aims to foster the emergence of agripreneurs and agri-startups by providing financial support and thus strengthening the incubation ecosystem. RKVY-RAFTAAR intends to leverage the existing incubation facilities and expertise of various academic, technical, management and R&D institutions in the country and to exploit the synergy created therefrom. The programme encourages innovations and technology-based ventures in agriculture and allied sectors.

An Agribusiness Incubator under the RKVY-RAFTAAR scheme was set up at CIRCOT on 31st January 2019. With this addition, CIRCOT R-ABI can extend its services also to other sectors related to agriculture. CIRCOTR-ABI is one of the 29 RKVY-RAFTAAR-Agri Business Incubators in the country with a vision to nurture innovators in agriculture and allied sectors for Agri-Startups and a mission to provide an incubation support system that would convert innovative ideas into sustainable business enterprises.

CIRCOT R-ABI provides a platform for graduates, rural youth and farmers to turn their innovative ideas and concepts in agriculture and allied sectors into viable products and services. This platform connects individuals and startups with innovative ideas to experts from the Institute and its network partners who can guide them to realize their goals. The platform also provides all the necessary support, mentoring and funding opportunities to the agri-innovators who can also avail of facilities in CIRCOT laboratories equipped with advanced analytical instruments to test and validate their innovations.

CIRCOT R-ABI has two grant-in-aid programmes: Uday and Ankur. Uday provides grants up to Rs. 5 lakhs to pre-seed stage startups for transforming innovative ideas into prototypes. Ankur provides grants up to Rs. 25 lakhs to seed stage startups to scale up and commercialize their products.

Since 2019, CIRCOT R-ABI has conducted six cohort meets to select, mentor and train agripreneurs who had applied for the funding programmes. Out of 375 applications, 91 startups have completed the Agripreneurship Orientation Programme (AOP) & Incubation-cum-training programme.

So far CIRCOT R-ABI has funded 51 agri-startups with a total grant-in-aid of Rs. 640.75 lakhs under the RKVY-RAFTAAR scheme. The break-up of the funding is as follows:

- 1st Cohort : 14 startups, Rs. 144.5 lakhs
- 2nd Cohort: 12 startups, Rs. 153 lakhs
- 3rd Cohort: 8 startups, Rs. 97.75 lakhs
- 4th Cohort: 7 startups, Rs. 102.5 lakhs
- 5th Cohort: 5 startups, Rs. 65.00 lakhs
- 6th Cohort: 5 startups, Rs. 78 lakhs

The startup proposals under the 7th Cohort are currently under evaluation.

18.4. ACADEMIC PROGRAMMES AT CIRCOT

The University of Mumbai had recognized CIRCOT as early as in 1958 as a centre for post-graduate courses in various disciplines, subject to periodic renewal. The Institute has many scientists recognised as post-graduate teachers in subjects allied to textile science and technology. The Institute has well-equipped laboratories, infrastructure and library facilities for conducting textile-related physical, chemical, and microbiological research. With effect from 2004, CIRCOT has been accorded permanent recognition by the University of Mumbai for conducting the following courses:

No.	Subject	Degree
1.	Physics	M.Sc. & Ph.D.
2.	Microbiology	M.Sc. & Ph.D.
3.	Bio-Physics	M.Sc. & Ph.D.
4.	Organic Chemistry	M.Sc.
5.	Physical Chemistry	M.Sc.
6.	Textile Technology	Ph.D.

Besides the above courses, CIRCOT has obtained recognition from SNDT Women's University, Mumbai, for M.Sc. and Ph.D. courses in Home Science (Textiles) with effect from 2004. The Institute has earned reputation for its high academic status and quality of research programmes. So far, 23 Ph.D. and 32 M.Sc. degrees have been awarded to the students of CIRCOT.

CIRCOT has also established academic collaboration with the following educational institutions:

1. Institute of Chemical Technology, Mumbai.
2. Veermata Jijabai Technological Institute, Mumbai
3. SNDT Women's University, Mumbai
4. Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli.
5. University of Agricultural Sciences, Raichur.

18.5. TRAINING IN GINNING

CIRCOT's Ginning Training Centre (GTC) at Nagpur, the only one of its kind in Asia, was set up in 1985 with financial support from the World Bank. It is a unique research and training centre that imparts theoretical and practical training on Double Roller ginning technology, fibre quality testing and industrial utilization of cotton by-products for the benefit of ginning factory owners, managers, supervisors and gin fitters besides personnel from cotton trade and farmer groups. GTC has trained a large number of employees of different levels from organizations like the CCI, MSCCGMF, private cotton trading companies and seed manufacturers. The groups trained at GTC also include many from countries abroad.

GTC regularly conducts training programmes around the year on "Double Roller Ginning Technology and Basics of Cotton Grading" for the benefit of ginners, fitters, graders etc. and "Post-harvest Management of Cotton and Value Addition to its By-products" to farmers and other stake-holders. The Centre also conducts tailor-made training programmes for groups with specific requirements. For example, GTC had recently organized a skill development programme on "Post-harvest Management Practices for Production of Premium Cotton Bales" under the World Bank-funded SMART project launched by the Government of Maharashtra. The project was aimed at transforming rural Maharashtra through interventions in agriculture and livelihood sectors. In this training, 523 lead farmers and cotton graders from 12 districts of Vidarbha and Marathwada regions were included. Further, the Centre has organized training programmes on "Appropriate Practices for Cotton Harvesting and Biomass Utilization"for the benefit of 6000 farmers associated with the project.

The training programmes of GTC have enabled the ginning sector to access skilled manpower and adopt best practices in cotton processing. In a span of 38 years, this Centre has trained over 13,000 participants who in turn have spurred the quality transformation of cotton ginning in India.

18.6. COMMERCIAL TESTING SERVICES

CIRCOT is a leading institute for testing and calibration of textile materials, with accreditation from NABL and BIS. Its laboratories are equipped with advanced instruments such as SEM, AFM, ICP-MS, GC-MS, and many others. CIRCOT can perform over 200 tests in physical, chemical and microbiological domains on different kinds of textile materials, including fibre, yarn, fabric, garments, and auxiliaries. It also has a unique trash and contamination laboratory. The Institute offers its commercial testing services to a wide range of stakeholders in the cotton and textile sectors.

CIRCOT's Test House provides a single-window facility for receiving samples, accepting test fees, and dispatching test reports. The Institute has been serving the textile industry since 1937 with its expertise in testing and strict adherence to quality standards. Since 1990, CIRCOT has remained in the Maharashtra State government's empanelled list of laboratories for testing textile samples from various bodies like Zilla Parishads, Municipal Corporations, Police Department, Central Jail etc. Our major client for fibre testing is the Cotton Corporation of India (CCI) and we have been receiving samples from all its branches. In the last 25 years, over one lakh samples of cotton were received from CCI for quality testing. In this period of 25 years, the total number of samples tested at CIRCOT from different clients has crossed the 3.5 lakh mark and the revenue generated from the tests has been nearly Rs. 15 crores.

18.7. STRENGTHENING COTTON VALUE CHAIN IN AFRICAN COUNTRIES

CIRCOT has been working with some African countries in the last 10 years for strengthening the components of their cotton value chain. This task has received support from the Government of India and a few international organizations. In association with CICR, IL&FS and the Directorate of Cotton Development, CIRCOT participated in the implementation of the Cotton Technical Assistance Programme (TAP) in seven African countries. The programme aimed to address the challenges faced by these countries in post-harvest management and value addition of cotton and its by-products. CIRCOT's activities in the first phase of this initiative included training and exposure programmes, in-country training programmes and setting up of a regional knowledge cluster-cum-training centre.

The first activity under this initiative was training-cum-exposure programme organised in 2013 on post-harvest management and value addition of crop residue left in the farms after cotton is harvested. A total of 31 delegates from six countries namely Benin, Burkina Faso, Chad, Nigeria, Malawi and Uganda participated as master trainers. The aim was to educate the participants on CIRCOT technologies for utilization of crop residues and to help stake holders in capacity building in the management of residue utilization. The training programme consisted of sessions in GTC, Nagpur as well as at CIRCOT Headquarters, Mumbai. The participants later organised in-country training programmes in their own respective countries.

The second activity was an in-country training programme arranged by CIRCOT personnel in each of the participating countries, between 2014 and 2016. This programme had aimed at capacity building, to benefit personnel from government R&D establishments engaged in production and extension activities. CIRCOT scientists coached as many as 152 trainees on Indian technologies with the help of master trainers who had gone through the first activity discussed above. Six programmes, one in each country, were conducted under the second activity. The participants showed keen interest in all the Indian cotton processing technologies, particularly those for value addition of crop residues.

The third activity was the creation of a regional hub for training and knowledge sharing in respect of cotton processing in Africa. This involved setting up of a pilot plant with Indian ginning and baling equipment in Bohicon, Benin. The plant was inaugurated in June 2016 and

handed over to INRAB, Benin. The facility thus created provides practical training on efficient cotton ginning for the benefit of ginneries from all African countries.

18.8. TARDY ADOPTION OF MODERN TECHNOLOGY IN COTTON SEED PROCESSING-A STUDY

Despite having access to advanced technologies, the cotton seed processing industry in India still relies largely on whole seed crushing method to extract oil. The yield in this conventional method is low as the cake would retain a significant fraction of the oil. The un-decorticated cake (UDC) and the oil thus extracted are of low quality and hence of poor commercial value. On the other hand, scientific method comprising delinting and decortication, followed by pressing and solvent extraction of the kernel, would yield more oil. Cotton linter extracted by delinting process, seed hull gathered from decortication and the meal left over after oil extraction are all marketable by-products. It is ironical that the cotton seed oil industry in the country is reluctant to employ modern technology for oil extraction, overlooking the advantages.

A study was conducted to understand the factors that influence the adoption or non-adoption of proven technologies by the cotton seed processing industry in the country. The study comprised survey of 48 conventional whole seed crushing units and 18 scientific processing units in different states in India. The results showed that the reasons for preferring the whole-seedcrushing method are: low investment cost, ease of operation and hassle-free management, notwithstanding the low profitability affected as it is by fluctuations in price of cotton seed on the one hand and the price level uncertainties of cattle-feed substitutes like hulls, on the other.

The main reason for oil mill owners not to adopt modern processing methods, however, is the high initial investment which is in the range of Rs. 20-25 Crores for a 200 TPD unit. The industry is also resentful of the absence of special benefits like investment subsidies, export incentives, electricity concessions, etc. Apprehension or misconception about the difficulty in selling the by-products like linters, hulls and meal (decorticated oil cake, DOC) is also strong as these by-products seem to have poor domestic demand. DOC is the main product used in the production of cattle feed, but it has a low demand in India due to the influence of brokers and commission agents who have been promoting UDC. DOC has a high protein content, but it cannot be used as feed for poultry and fisheries because of the presence of gossypol which is toxic. DOC is mainly exported to other countries, but the prices are vulnerable to the changes in trade policies of governments. The adoption of scientific extraction method for cotton seed oil in India thus remains remote.

18.9. IMPACT ASSESSMENT OF CIRCOT TECHNOLOGIES

Over the decades CIRCOT has developed several technologies in the realm of cotton textiles and cotton by-product utilization. Some of them have been put to practical use by stakeholders while others are being promoted through various technology transfer instruments. An impact assessment of technologies developed by CIRCOT will act as a tool to highlight the importance of the role played by the Institute. A few CIRCOT technologies hand-picked for the illustration of impact assessment are discussed in this section.

18.9.1. CIRCOT-Bajaj Cotton Pre-Cleaner

This pre-cleaner is a technology tool that improves the quality of cotton lint by removing trash before ginning. It was licensed to M/s Bajaj Steel Industries Ltd, Nagpur in 1999. The technology has been adopted by about 32% of the ginning factories in India as of 2020, up from 12% in 2009. The technology increases the output of cotton lint by 5%. Using the elasticity of demand (0.30) and supply (0.23) for cotton lint, the economic benefit of the technology was calculated at Rs. 438 crores per annum. This benefit comes from the higher commercial value of the cotton bales with reduced trash content resulting from the use of CIRCOT technology.

18.9.2. CIRCOT Calibration Cotton

This is a product of the Institute's own innovation under a Revolving Fund Project. It has been in production since 1997 and has more than 300 clients across the country, including mills, research institutes and testing instrument manufacturers. The product is needed for calibrating the High Volume Instrument (HVI) for fibre testing and replaces the imported USDA calibration cotton. CIRCOT is the only institute in the world besides USDA that produces calibration cotton. The Institute has sold over 12,877 boxes (200g each) of the product since its inception. The average annual sales are around 500 boxes. The product saves about Rs. 58 lakhs per annum in foreign exchange and reduces the calibration cost by up to 60% for cotton testing laboratories in India. There is a huge potential to expand the market beyond the domestic customers.

18.9.3. Value Addition to Cotton Stalks

Briquetting and Pelleting: Cotton stalks are a low-cost, renewable biomass suitable for briquetting and pelleting industries. However, transporting them from farms to factories is a challenge due to their huge bulkiness. CIRCOT has developed a supply chain logistics system that facilitates economic transportation of cotton stalks within a 50 km radius. This system has been transferred to the farmer groups for adoption.

A case study of a briquetting plant that uses cotton stalks as raw material has demonstrated the impact of this technology. The plant processes about 20 tonnes of cotton stalks per day and needs 5000 tonnes per year. The cotton stalks are available at Rs. 1,000 per tonne at farm level and Rs. 2500/tonne at factory site, which is cheaper than other alternatives. This technology also creates seasonal and regular employment opportunities for the rural population, as well as additional income for the farmers who sell their cotton stalks. The value addition to 1% of cotton stalks amounts to Rs. 84 crores per annum. Moreover, this technology reduces the environmental pollution caused by burning of cotton stalks and the carbon footprint of the user industries that switch to biomass-based briquettes as a green energy source.

Compost from cotton stalks: Cotton stalks are a major agricultural waste in India, where 12.7 million hectares of land produce over 30 million tonnes of this residue every year. Instead of burning the stalks and causing air pollution and soil degradation, farmers can convert them into bio-enriched compost with the help of microbial technology developed by CIRCOT. This technology can decompose the cotton stalks in 45 to 60 days, depending on their moisture

content, and reduce the C:N ratio to less than 20:1. The compost can enhance the soil carbon and fertility, and benefit the farmers. CIRCOT has been promoting this technology among the cotton growers through various awareness and training programmes. Some farmers in Haryana and Vidarbha have already adopted this practice and are reaping the benefits of cotton stalk composting.

Mushroom cultivation on cotton stalks: Edible mushrooms constitute delicious and nutritious food relished by most people. Mushrooms have high protein content besides several vitamins and minerals. The low starch content makes mushrooms suitable for people with diabetes. One of the mushroom types that can be cultivated in India is the oyster mushroom (*Pleurotus* spp.), which is second only to the button mushroom in the size of production. Traditionally, mushrooms are grown on substrates like rice and wheat straw. CIRCOT has attempted using cotton stalks as substrate for oyster mushroom cultivation by a standardized procedure, and has found that it gives a comparable yield. One kg of dry cotton stalks can produce about 300 g of fresh oyster mushroom, saleable for at least Rs. 30/- per kg. This technology has been shared with farmers and stakeholders through skill development programmes, newspaper articles and publications. Fourteen awareness programmes have been organized in 13 villages in the Vidarbha regions, with 508 farmers participating. At GTC, 18 training programmes have been conducted, with 483 farmers participating. These trainings included demonstrations on how to grow mushrooms and make compost out of cotton stalks.

18.10. TRAINING PROGRAMMES AT CIRCOT

CIRCOT is a leading institute for researches in cotton technology and value addition of its byproducts. It also offers commercial services to its stakeholders in textile testing, consultancy, startup incubation and skill development. The Institute conducts customized short term training courses for the benefit of textile and ginning industries. Two types of training programmes are offered. One is the normal cotton quality evaluation programme to provide hands-on experience in the testing of cotton fibre, yarn and fabric in CIRCOT's testing laboratories, together with oral lessons in testing through lectures and industry visits. The trainees are supplied with a book on testing methods including statistical analysis of test results. The other type of training programme aims at providing exposure to sophisticated analytical techniques and tools in CIRCOT's ever-expanding laboratories. Such programmes are not regular items in the Institute's work agenda, but they are organized sporadically, depending on perceived demand from related industries.

The topics under which training programmes of the second type mentioned above were conducted in recent years, are listed here.

1. Specialized Training Course in HVI & AFIS
2. Short Course on Application of Electrospun Nanofibers in crop health and post-harvest technology
3. Cotton seed: Scientific Processing

4. Basics of Nanotechnology and its Application
5. Training on Cotton Spinning
6. Advances in Microscopy (SEM, AFM, FLUO & Polarized Light)
7. Chemical Characterization of Textile Materials & Auxiliaries
8. Advances in Textile Characterization
9. Absorbent Cotton Technology
10. Fermentation Technology for Value-addition to Cotton By-products and Biomass
11. Spectroscopic and Chromatographic Techniques for Material Characterization
12. Cotton TAP for Africa
13. Basic Statistical Techniques for Textile Research
14. Characterization of Materials Using X-Ray Diffractometer (XRD)
15. Synthesis and Characterization of Nanomaterials for Agricultural Applications
16. Electrospinning Techniques & their Applications
17. Technology Advances in the Application of Nano Technology
18. Training on Knitting and Knit Garments
19. Training on Advances in Microscopy, Spectroscopic & Chromatographic Technology for Material Characterization
20. Electrospinning for Nanofibre Production and its Applications
21. Instrumental Evaluation of Clothing Comfort
22. Training on Fibre Reinforced Composites

DIRECTORS



Dr. A. James Turner
1924-1930



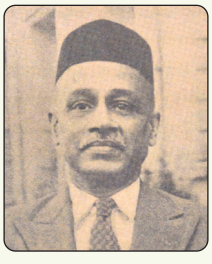
Dr. Nazir Ahmad
1930-1945



Shri. D. L. Sen
1945-1951



Dr. C. Nanjundayya
1951-1956



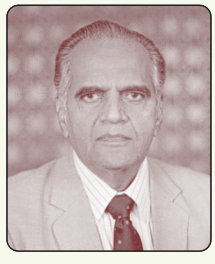
Shri. H. Navkal
1956-1957



Dr. R. L. N. Iyengar
1957-1966



Dr. V. Sundaram
1966-1988



Dr. N. B. Patil
1988-1994



Dr S N Pandey
1995-1995



Dr. K. R. Krishna Iyer
1995-2000



Dr. S. Sreenivasan
2000-2010



Dr. A. J. Shaikh
2010-2012



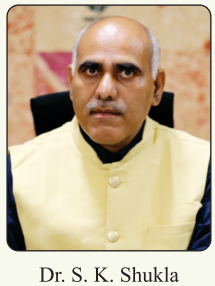
Dr. S. K. Chattopadhyay
2012-2014



Dr. P. G. Patil
2014-2021

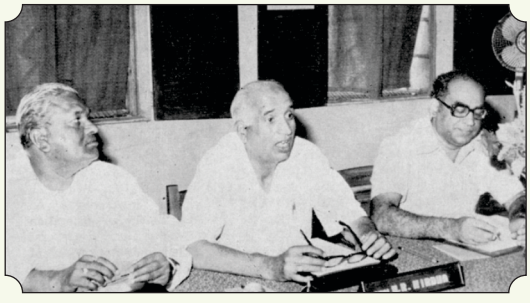


Dr. Sujata Saxena
2021-2022

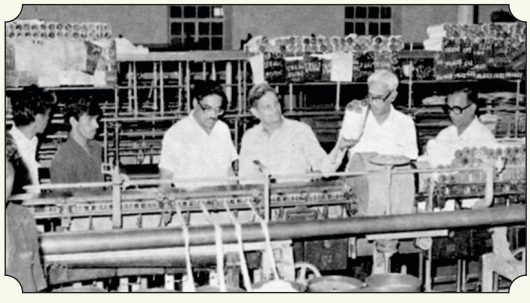


Dr. S. K. Shukla
2022-Present

VISIT BY DIGNITARIES



Visit of the Parliamentary Committee in 1981



Visit of Shri P. N. Rau, Secretary, ICAR to CTRL in 1985



National Seminar on Eco-friendly Cotton at
ICAR-CIRCOT, Mumbai held during June 8-9, 1996



Inauguration of Jubilee Hall at the hands of
Dr. R. S. Paroda, DG, ICAR during December 10, 1999



National Seminar on Production and Characterization of
Natural and Man-made Fibres on July 03, 1999



Brainstorming Session on Cotton Promotion 2005



Visit of Shri Sharad Pawar, Hon'ble Minister
of Agriculture to ICAR-CIRCOT in November 2008



International Conference on Emerging Trends in Production,
Processing & Utilisation of Natural Fibres
held during April 16-18, 2009

VISIT BY DIGNITARIES



Visit of Dr. S. Ayyappan, DG, ICAR on 25th Anniversary of Ginning Training Centre, Nagpur on December 11, 2011



Silver Jubilee Celebration of Ginning Training Centre (GTC), Nagpur on December 11, 2011



Shri K.H. Rao. Hon'ble Textile Minister, during his visit to ICAR-CIRCOT, Mumbai on October 11, 2013



African Delegates at ICAR-CIRCOT, Mumbai, Participating in the Cotton TAP training programme for Africa held during January 12-25, 2013



Awareness Creation & Popularisation of Natural Dyes among Tribal Farmers under the Tribal Sub-plan Programme at village near Naranyangaon, Pune on March 18, 2014



Visit of Afghan Delegates 2014



Visit of Afghan delegates to Ginning Training Centre, Nagpur on November 19, 2014



Nanocellulose Pilot Plant Inauguration by Dr. R. A. Mashelkar 2015

VISIT BY DIGNITARIES



Visit of ICAC delegates to Ginning Training Centre, Nagpur on December 12, 2015



Inauguration of Nanocellulose Pilot Plant at ICAR-CIRCOT, Mumbai by Padma Vibhushan Dr. R. A. Mashelkar on August 21, 2015



Shri Nitin Gadkari, Hon'ble Union Minister, during his visit to Ginning Training Centre, Nagpur on June 6, 2015



Visit of African Delegates 2016



Visit of Shri Radha Mohan Singh, Honorable Minister of Agriculture to ICAR-CIRCOT, Mumbai on July 3, 2016



Visit of SAARC delegates to Ginning Training Centre, Nagpur on August 31, 2016



7th ACRDN Meeting at Nagpur, September 15-17, 2017



Dr. K. Alagusundaram, DDG (Agricultural Engineering), Inaugurating the Workshop on Mechanization of Cotton on May 5, 2017 at ICAR-CIRCOT

VISIT BY DIGNITARIES



ICAR-CIRCOT, Mumbai, honored with the Cashless Institute Award on February 14, 2017; Presented by the Hon'ble Agriculture Minister Shri Radha Mohan Singh



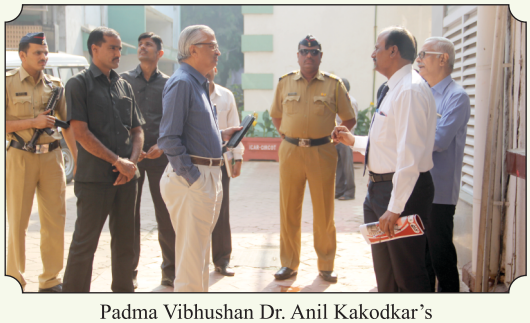
ICAR-CIRCOT, Mumbai Organised 7th Asian Cotton Research & Development Network Meeting in Nagpur, held on September 15-17, 2017



Ethiopian Delegates' Visit to ICAR-CIRCOT, Mumbai on April 29, 2017



Visit of the Parliamentary Committee from Rajbhasha to ICAR-CIRCOT held on January 11, 2017



Padma Vibhushan Dr. Anil Kakodkar's Visit to ICAR-CIRCOT, Mumbai in 2017



Visit of Dr. Trilochan Mohapatra, Secretary (DARE) & DG (ICAR), New Delhi to ICAR-CIRCOT, Mumbai on January 19, 2018



Visit of Iranian delegates to ICAR-CIRCOT, Mumbai in March 2018



Visit of Kenyan delegates to ICAR-CIRCOT, Mumbai on September 17, 2018

VISIT BY DIGNITARIES



Visit of Shri Sushil Kumar, Additional Secretary (DARE), Secretary (ICAR) to ICAR-CIRCOT, Mumbai on May 1, 2019



Visit of Shri Abhishek Singh, Secretary, ASRB, New Delhi to ICAR-CIRCOT, Mumbai on July 20, 2019



Visit of Ugandan delegates to Ginning Training Centre, Nagpur on September 21, 2021



Visit of Brazilian delegates to Ginning Training Centre, Nagpur in 2021



Visit of Dr. R. K. Singh, ADG (Commercial Crops) to ICAR-CIRCOT on October 13, 2021



Visit of Dr. Trilochan Mohapatra, Secretary (DARE) & DG (ICAR), New Delhi to Ginning Training Centre, Nagpur on June 26, 2022



Dr. S. N. Jha, DDG (Agricultural Engineering), ICAR, New Delhi Inagugurating National Laboratory for Assessment of Trash and Contamination in Cotton on July 12, 2022



Visit of Dr. Himanshu Pathak, Secretary (DARE) & DG (ICAR), New Delhi to CIRCOT, Mumbai on March 23, 2023

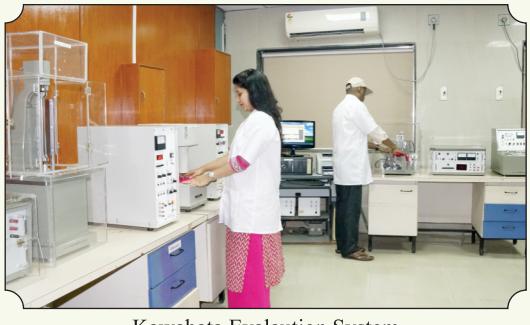
INFRASTRUCTURE



Speed frame Machine in MPD



DREF Spinning Unit



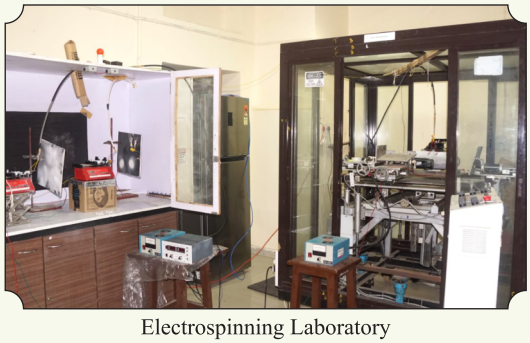
Kawabata Evalaution System



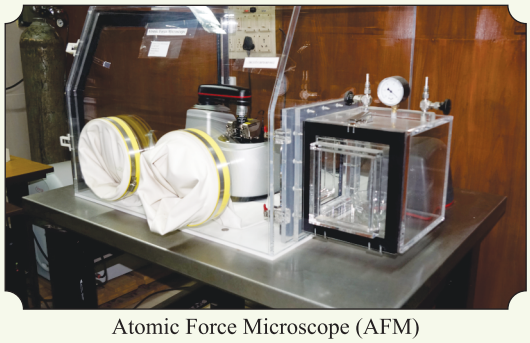
Fibre Testing Laboratory



Yarn Testing Laboratory



Electrospinning Laboratory



Atomic Force Microscope (AFM)



National Laboratory for Advanced Material Characterization

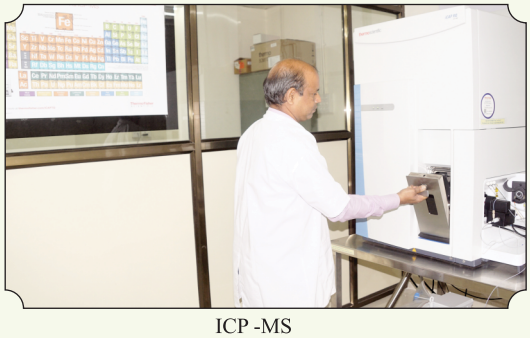
INFRASTRUCTURE



X-Ray Diffraction Unit



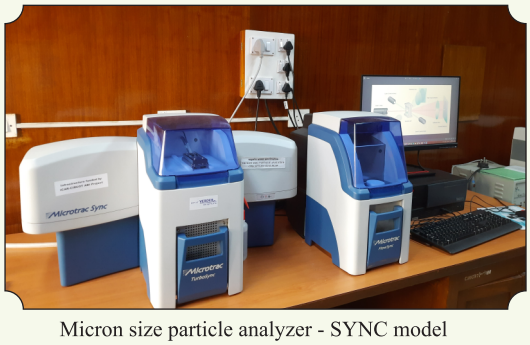
Chemical Laboratory



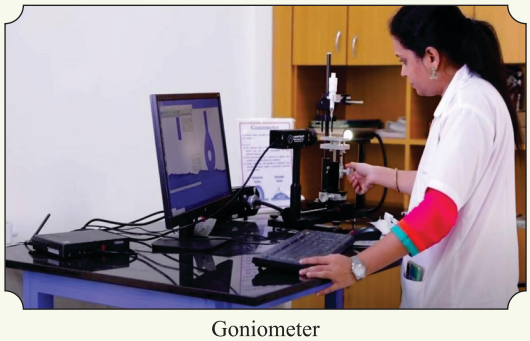
ICP -MS



Weaving Machine



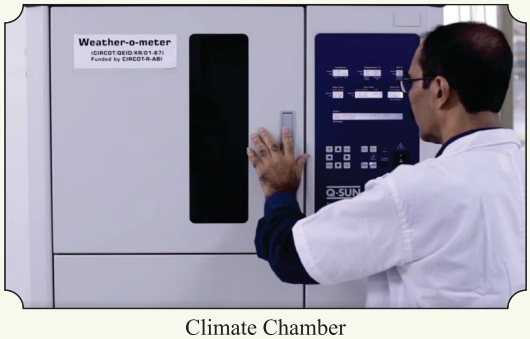
Micron size particle analyzer - SYNC model
Laser Diffraction with Dynamic Image Analysis cicot



Goniometer



Raman Spectroscopy



Climate Chamber

INFRASTRUCTURE



Modern Double Roller Ginning Plant at GTC, Nagpur



Scientific Cotton Seed Processing Plant at GTC, Nagpur



Particle Board Pilot Plant at GTC, Nagpur



Pelleting Plant at GTC, Nagpur



Rotobar Gin



93' Saw Gin Machine at GTC, Nagpur



Rotary Knife Roller Gin machine at GTC, Nagpur

ICAR-CIRCOT TECHNOLOGIES



CIRCOT Miniature Carding Machine



Village Level Carding Machine



Check Dam using Rubber Textile Fabric Composite



Micro Spinning Process



CIRCOT Miniature Draw Frame Unit



Multi-phase Electrospinning Machine



CIRCOT-Phoenix Charkha



High Performance Composite Wound Dressing Pad

ICAR-CIRCOT TECHNOLOGIES



Engineered Fabric Face Mask



CIRCOT Calibration Cotton



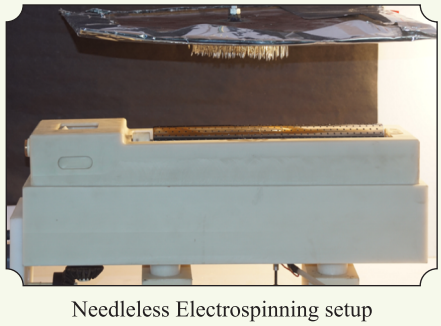
Cooling Belt for PPE Suit



PPE Jacket using E-textile



Engineered Fabric Face Mask with Nanofibre Catridge



Needleless Electrospinning setup



Protective Gloves E-textile

ICAR-CIRCOT TECHNOLOGIES



E-Textile



Glove



Naturally Coloured Cotton Handkerchief



Naturally Coloured Cotton Babywear



Naturally Coloured Cotton Jacket



Naturally Coloured Cotton Gamcha



Cotton Products Dyed with Natural Colours



Starch-PVC Composite Films for Food Packaging

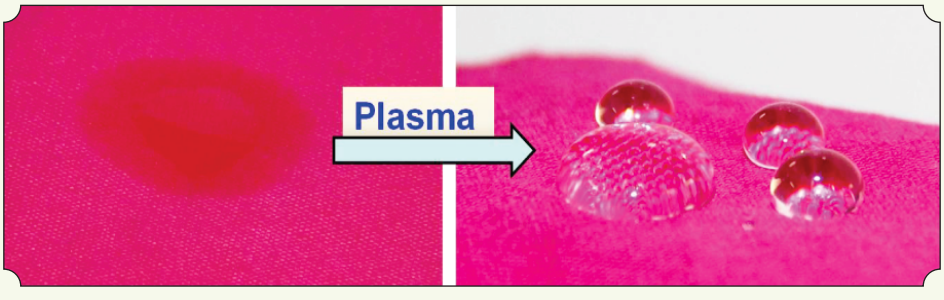
ICAR-CIRCOT TECHNOLOGIES



Seedling Trays from Banana Fibres



False Ceiling and Wall Panels from Banana Fibres



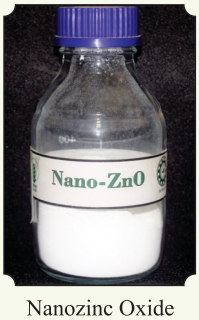
Water Repellent Fabric through Plasma Treatment



Decorative Banana Fibre Panel



Refined Cotton seed Oil



Nanozinc Oxide



Nanozinc Suspension



Nanocellulose Products

ICAR-CIRCOT TECHNOLOGIES



CLOY Gin



DR Gin with Rubber Roller



Lint Opener



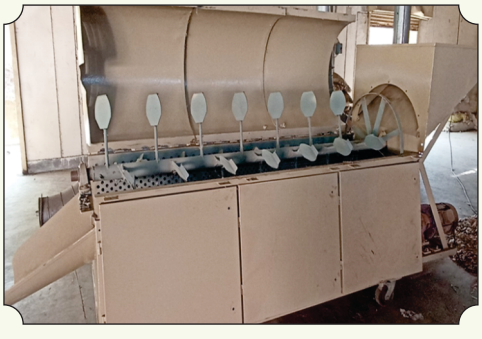
CIRCOT-Bajaj Pre-cleaner



Pellet Stove



CIRCOT-Bajaj Cotton Seed Dryer



Kawadi Opener



ICAR-CIRCOT Briquette-based Green Crematorium

ICAR-CIRCOT TECHNOLOGIES



Stick Remover Machine



Axial Flow Precleaner



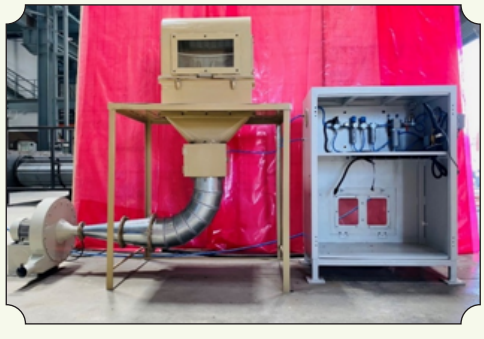
ICAR-CIRCOT Digital Ginning Percentage Indicator



Biomass Pellets Bulk Density Measurer



Single Locking Auto Feeder



Seed Cotton Trash Content Analyser

TRAINING PROGRAMMES



Training on Nanotechnology organized at ICAR-CIRCOT, Mumbai in 2013



Cotton Spining Training at ICAR-CIRCOT, Mumbai in 2016



Training on Nanotechnology organized at ICAR-CIRCOT, Mumbai during 2018



Training on Nanotechnology organized at ICAR-CIRCOT, Mumbai in 2019



Cotton Spining Training at ICAR-CIRCOT, Mumbai in 2022



Training on Electrospinning at ICAR-CIRCOT, Mumbai in 2023



Training on Nanotechnology organized through Videoconferencing in 2022

TRAINING PROGRAMMES



Demonstration of Clean Cotton Picking to Farmers under Tribal on Sub-plan at Coimbatore, Tamil Nadu in 2014



Skill Development Training Programme organized for cotton graders at GTC, Nagpur in 2016



Training imparted for Agriculture Officers of Maharashtra at GTC, Nagpur during Covid-19 lockdown in 2020



Training for Members of SC community at GTC, Nagpur in 2021



Training programme for Ginners in September, 2021



Training programme under SCSP during March, 2022



Training programme for Lead Resource Persons (LRPs) in October 2022



One Day Training programme for farmers under SMART Project in November 2022

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A CENTURY OF RESEARCH AT CIRCOT

This book highlights the researches of CIRCOT over a period of 100 years from December, 1924. Set up as a testing laboratory to help cotton breeders in ascertaining the technical worth of new strains evolved by them, CIRCOT grew in size and scope over the decades to assume the role of a full-fledged research institute of national stature. The Compilation of this Book has been the outcome of a group effort under the guidance of Dr. K. R. Krishna Iyer, former Director of CIRCOT (1995-2000)



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