

# The ICAC Recorder

International Cotton Advisory Committee



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## Innovative Interventions for Value Creation in Cotton Lint & Waste to Wealth

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Dr. Sreenivasan prepared this report for the ICAC. He presents a birds' eye view on novel applications and value addition of lint and creating wealth from comber noil and linters, which are considered as mill waste. The report basically highlights the major value-addition possibilities and prospects of all the predominant forms of cotton fibres that grow on cotton seeds. Needless to mention, cotton lint is a highly valued commodity and is used by the industry for various purposes. The mill waste, comber noil fibres are seldom wasted and like lint are also traded internationally and also in domestic markets, but linter wastage is a major international concern. Dr. Sreenivasan points out that though the global annual production of linters is 5.0 to 5.2 million tonnes, only 1.0 million tonnes are extracted and used. A conservative estimate shows that the annual value of the unused linters of 4.0 to 4.2 million tonnes is about US\$ 5.0 to 6.0 billion; which means that we have been ignoring the potential value of a precious cellulosic commodity, mostly because of the lack of national policies that could have otherwise captured the untapped potential of linters. Why are linters not extracted? Why are they allowed to be wasted? The simple answer is that though globally 75% of cotton seeds are crushed for oil extraction, most countries follow unscientific methods to directly crush seeds without extracting linters and hulls. Dr. Sreenivasan mentions the Indian case as an example, wherein "hardly 10% of ginned seeds undergo the rigorous processing to extract invaluable constituents (linter, hulls etc.), and the rest 90% seeds are directly crushed for oil extraction". Estimates show that India may have been wasting linters worth at least US\$ 1.0 billion annually because of unscientific seed processing. Calculations also show that the annual wastage of linters in Africa could be about US\$ 250 to 300 million. Linters are also wasted in USA, China, Benin, Greece, Pakistan, Argentina, Burkina Faso, Australia, Cote d'ivoire etc. Dr. Sreenivasan emphasizes the urgent need to devise a highly energy efficient or an alternate novel cost-effective mechanism to extract linters. He recommends the development of appropriate sized delinters capable of serving the ginning industry all through the year for extraction of linters from its seed.

For thousands of years man has tested and tried natural fibres such as flax, hemp, jute, coir, abaca, ramie, sisal, banana fibres, pineapple fibres, alpaca, angora, camel hair, cashmere, mohair, silk, wool etc. These fibres are valuable but contribute very less to the global fabric requirements. Cotton remains the undisputed leader of all the natural fibres, because there is no other fibre on earth that comes anywhere close to the virtues of cotton fibres relating to human comfort and fibre needs. Cotton fibres are almost pure cellulose. They are most skin friendly of all the fibres known to mankind. Cotton fibres are 100% natural and biodegradable. It is for these premium properties that cotton fibres are preferred over synthetic fibres.

For more than 7000 years cotton has been considered as white gold across the world. The fibres not only clothed the world but also provided comfort in bedding and mattresses. All parts of the plant including seeds and stalks have a commercial value. Cotton lint is mainly used for textile yarns, fabrics, garments, non-woven, industrial textiles and medical textiles; linters and comber noil are used to make absorbent cotton, pulp & paper, regenerated cellulose, micro crystalline cellulose, nano cellulose, modified cellulose, non-woven, carbon fibres, viscose, lyocell and high tenacity rayons. Seeds are crushed for cooking oil, the resultant seedcake is used as animal feed and hulls are used as animal feed and for peptone production. Cotton stalks are used to manufacture particle boards, hard/ fibre boards, pulp and paper, extruded products such as briquets, pellets and compressed blocks and to grow mushrooms. Cotton ginning waste is used for soil application, livestock feed, fuel and extruded products. Cotton plant biomass and cotton ginning waste serve as valuable raw material for composting.

This report also describes innovative textile cotton applications as wellbeing and health textiles, for moisture management, wound dressing fabric, flame retardant textiles, super hydrophobic textile, self-cleaning textiles, protective textiles and multi-functional textiles. The part on self-cleaning textiles is indeed fascinating, wherein cotton fabrics would not need water and detergents for cleaning. Instead, fabrics coated with nanoparticles of  $\text{TiO}_2$  and  $\text{SiO}_2$  in the presence of  $\text{ZnO}_2$  get self-cleaned with exposure to UV light by disintegration of organic stains into water and  $\text{CO}_2$ . Fabrics with mono layers of porphyrin compounds on anatase- coated cotton fabric get self-cleaned when exposed to visible light -very innovative and novel indeed! These technologies could mean a lot to the environment because they could save tremendous amounts of water and reduce detergent pollution.

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Dr Sreenivasan has 37 years of Research experience in Fibre Science and Technology out of which, 10 years in a Research management position as Director of CIRCOT, Mumbai. He is internationally renowned for his accomplishments on non-destructive methods of blend composition analysis in textile blends more importantly cellulose-cellulose blends using instrumental

techniques; understanding fibre disposition in newer yarn manufacturing systems and for the development and fabrication of a “moisture transfer measuring apparatus” for quick and accurate evaluation of moisture transport through fabrics. He was bestowed with the “Distinguished Accomplishment Award” in 2009 (ATNT) jointly by Bannari Amman Institute of Technology; Coimbatore and Texas Tech. University, U.S.A. Dr Sreenivasan guided six students for Ph.D degree in Physics for Mumbai University and three students for M.Sc degree in textile and clothing, SNDT University, Mumbai. He obtained five patents, published 175 scientific papers, 4 book chapters and 110 technology bulletins.



## Innovative Interventions for Value Creation in Cotton Lint & Waste to Wealth

### Part-1: Value Addition to Comber Noil

## 1. Introduction

“Cotton is grown to be spun” is an old dictum among cotton processors. Spinning is considered to be a mechanical process by which a few fibres are brought and drawn together in such a manner that a cohesive twisted structure is formed. The number of fibres brought together is dependent upon the count or yarn diameter envisaged. In the process of dismantling a high density compressed bale to produce a yarn, the fibres undergo a series of processes such as opening and cleaning, individualization and parallelization, drawing, thinning down with all fibres brought together and made parallel to an imaginary yarn axis, before being inserted with a twist to form a yarn. In these mechanized operations the compressed fibres are decompressed, opened and individualized devoid of organic trash that was entangled with them. The individual fibres as a result are subjected to mechanical forces in all directions longitudinal and lateral with a preferential longitudinal pull. While preparing a homogenized drawn sliver prior to twisting, the now opened and separated fibres undergo a predominantly longitudinal drag and in both the

above major operations wastes are generated that comprise in the initial stages more organic trash and less of good fibres. In the later stages of processing on a larger measure, good fibres are discarded as waste.

### (a) Waste Generated in Processing

The composition of the waste generated depends on the type of operation viz. cleaning, parallelizing drawing, combing (a process to remove short fibres), and in the final stage of twisting and forming a yarn (fibre fly) {1,2}. The amenability to cleaning of cotton fibres dictated by the initial trash content, fibre length and maturity, also decides the type and quantity of waste released in each mechanical operation. As far as fibre wastes are concerned, Card waste and comber waste

are the two major fractions that contain good fibres which could be put to further use. Flat-strip waste although contains less amount of fibres longer in nature, Comber waste or noils as they are referred to, are a source of good fibres large enough in quantity capable of being put to use separately.

### (b) Comber Noils

Comber noil is regarded more as a by-product of yarn manufacture during combing, an operation designed to remove short floating fibres in a sliver. It is a relatively trash-free waste generated

Table-1. Parameters of Virgin Cotton and Comber Noil  
Extracted from the Virgin Cotton.

| Parameters                   | Cotton       | Comber Noil                             |
|------------------------------|--------------|-----------------------------------------|
| 2.5% span length (mm)        | 28-32.5      | 15-21                                   |
| Micronaire Value             | 3.8-4.2      | 2.5-3.5                                 |
| Tenacity(g/tex)*             | 24-28        | 17-19                                   |
| Short fibre Content          | 10           | 8-10                                    |
| Immature Fibre Content (%)   | Less than 10 | 18-21                                   |
| Neps and Seed coat fragments | 150 & 10     | Significantly higher than virgin cotton |

\*Tenacity in ICC mode



in large quantity. The operation of combing is carried out to produce combed yarns unlike carded yarns (where this operation is avoided) of high quality devoid of shorter fibres for special down-stream processing. To make the parallelized sliver further aligned, bereft of short and floating fibres, the comber removes about 15 -18% of the fibres from the sliver. This is the place in mechanical processing of cotton, wherein, bulk of waste of shorter fibres is produced. For a cotton to be used to prepare combed yarn, the virgin material has to be of certain characteristics. Table-1 enumerates the characteristics of both the virgin material as well as comber waste generated.

Since combing is done both in the forward and backward directions to achieve better cohesiveness and longitudinal alignment without floats, the penetration of combs and number of passages decide the fibre parameters and extent of noils removed {3}. A study on the distribution of the length of fibres prevalent in Comber noil led to an interesting inference that, about 2/3 of the comber waste contained fibres less than 15 mm length while 1/3 of the fraction was above that category {4}. As already noted, being trash free, and essentially consisting of short opened fibres, these are either alone or in blends with virgin cotton used to prepare rotor/OE yarns and further converted into fabrics in handloom as well as in power loom.

### (c) Bleached Comber Noil

In order to make comber noil as a marketable commodity, the material has to be cleaned, got rid of the wax content and colour. Therefore, scouring and bleaching are the two processes carried out to improve its grade. While scouring is a process to remove natural impurities including wax and pectin, traditionally it is carried out by treating with low concentration of NaOH at high temperature. To comply with eco regulations, nowadays enzymatic treatment either with a single enzyme or a cocktail of enzymes is carried out to get the desired impact.

Bleaching is a process to get rid of the residual colour and to make the noil white. Again, conventionally, the bleach used to contain chlorine. However, the modern practice is to bleach using peroxide solution due to environmental considerations of effluent. More recently, a single bath enzymatic scouring and peroxide bleaching has been developed {5} to achieve the output with less water and chemical, keeping the impact of the treatment to the environment to the minimum. The chemical composition of bleached comber noil is given in Table-2.

Table-2. Chemical Composition of cCmber Noil

| Parameters                       | Content |
|----------------------------------|---------|
| Cellulose (%)                    | 98-99   |
| Solubles (water, Ether etc.) (%) | 1.0     |
| Ash (%)                          | 0.40    |
| Degree of Polymerisation         | 1500    |

## 2. Comber Noil as a Marketable Commodity

Comber noil is sold as a compressed bale of weight 100 Kg (for internal consumption) and 170 Kg (for export) in India. The open-end yarn industry, in India, predominantly uses this as raw material for spinning rotor yarns of lower counts; while the combed yarns are consumed by the ring spinning industry for producing high value finer count yarns. As the comber noils have found their applications in other value-added products such as sanitary napkins and other personal care items and also in the manufacture of regenerated cellulose, the raw material got diverted into these sectors. As a result, the primary user viz. the OE yarn industry has found it to be increasingly difficult to source good quality noil both due to non-availability as well as a spurt in the raw material cost. This has put the OE yarn industry in quandary which was encouraged to add more and more rotors in the country due to easy access to raw material. The bleached noil, due to its increased accessibility to chemical reagents (low DP combined with no wax), purity and high cellulose content (see Table 2), is being favourably exploited by the Cellulose industry for manufacture of regenerated cellulose. Particularly, the small-scale manufacturers and the handloom industry find it hard to source noil at affordable prices since 2005. The export of noil to other countries has also added to this misery in good measure.

There are no authentic reports about how much noil is being produced worldwide nor what is the quantity transacted by different processing countries. In India annually about 0.25 million metric tonnes of comber noil is produced {6}. An indirect guestimate of comber noil production/ availability globally could be around 5 million bales worth US\$ 1500 mn.

Figure-1. Bale of Cotton and Processing Wastes Generated



### 3. Application of Comber Noil for Diversified Value Addition

As noted already, unbleached, cleaned comber noil is used to manufacture OE yarns which could further be value added by producing knits. Cleaned and bleached comber noil with its major constituent being pure cellulose, is used as raw material for cellulose manufacture and more recently in cotton nonwovens and bio-degradable cotton nonwoven based composites. In this section, a brief account is being provided on the application of comber noil for the manufacture of diversified products from low value –high volume (OE yarns) to high value - low volume cellulose and modified celluloses and nonwovens.

#### (a) Open-end Yarns

Cleaned comber noil either alone or in mix with virgin cotton of a desired proportion as desired by the final quality of the product, is used in a OE spinning process to produce rotor yarns {7}. Blends of comber noil and virgin cotton in different proportions were processed and OE yarns produced. From the quality of the yarns, it could be judged that addition of noil in the blend up to 25-35% did not significantly alter the mechanical behavior, although presence of virgin fibres in higher proportion enhanced the tenacity of the yarn which otherwise was found to be weaker.

If comber noil is alone used to produce OE yarns, then the counts were found to be medium-coarse. Since the majority of fibres were less than 15mm, this explains the coarser count, and that the yarn strength was marginally lower although the speed of production did not get affected. Knitted garments could be produced successfully by using those OE yarns.

#### (b) Absorbent cotton: Cotton balls

Apart from textiles and garments, one of the most sought-after value-added-product prepared after minimal processing is absorbent cotton or referred to as surgical cotton in medical parlance. Comber noil is cleaned, bleached, and carded to make it completely hydrophilic, free from other external agents including organic trash. The treated material is softened and

sterilized (if need be) and carded (depending on the application) and compressed and baled (for easy transportation). Another form of the treated material is made into a ball, essentially for wiping. For the material produced from Comber noil, the average length of the staple is about 15mm. The salient features of this product are its inertness, lack of irritation and softer to skin {8}, highly absorbing and retaining fluid within its body without the skin/body feeling the damp, a characteristic of cotton. For medical applications, the product should satisfy the parameters prescribed in Indian/British Pharmacopodia standards.

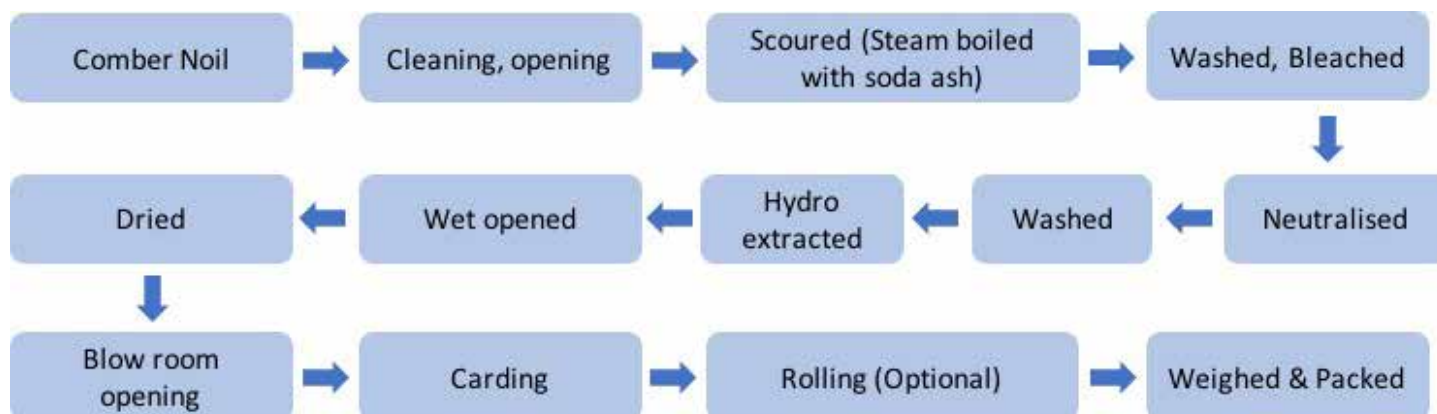
A schematic diagram (figure-2) given below illustrates the preparation of absorbent cotton from noil.

Since the production capacity could be smaller (150 mt/year), it is suitable for a small and medium enterprise establishment. Being classified as medical textiles, it is considered as a high value –low volume enterprise, with minimal processing.

#### (c) Cotton –based Non- woven

Cotton non-woven preparation by using comber noil has received considerable attention by researchers in the recent past {9-15}. Earlier the use of cotton in non-woven was restricted to 2%, whereas poly propylene, polyester, and other synthetic fibres used to occupy 98% of applications. The presence of foreign matter, wax, and variation in quality from batch to batch used to be referred to as hindrance in using cotton. Moreover, some of the bonding mechanisms used in the preparation of non-woven suited more to synthetic fibres. With the advent of hydro-entanglement /spun-laced/ spun-bonding technology cotton has found its application in non-woven for use in a variety of value-added-products. Non-woven, in general, possesses the advantage of high economic efficiency in production retaining the desired performance capability. Another advantage is its ability to form light weight fabrics. Cotton is preferred in special applications of skin contact as well as medical purposes due to its high absorbency, breathability, high wet strength, non-allergic, soft and its ability to hold but prevent passage of fluids. It becomes a preferred material for applications in high temperature due to its excellent resistance

Figure-2. Material Flow diagram for Absorbent Cotton



to heat, dimensional stability, and high strength at these temperatures ( $175^{\circ}\text{C}$ ).

For preparation of hydro-entangled non-woven, comber noil is employed as raw material. A batt prepared with noil either using air laying system or needle punching, is subjected to varying water pressures to make a non-woven that could be converted to wipes, pads, gauzes and cosmetic applications. Hydro-entanglement has the added advantage that scouring could be avoided prior to bleaching as water jet is able to remove the waxy material in cotton.

#### (d) Pulp and paper

Comber noil after removal of organic trash and other non-cellulosic impurities could be used for pulping and converted to high value paper for use in currency, security paper etc. A dissolving grade pulp is prepared before converting the pulp to paper in conventional machines. Due to severe eco-regulations, the process of pulping and bleaching has to ensure all the norms prevalent in the region and also a fool-proof effluent management programme. Cellulose from cotton waste such as comber noil and others, were preferred to wood pulp due to their purity and fibres in pulp exhibited higher tenacity and E modulus.

#### (e) Regenerated Cellulose

What has been described so far concerned applications that predominantly depended on the form of the fibre, its length, short fibre content, tenacity, and maturity. Conversion of cellulose waste such as comber noil and linters to regenerated fibres relies on the quality (amount of foreign material, Degree of polymerization) and quantity of cellulose present (cellulose content) to be dissolved and regenerated.

Traditionally, regenerated cellulose known as viscose rayon, is produced by dissolving cellulose in suitable solvent, carbon-di-sulphide, and extruded into filaments/staple fibres. This

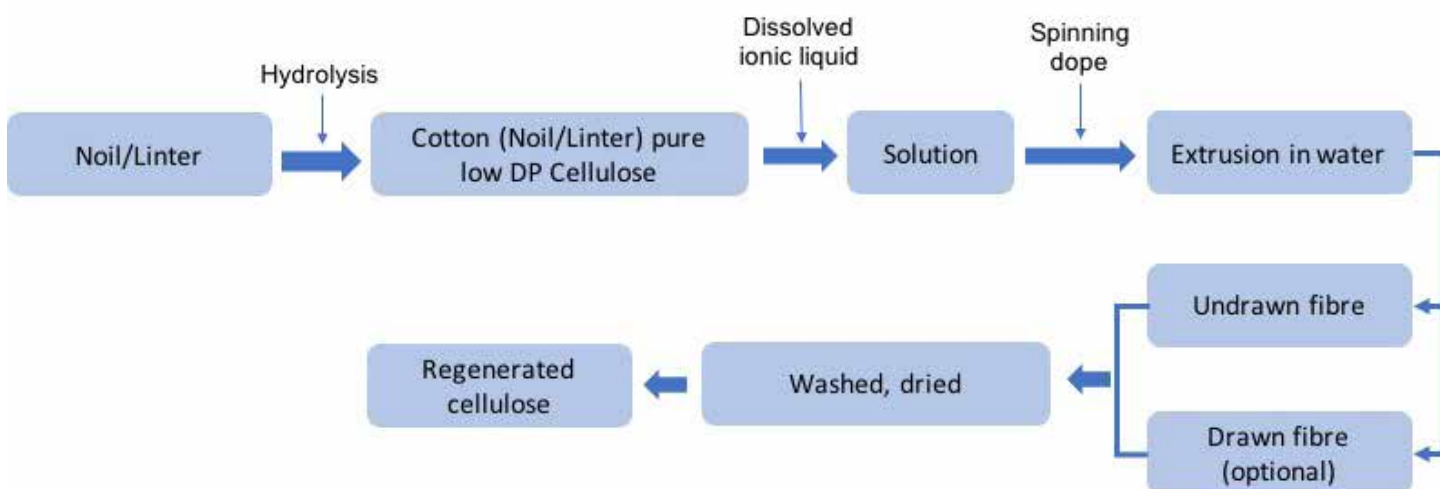
has environmental issues related to release of  $\text{CS}_2$ , a toxic gas. Improvements in this process led to production of 'LYOCELL' fibres, which also has problems with the solvent (N. methyl morpholine oxide) and also fibrillation of cellulose. More recently use of ionic liquids to dissolve cellulose and then extrusion into fibre/filament has resulted in improved quality of regenerated cellulose fibres [16].

Figure 3, below describes the process sequence in a schematic diagram for regenerated cellulose production by using comber noil. The choice of hydrolysis depends upon the molecular order of the starting material. The degree of polymerization of the starting material and the selection of a suitable ionic liquid are crucial factors that determine the quality of cellulose produced. These fibres produced from waste cotton lint exhibited highest thermal decomposition temperature indicating higher stability associated with high crystallinity of the material [17]. These fibres had roughly round cross sections, relatively smooth surface and rod-like longitudinal morphology. Regenerated cellulose fibres had higher tenacity and Young's modulus than conventional: 'TENCEL' fibre [18].

#### (f) Micro crystalline cellulose

Microcrystalline cellulose is obtained by treating cotton with acids at desired temperature thereby hydrolyzing the chain, decreasing its degree of polymerization in a controlled manner. The final product, the purest form of cellulose produced, is used as a filler for capsules and its hardness and high binding capacity enables the active component (medical formulation) to be bound into a compact tablet. The tablet produced by using comber noil was found to disintegrate quickly in a fluid medium, enabling the release of active component at the desired source. MCC prepared from cotton (be it waste cotton, comber noils, linters, post-consumer waste) meets all the specifications of USP norms with respect to chemical identity [19] and proved to be a good additive for tablet preparation.

Figure-3. A Schematic Flow Diagram of the Material for Regenerated Cellulose Preparation by Using Comber Noil





### (g) Nano Cellulose

Nano cellulose has received concerted attention by researchers due to its very specific attributes such as very large specific surface area, low weight/volume ratio. The methods of production include treatment of cotton noils/linters with acid (hydrolysis) and centrifugation to Nano-size cellulose fibres/powder {20}. Alternately, fibrillation at very high speed also results in Nano fibrils after ensuring the starting material to be highly de-crystallized (treating cotton with alkali hydroxides or ethylene di amine or zinc chloride). A novel method of nano cellulose production is by producing Nano fibres by applying an electric field on a fluid jet and the process is known as electro-spinning. Cotton fibres by dissolving in suitable solvents such as trifluoro acetic acid could be converted into a fluid before subjecting to an electric field {21, 22}. The output is a mat of uniform thickness of Nano fibres which could be used in various areas such as industrial filters etc. Production of nano cellulose powder/ nano mat of fibres is a surer way of adding very high value to a material considered as low value (comber waste) by either chemical or mechanical action {23}.

### (h) Bacterial Cellulose

Bacterial cellulose is a cellulose product with high purity, mechanical strength, liquid absorbing capability, biocompatibility, biodegradability with fairly high strength and crystallinity {24}. A material with high cellulose content but with low lignin content is eminently suitable for bacterial cellulose production. The dis-advantage in bacterial cellulose production is its high production cost. In order to minimize cost, efforts are being made to use novel microbial strains as well as use cotton waste as raw material {25}. The bacterial cellulose is conventionally produced by using cotton in culture media for saccharification in *Gluconacetobacter Xylinus*. The conversion rate into bacterial cellulose could be enhanced first by treating cotton waste in a suitable ionic liquid prior to introducing the culture. The water holding capacity of the product is around 99.5%, and the thickness about 2.8 mm with fairly high strength of 0.48 Newtons.

## 4. Entrepreneurship in Value Addition to Comber Noil

As already noted, though comber noil is extracted as a by-product during mechanical processing of cotton bale, the good amount of useful fibres that could be recovered from this so-called waste material has generated huge interest not only among researchers but also in building entrepreneurship {8, 26, 27}. Since a lot of avenues for value addition to this cellulose fibre has been discussed in the preceding section, it is necessary to rigorously analyze the economic benefits of the process of value addition before venturing into any business activity. The non-recurring investment in land, building, & machinery, and annually recurring expenses towards water, electricity, chemicals, labour as well as in setting up a fool-proof effluent treatment mechanism has to be thoroughly examined before making a judicious choice about the plausible route for value addition.

Preparation of absorbent cotton from comber noil (referred to as cotton-wool in some circles) is considered as one of the viable value addition endeavour capable of running a successful business venture. With rising awareness about health care and increasingly available medical facilities even in every nook and corner of the country, the demand for surgical cotton is rapidly growing at the rate of 8-10% in India alone. It has been reported that a plant capacity of 100 tonnes per annum could be profitably set up with a capital investment of about US\$ 75,000 and with a working capital of double the amount. The costs of land and building are not considered here as they vary from place to place. A Rate of Return (ROR) on investment of about 30-33% is also envisaged in such a plant. More improved project reports prepared recently with innovative modern processing technologies are available {28, 29} for further consultation.

Table 3. Price of Raw material and Value Added Product

| Material              | Price (us\$/Kg)              |
|-----------------------|------------------------------|
| Comber Noil           | 0.75-1.35                    |
| Bleached comber Noil  | 2-2.5                        |
| Cotton linter         | 1-1.5                        |
| Bleached linter       | 1.5-2.5                      |
| Absorbent cotton      | 2.25-2.75                    |
| Open End yarn         | 3.0-5.0 (depends on quality) |
| viscose               | 1.5-2.25                     |
| Pulp-paper Grade      | 1.25                         |
| Pulp-dissolving grade | 1.5                          |
| Cotton linters pulp   | 1.5-1.75                     |
| Viscose grade pulp    | 1-1.2                        |
| High end paper        | 1.75-2.0                     |

## 5. Future Outlook

Resource use-efficiency, resource conservation and waste management and containment have become the operating buzz words of any industrial activity in recent years. Textile industry is no exception to this Mantra. The comber noil generated during processing of a compressed bale has served the Open-End-Yarn industry as a veritable raw material with profitability. Many more new, exciting but unexplored business activities are waiting to be taken up and benefits reaped in coming times using this excellent cellulosic reserve. As many new ventures start springing up, the availability and price of noil would become dearer and unaffordable especially for the conventional processors as well as for small and medium enterprises. Adoption of efficient processing routes and tools and modern methods of management and a continually upgrading human resource would be the key ingredients for a successful venture using this invaluable cellulosic raw material.



## References Cited

1. Cotton Waste Recycling- Quantitative and Qualitative Assessment: M. T. Halimi, M. B. Hassen and F. Sakli. *Resources Conservation and Recycling*, 52, 785-791, (2008).
2. Utilization of Cotton Spinning Waste in Yarn Production: T. B. Ute, P. Celik and M. B. Uzumcu. *Textile Industry and Environment*, 2019, Intech Open.
3. Studies on Backward and Forward Feed in Combing Process and its Impact on the Quality of Extracted Sliver and Noil: S. Venkatakrishnan and S. Mukundan. *International Journal of Scientific Research*, 6, 192-195, (2017)
4. Combing Behaviour at Different Parameters: Sunil Kumar Sharma. *Spinning Textile Magazine*, 7, 7 (2013).
5. Single Bath Enzymatic scouring and bleaching Process for Absorbent Cotton: A. S. M. Raja, A. Arputharaj, Sujata Saxena and P. G. Patil. *Indian Journal of Fibre and Textile Research*, 42, 202-208, (2017).
6. Priority Cotton By-products Activities for Development: P. G. Patil. *National Capacity Building workshop*, (UNCTAD), Harare, Zimbabwe, 2017.
7. The Use of Comber Noil in the Open-End-Spinning process for Cotton: Patrica N. Marino, & J. Gafalo. *J. Text.Inst: No 4*, 189-192, (1982).
8. Project profile –Absorbent Cotton: Prepared by Ministry of Micro, Small, and Medium enterprises, government of India, 2011.
9. Greige Cotton Comber Noils for Sustainable Non-wovens: P. Sawhney, M. Reynolds, C. Allen, B. Condon, R. Slopek, D. Hinchliffe, and D. Hui. *World journal of Engineering*, 8((3), 291-294, (2011).
10. Advantages of Using Natural fibres in Non-woven Composites: T. A. Calmari jr. *Beltwide Cotton Conference*, Atlanta, 2002.
11. Spun-laced Cotton and Cotton Blend Cosmetic Pads and Bed Sheets: Study of Fibre Entanglement: D. V. Parikh, R. R. Bresec, V. Muenstemann, A. Watzi, and L. Crook. *Journal of Engineered Fibres and Fabrics*, 2, 40, 2007.
12. Mechanical and Comfort Properties of Hydroentangled Nonwoven from Comber Noil: F. Ahmed, M. Tausif, M. Z. Hassan, S. Ahmed and M. H. Malik. *Journal of Industrial Textiles*, 47, 2014-2028, (2017).
13. Non - Woven and Life-Style –Spun laced and Air-laid Non-Woven for Medical-Surgical-Health Care –Personnel Hygiene: A. Watze, J. Eisenacher, and D. Gillepsie. *Proceedings of the Belt Wide Cotton Conference*, 1, 698-701, (2001).
14. Future of Cotton in Non-wovens: A. P. S. Sawhney, and B. Condon. *Textile Asia*, 13-15, (2008)
15. Fibres for Non- woven-In Pursuit of Viable Alternatives: A. Wilson. *International Fibre Journal* (2020).
16. Utilization of Cotton Waste for Regenerated Cellulose Fibres: Influence of Degree of Polymerization on Mechanical Properties: Rasika De Silva, Nolene Byrne. *Carbohydrate Polymers*, 174, 89-94, (2017).
17. Eco-friendly Post-consumer Cotton Waste Recycling for Regenerated Cellulose Fibres: W. Liu, S. Liu, J. Liu, Tuan Liu, J. Zhang and H. Liu. *Carbohydrate Polymers*, 206, 141-148, (2019).
18. Textile Qualities of regenerated cellulose fibres from Cotton waste pulp: S. Bjorquist, J.Aronsson, G.Henriksson and A. Persson. *Textile research Journal*, 88(21), 2485-2492, (2018).
19. preparation of Micro crystalline Cellulose from Cotton and its Evaluation as Direct Compressible Excipient in the Formulation of Naproxen Tablets: M. Nurul Islam Setu, Md. Yeunus Mia, Nur Jaharat Lubna and Abu Asad Choudhry. Dhaka University. *Journal of Pharmacy Science*, 13(12), 187-192, (2014).
20. Extraction of Cellulose Nano Crystals (NCC) from Cotton Waste and Morphology of NCC obtained with Different Alkali Neutralization: F. Scognamiglio, C. Santullil, and G. R. Oselli. *Current Journal of applied sciences and Technology*, 36(5), 1-8, (2019).
21. Producing cellulose nano fibre from cotton Waste by Electro -spinning Method: R. Dashtbani, and E. Afra. *International Journal of Nano Dimensions*, 6(1), 1-9, (2015).
22. Structural Studies of Electro -spun Cellulose Nano fibres: C. W. Kim, D. S. Kim, S. Y. Kang, M. Marquez, and Y. L. Joo. *Polymer*, 47, 5097-5107 (2006).
23. Characterization of Nano Crystalline Cellulose obtained from Cotton Waste: F. A. Fazli, M. R. Ehsani, B. Ghabarzadeh and G. H. Asadi. *European Journal of Zoological Research*, 3(1), 142-146, (2014).
24. Bacterial Cellulose production from Cotton based Waste Textiles: Enzymatic Saccharification enhanced by ionic Liquid Treatment: F. Hong, X. Guo, S. Zhang, Shi-fen Han, G. Yang and L. Jonsson. *Bio Resource Technology*, 104, 503-508, (2012).
25. Production of Bacterial Cellulose and Enzyme from Waste Fibre Sludge: A. Carka, X. Guo, Shui-Jia Tang, S. Winstrand L. J. Jonsson and F. Hong. *BioTechnology for BioFuels*, 6, 25, (2013).
26. Project Report Manufacturing Absorbent Cotton Wool-Shom Consultancy Services: <https://www.slideshare.net> (2016).
27. Surgical Cotton Manufacturing Business: Absorbent Cotton Roll Production Plant. Absorbent Cotton Wool Manufacturing Project: NIIR Project Consulting services (NCPS) [www.entrepreneur.co](http://www.entrepreneur.co)
28. Eco-friendly Process of Absorbent Cotton Preparation for Rural Entrepreneurship: P. Jagajanantha, V. Magheswaran, Varsha Satankar, and P.G.Patil. *International Journal of Current Microbiology and Applied Sciences*, 7, 1097-1103, (2018).
29. C. Sundaramoorthy: Regional workshop on Promotion of Cotton By-products in Eastern and Southern Africa, *UNCTAD Seminar*, Nagpur, May 2019.

## Part-2: Value Addition to Linters

### 1. Introduction

Seed cotton harvested in the field undergoes the primary processing of separation of lint and seed in ginning factories. This process is the most important and significant operation that decides both the yield of lint and its quality. The cotton seed that gets separated in the process is an important genetic material having the potential to yield a fresh crop as well as several valuable by products, if processed in a scientific manner, sequentially.

The current availability of Cotton seed is estimated to be more than 50 million tonnes world-wide. The Global cotton seed sector is a vibrant industry projected to grow with a CAGR of 5.2% since 2019. It is envisaged that this thriving sector attracting newer investments and players is expected to touch US\$ 1.0 Billion in the near future. With the introduction of genetically modified cotton in many countries, this industry has witnessed increased investments from the private sector in developing and releasing newer strains of cotton with active participation of the farming community.

The cotton seed that leaves a ginning factory is surrounded on its surface by a thick fuzz that could not be separated during ginning. The amount of fuzz residue on the seed is, however, decided by the type of ginning/mechanism employed for ginning viz. saw ginning or roller ginning. The fuzz, known as linters, is a mass of short fibres that adhere to the seed tenaciously even after ginning, and has a thicker secondary wall at the seed surface accounting for the resistance to removal during separation. If the cotton seed is processed in a scientific manner then the fibres could be separated and put to effective use. Scientific processing of cotton seed is a system of operations that enables separation and recovery of invaluable constituents viz. linters, seed hulls (outer cover of the kernel) and kernel, and also provides avenue for preparation of seed meal or de-oiled

cake. (Figure-1). Each of these by products or constituents has tremendous scope for value addition and contributes effectively to the composite economy of cotton.

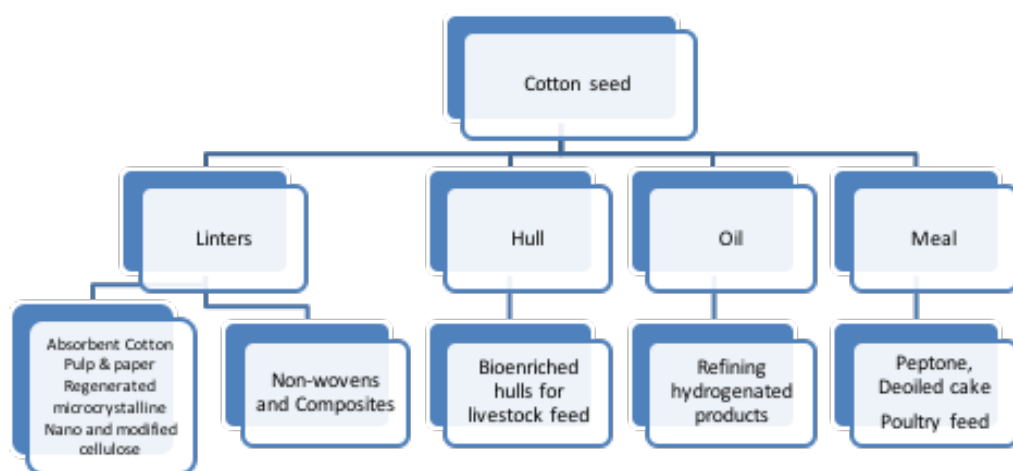
As already noted, the process of separating the fuzz from ginned seeds is known as de-linting. This process of removal of short fibres adhering to the seed can be effected in more than one way depending on the end use of the seed. Two processes, in vogue, commercially have gained importance 1. Acid delinting and 2. Mechanical delinting. Though, many other mechanisms such as flame treatment have evoked research interest in purifying seed to enhance its germination potential in the field, they have not gained popularity. While acid delinting is a process of treating ginned seeds with acids with the primary purpose of sowing the seed for the next crop, the fuzz is completely lost in the process. In mechanical delinting the fibres are not degraded unlike in acid delinting and is recovered for further use. This is usually accomplished by high speed rotating sharp screws or abrasive surfaces to cut or rub the fibres off the surface of the seed hull. This process heavily relies on the physical friction to remove the fuzz forcibly.

#### (a) Advantages of Mechanical Delinting

Several beneficial traits have been identified during mechanical delinting of ginned seeds. The recovery and recyclability of the fuzz (linter) is the primary advantage apart from prevention of environmental pollution. However, the cost of delinting is found to be higher compared to acid delinting. In view of the emerging uses of linters enhancing its scope for value addition, several researchers have attempted to improve the functioning of mechanical delinter particularly its ease of operation {1,2,3}.

A typical yield of cotton linters is around 9% by weight of the seed. A study of yield of linters from different species of Cotton {4} revealed that, the linter content from *G. hirsutum* cotton is about 10.5%, whereas the native cottons from India belonging to *G. arboreum* & *G. herbaceum* yield linters varying from 4.3-5.9%. *G. barbadense* species produce naked seeds. Hybrid cotton seeds (intra-hirsutum and *hirsutum* x *barbadense*) have shown higher fuzz with linter content exceeding 10%. The linters collected after the first phase using delinting machines are called "First Cut Linters" and after second phase are called "Second Cut Linters". "Third Cut Linters" are often referred to as hull fibres. However a mixed version of linters, denoted as "mill runs" is used for production of pulp.

Figure-1. Scientific processing of cotton seed-constituents and possible value addition



## (b) Physical & Chemical Characteristics of Linters

The physical parameters of the linters recovered depended on the phase of collection from the delinting machine.

Table-1 describes in detail the characteristics of the linters.

| Parameters                                                    | Value                                    |
|---------------------------------------------------------------|------------------------------------------|
| *Fibre length<br>1st Cut (mm)<br>2nd Cut (mm)<br>3rd Cut (mm) | 2.5-6.0<br>2.0-3.0<br>Less than 2.0      |
| Colour (depending on cut)                                     | Clear, clear to brown, brown             |
| **Cellulose<br>Holo cellulose<br>Alpha cellulose              | Higher than 80% up to 85 %<br>80%<br>78% |
| Water/moisture content (%)                                    | 6.0-8.0                                  |
| Extractables (%)<br>Fat & waxes (%)<br>Pectin (%)             | 5.0-6.0<br>2.0<br>1.0                    |
| Proteins (%)                                                  | 2.0                                      |
| Ash (%)                                                       | 2.0                                      |
| Insoluble lignin(%)                                           | 0.7                                      |
| Foreign matter (%)                                            | 1.0                                      |
| Seed hulls                                                    | 11.0                                     |

Note: The constituents do not necessarily add up to 100% as they are measured on different samples. \*The ensemble contains a large proportion of short fibres (fibres less than the average length). \*\*The cellulose linter has low viscosity and therefore low degree of polymerization.

## (c) Comparison of Attributes of Lint, Noil & Linters

| Parameters                    | Lint                                                         | Noil                                                            | Linters                                                 |
|-------------------------------|--------------------------------------------------------------|-----------------------------------------------------------------|---------------------------------------------------------|
| Length (mm)                   | 20-38                                                        | 15-19                                                           | Less than 6                                             |
| Micronaire/maturity           | 3-6.5 (depending on length)                                  | Less than lint                                                  | Less than noil                                          |
| Strength (g/tex)              | 16-34                                                        | Weaker than lint                                                | Weaker than noil                                        |
| Short fibre content (%)       | 4-5 (increases with decrease in length)                      | Increases to 10%                                                | Shortest fibres                                         |
| Amenability to cleaning       | Depends on maturity & length, generally poor                 | Better than lint                                                | Better than lint and noil                               |
| DP (chainLength)              | 1800-3200                                                    | 1200-1500                                                       | 600-800                                                 |
| Cellulose content (%)         | 80-85                                                        | 85-95                                                           | Above 98                                                |
| Specific surface area         | Lowest                                                       | Higher than lint                                                | Very high surface Area                                  |
| Affinity to chemical reagents | Poor                                                         | Increases commensurate to lowering DP                           | Very high affinity                                      |
| Adhesion of Micro-organisms   | Poor                                                         | Increases with Surface area                                     | High adhesion                                           |
| Value addition                | Heavily dependent on length, fineness strength and structure | Quality of cellulose primarily, fibre parameters secondary role | Mainly on the quality and quantity, purity of cellulose |

The comparison here is among three types of celluloses.

1. Lint (Primary processed – fibre extracted from seed cotton,
2. Noil (compressed bale opened, reprocessed, individualized) and
3. Linter (ginned seed, reprocessed by saws to remove fuzz).

While the primary processed material has a form dependency, the reprocessed material relies on internal organization and quantity of the constituent cellulose.

## (d) Primary Processing of Linters – Bleaching

The foreign matter present in linters is removed by bleaching, currently by using peroxide. The bleached linter is one of the purest forms of alpha cellulose (more than 99%) {5}. Due to their purity and whiteness and lower DP (around 600-800), this cellulose forms the basis for a large number of special and niche products.

## 2. Availability and Market Prospects of Cotton Linters

Globally, the availability of cotton linters depends on the production of cotton in general, barring the *G. barbadense* species. A rough estimate of linters is projected to be approximately 18% of the cotton production in that year. The current level of production potential for linters globally is around (prospectively could be) 5-5.2 million tonnes. However, it is reported that the global availability would not be more than 1.0 million tonnes {6}. In India, the extraction of cotton linters is about 90,000-100,000 tonnes, contributing only to less than 10% of the world production. The price of cotton linters depends on the foreign matter content, whether it is first cut or mill run, and its cellulose content. The price varies with that of cotton internationally. The price in India, fluctuates with the availability in the market, governmental regulations, and export. The price in recent years varies between US\$ 1000 to US\$ 1500 per tonne again depending on the quality of bleaching. The marketable commodity in export arena is in the form of a bale.

In India, cotton linters are always in short supply and as a result it becomes unaffordable to small processors. This situation is essentially due to absence of scientific processing of cotton seed in large quantities. However it is reported that out of the available quantity, internationally, a very small fraction of the linters (say about 10%) is used for value addition, offering scope for its enhanced utilization, posing no threat to the availability of the raw material.

Market research analysis and prospective growth rate predictions in global cotton linter sector are routinely carried out by market analysis experts, although all such information is not available in public domain {7}. However, Asia Pacific region is expected to hold the largest share in global bleached linter cellulose market. The factors supporting Asia pacific is the availability of cotton. India and China are prominent cotton lint manufacturers with cost effectiveness. Owing to improved socio economic aspects in the region, use of cotton linters in pharmaceutical, food, and personal care products are expand-

ing, there by contributing to the growth of the bleached linter cellulose market.

The linter market is segmented into high grade and technical grade {8}. The technical grade market constituted the major chunk of the overall industry in 2018. Technical grade linter is used in pulp & paper, personal care, paints, packaging etc. The market size in 2018 was around US\$ 1.0 billion and in 2025, it is expected to be about US\$ 1.3 billion with a CAGR of around 4%.

Bleached linter market, due to presence of several small and medium scale manufacturers, remains fragmented. However, this is the product that is used as raw material for viscose, acetate, carboxymethyl cellulose etc., for their manufacture. This industry is always on the look-out for cheaper raw material from plant biomass of natural fibres in general, that could prove to be cheaper substitute for linter. This can limit the prospective potential of bleached linter market in the near immediate future.

### 3. Diversified Value Added Products from Cotton Linters

As already noted, being the purest form of cellulose, linter contains only cellulose up to 98-99%, in which alpha cellulose constitutes more than 80%, with negligible lignin, and other non-cellulosic components. Linters are employed traditionally and in modern times with improved technology, for manufacture of several products with diverse application in wide-ranging fields. A panoramic view of the products that could be manufactured from bleached linters is summarized in Figure-2.

In the sections below, it is intended to summarize the research carried out in some of the above areas, delineating salient findings and applications.

#### (a) Absorbent Cotton

Absorbent cotton is one of the value added products, manufactured with minimal processing once the bleached cotton linters are available. Also referred to as “surgical Cotton”, this product becomes highly absorbing and is soft on skin. The ease with which surgical cotton is made both by using comber noil

as well as linters (depending on the availability in a region) has made it very popular among small scale manufacturers.

Linters from the first cut consisting of longer fibres, if in a compressed bale form, are opened, scoured, and bleached. In the wet state, the bleached fibres are opened, got rid of water and dried. The dried fibres are again opened, carded and made into a roll. The absorbent cotton is then converted into wipes, pads or wound dressing cloth/gauze depending on the need.

#### (b) Pulp and Paper

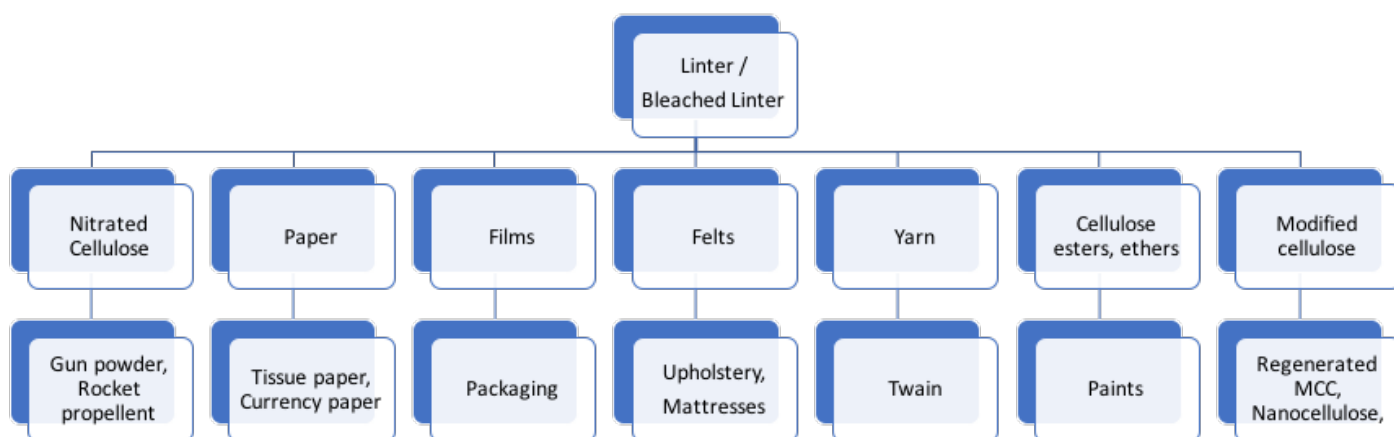
Bleached cotton linter is made into pulp and the pulp then is used to prepare various kinds of high grade paper products such as, technical paper, security paper, insulating paper, filter paper, art paper, and also high quality printing paper.

The originally brown coloured linter cellulose, is bleached with 12% sodium hypochlorite {9}. The bleached linter pulp has a whiteness index of 67.5%, bright ness of 64%, and yellowness reduced to a single digit, 6%. Several pulping methods have been used to produce pulp with better qualities and with least load on the environment. Organo-solv pulping {10}, has been attempted to prepare quality pulp on Egyptian cotton linters, that possessed good length but simultaneously higher impurities.

Conventionally, cotton linters are used in small quantities or in a mix with wood pulp. This is due to poor inter fibre bonding and low tensile and burst strength. The above deficiencies are ably overcome by introducing addition or substitution reactions to modify and make the material amenable to pulping.

Chemically modified celluloses showed good inter fibre bonding and thus removed inherent shortfall in linters. Hydroxy-ethyl cellulose and carboxy methyl cellulose (CMC) improved inter fibre bonding by 85% and also exhibited significant tenacity improvements when they were mixed in proportion with a cationic cellulose. Several attempts have been made {11}, to improve paper quality by introducing additional treatments to the bleached pulp. Addition of 0.25 to 2.0% of potassium permanganate solution improved the paper characteristics. When comber noil and linters are mixed in a blend as 80/20 and pulp prepared; the quality of pulp and that of paper

Figure-2. A panoramic view of value added products from linters





products did not show any reduction thus paving the way for some cost saving {12}.

An innovation that has been brought about in paper making is by additives in the pulp mixture to effect special properties to paper. Electrical Insulated paper {13} has been prepared by the addition of hydrophobic fibres such as polyester to pulp to prepare paper of low density, high porosity, and high dielectric resistance. The dielectric constant has been shown to improve further if lead sulphate is added to the pulp. A very recent study {14}, has clearly demonstrated that addition of micro-fibrillated cellulose extracted from cotton linters up to 10% to unbleached Kraft pulp/paper improved the tensile strength by 11-18%, burst factor by 11-13%, and enhanced the Z directional tensile strength.

### (c) Regenerated Cellulose

Another well developed route to add value to linters is to convert them into regenerated cellulose in various forms such as staple fibre, continuous filament yarn, films etc. Over the years, regenerated cellulose manufacturing process has undergone several changes. Cotton linter as an effective raw material has significantly contributed to these developments in no small measure.

Traditionally, cellulosic fibres (comber noil or linters) after purification and bleaching are treated with carbon-disulfide (CS<sub>2</sub>) solution to dissolve cellulose and by using an appropriate extrusion mechanism, regenerated cellulose fibres/filaments are prepared. An alternate route has been to prepare Cuprammonium Rayon {15} by dissolving cotton linters in a solution of cuprammonium hydroxide and ammoniacal copper sulphate and the dissolved cellulose is treated with sulfuric acid and extruded as regenerated cellulose. These conventional celluloses referred to as "Rayon" had problems with toxic releases and other environmental issues. An improved process of preparing regenerated cellulose known as "LYOCELL" process {16} is to dissolve cellulose in NMMO solution prior to regeneration. The over-all process involves dissolution- spinning-deformation- cooling- relaxation- coagulation- washing and finishing. There were several positive characters in LYOCELL such as environment friendliness, efficiency, high crystallinity, long crystallites, high strength and modulus in comparison to conventional Rayon. One of the demerits of this process has been fibrillation of cellulose.

In order to counter the fibrillation problems in LYOCELL cellulose, an attempt was made {17} to prepare a dope of cotton linters and wood pulp prior to dissolution. This dope could, not only significantly reduce the cost of raw material but also could to a large extent reduce fibrillation. Another way to reduce fibrillation has been noted {18}, in spun regenerated fibres prepared from high molecular weight cotton linters (derived from high molecular weight cotton) treated with NMMO via LYOCELL process.

A large number of research reports concentrated on enhancing the solubility of cellulose prior to regeneration to improve the properties of cellulose extruded / produced. This included dissolving linter cellulose in NaOH/Urea solutions {19, 20}, organic electrolyte solution {21} and ionic liquids {22}. It was noted

that the procedure of dissolving cellulose in NaOH (6%wt)/Urea (4%wt) was a non-polluting process. The strength of the regenerated cellulose film so produced was much better than commercially available cellophane film.

Treatment with organic electrolyte solution reduced cellulose degradation significantly and improved the mechanical properties and thermal stability of the film cast. A novel way of dissolving cellulose is by using ionic liquids. The regenerated fibres displayed smooth, highly uniform and dense morphology. The fibres could effectively replace polypropylene and polyethylene in preparing a transparent, biodegradable packaging material.

### (d) Micro Crystalline Cellulose

Microcrystalline cellulose is a form of cellulose having industrial applications and wide variety of uses, Microcrystalline cellulose popularly known as MCC, has received serious attention of researchers and manufacturers alike. MCC is a type of cellulose possessing a balanced degree of polymerization (due to hydrolysis) and mechanical separation of particles. It has a porous structure and density similar to crystalline density of cellulose (1.539-1.545 g/cm<sup>3</sup>). MCC is dispersive but insoluble in water and acids, organic solvents, oil etc. It swells in dilute alkaline solutions and partly dissolves in it {23}. A white transparent paste or gel is formed if MCC is dispersed in water and this dispersion remains stable but for very dilute solutions. Table-3 below summarizes properties of MCC prepared from linters, {24, 25, 26, 27}.

MCC is produced from bleached linters by treating with dilute acids (hydrolysis) at desired temperatures. Slow hydrolysis (low concentration acid, low temperature, long duration) enhanced the yield and growth of crystals. The duration of hydrolysis affected the yield, quality, and polymeric form of the processed Alpha cellulose.

MCC is widely used in pharmaceutical, food, chemical industry, and synthetic leather industry {28}. Alternate raw materials other than linters have been used for the production of MCC, sometimes with better yield and properties {29, 30}.

| Parameters                    | Value     |
|-------------------------------|-----------|
| Yield (%)                     | 75.3-85   |
| Moisture content (%)          | 7.2       |
| Ash content (%)               | 0.12      |
| Density (gm/cm <sup>3</sup> ) | 1.38-1.55 |
| Crystallinity (%)             | 65-80     |
| Crystallite width (nm)        | 8.8       |
| Crystallite length (nm)       | 35-45     |

Note: Properties varied considerably with quality of raw material, hydrolysis conditions, and measurement techniques.

### (e) Nano Cellulose

Bleached cotton linter is one of the most preferred raw material for preparation of nano cellulose be it in a powder form or fibrillar form. Being a pure cellulose form with appropriate

DP and optimum access to reagents, nano-cellulose is one of the most sought after starting material. Several studies have dealt with different pathways for production of nano material from linter/cotton cellulose. J. P. S. Morais et. al., {31} have developed a method to produce nano cellulose structures (composites) from raw cotton linters without the necessity to make pulp. *G. hirsutum* linters, once converted to nano cellulose showed increased hydrophilicity despite higher crystallinity owing to improved surface area for adsorption. The nano crystals so developed possessed good size, measuring up to 177 nm in length and 12 nm wide.

In the hydrolysis- homogenization procedure for nano cellulose powder preparation, pretreatment with zinc chloride solution (70%) for a fixed duration, enhanced the yield of nano cellulose {32}. A pretreatment with cellulase enzyme also improved the yield of nano cellulose {33}. Cellulase pretreatment prior to acid treatment improved the yield of nano crystalline cellulose (NCC) by 12%. This pretreatment reduced sulfur content by 0.8% and average particle size rose to 35nm, and also the concentration of acid could be reduced thereby saving on chemicals. Another variation in the hydrolysis- homogenization routine is the use of ionic liquids to dissolve the cellulose {34}. Nano fibrillated cellulose (NFC) is yet another form of nano cellulose, widely used in various applications such as paper, electronics, pharmaceuticals, fuel cells, and even in fertilizers {35}. A combined process of enzymatic pretreatment and fibrillation (refining) resulted in optimum production of NFC with reduced energy requirement (by 27%) and is one of the areas where NFC production needs serious improvement. The fibrillated cellulose had a diameter ranging from 50 to 200 nm with very good separation into individual fibrils. A cocktail of cellulase and another oxidative enzyme could improve the mechanical fibrillation significantly to increase the yield of NFC. This treatment brings in enhancement in transparency and barrier properties essential for packaging {36}.

Significant advances have been made in the recent past to use nano cellulose efficiently and effectively in various areas. Nano cellulose from cotton linters in fibrillated form has been used as a reinforcing agent for guar gum in film preparation for packaging purposes {37}. Antimicrobial nano materials were prepared using regenerated cellulose from cotton linters by incorporating silver, copper oxide, or zinc oxide nano particles in the dope. Strong antibacterial activity {38}, against *E. coli*, and *L. monocytogens* was noted and this material could be used as filler in antibacterial packaging films containing nano whiskers {39}. As reinforcing material in thermos plastic starch, nano composite films prepared thereby could be effectively used in food and pharmaceutical packaging.

### (f) Chemically Modified Cellulose

Raw cotton fibres, owing to the presence of a primary wall composed of pectin and waxes and a longer chain length, remain inert to most of the chemical reagents. Cotton linter, on the other hand, with appropriate degree of polymerization (DP) and pure cellulose as constituent becomes a perfect raw material for preparation of chemically modified cellulose products, cellulose acetate, cellulose nitrate, and carboxy methyl cellulose, all industrially relevant products.

- **Cellulose Acetate:** Homogeneous acetylation of cellulose to manufacture cellulose acetate (cellophane film) has been attempted employing different chemicals, di methyl sulfoxide (DMSO), and paraformaldehyde {40} and a combination of DMSO and tetrabutyl ammonium fluoride tri hydrate {41}. The cellulose acetate so prepared had degree of substitution (DS), varying from 0.5 to 2.8. Using different temperatures for varying durations, employing acetic anhydride as the reagent, iodine as catalyst, cotton linter was acetylated to DS 2-2.5 when the starting pulp was 98% pure {42}. Cellulose acetate films are ecofriendly materials and exhibit high level of biodegradability {6}. The rate of decomposition of this material is 1.5 times faster than conventional products.
- **Carboxy Methyl Cellulose:** Carboxy methyl cellulose, more popularly called CMC has wide spread applications in textile, paper, detergents, pharmaceuticals, paints, lubricants, food, ceramics, cosmetics, etc. It is specially used as a thickening agent in food, if the viscosity is quite high. Cotton linter in mono chloro acetic acid and NaOH reacts slowly, and when neutralized with acetic acid and methanol, yields CMC. Homogeneous carboxymethylation process is also attempted on cotton linters using NaOH/Urea system, to achieve a DS of 0.2 to 0.62. The CMC so produced was soluble in water {44}.
- **Cellulose Nitrate:** Popularly known as gun powder, cellulose nitrate is an important industrial product. In the DS range of 1.8 to 2.8, it is a white transparent, odorless, nontoxic and hydrophobic material. Linters are treated in nitric acid at optimum concentration to prepare cellulose nitrate. Cotton linters are preferred for preparation of military grade nitro cellulose {45}. More often, the nitration bath contains sulfuric acid as a condensing agent and a typical bath producing cellulose nitrate has a nitrogen content of 11%, (nitric acid 25%, sulfuric acid 55% and water 20%). Since cellulose nitrate is extensively used for defence purposes, more often than not, cotton linter use within the country and export are regulated by governments.

## 4. Recent Innovations in Value Addition

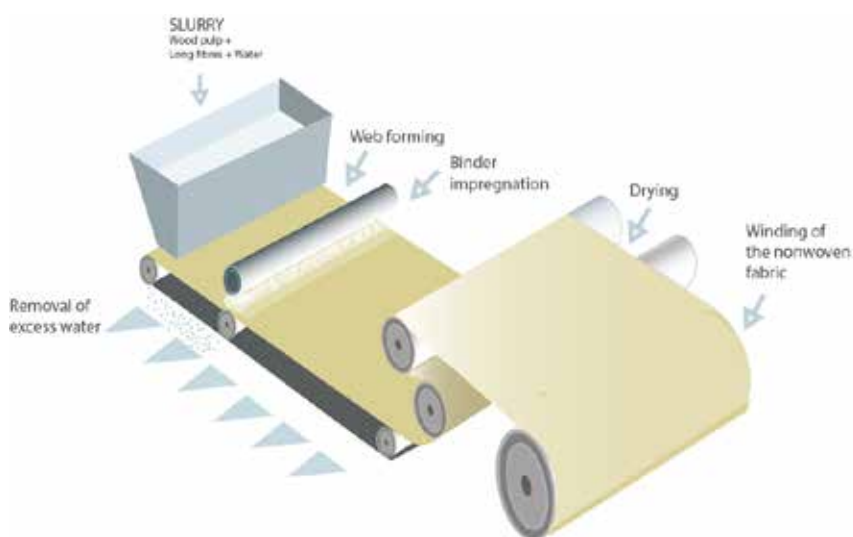
What has been described so far, pertains to value addition areas and products where cellulose holds an upper hand. In this section a few of the most innovative pathways of value creation would be described where cellulose is either entering the synthetic market or where cellulose is effectively and more competitively replacing products traditionally manufactured by using synthetic fibres.

### (a) Non Wovens and Composites

A composite is a select combination of two or more dissimilar materials formed with a specific internal structure with non-woven as one of the component. They are designed to produce materials with unique mechanical properties and superior performance characteristics, not possible with any one of the components, alone {46}. The non-woven material characteristic depends on forming the fibre web and bonding the web suitably (needle punching, thermal bonding, wet-laid

etc.). For preparation of cotton, non wovens, cotton linter/comber noil is extensively used for non-woven in a composite application. Sometimes cotton linters are pretreated with solvents like dimethyl peroxide / acetic anhydride / acrylamide and then incorporated in composite preparation to improve thermal properties {47}. Global non-woven market is a growing sector having a size of US\$ 40 billion. A process of non-woven manufacture known as wet laid, a technology taken from the paper industry, enables achievement of cloth-like characteristics without weaving and also without the use of continuous filaments. This process is endowed with high speed and flexibility. The fibres are suspended in an aqueous solution and then formed into a sheet in a moving screen, where the water gets removed.

Figure-3. A schematic layout of wet laid non-woven



Cotton linters of 12 to 15mm preferred in wet laid more often in combination with other fibres (synthetic). A schematic lay out of wet laid non-woven is shown in the figure-3.

When the web, now devoid of water is moved further, it gets impregnated with a suitable binder (specially required if a blend of hydrophilic and hydrophobic fibres are employed in combination). Here refined cellulosic pulp fibres get better bonded with synthetic fibres to form a good wet laid. Thin wet laid non-woven finds extensive applications in hygiene, filtration, wipes, coverings, upholstery etc. Another application of thin non-woven is as cover material for agricultural crops {48}.

### (b) Bio Degradable Composites and Plastics

With concern for the environment and its conservation rising over the globe, degradability of a material in quick time with least load on the atmosphere has gained importance. Cellulose composites and plastics made from them are proven biodegradables and environment friendly as per their life cycle assessment. Recent interest in research and manufacture of bio-plastics centered around cellulose/cotton linters {49, 50}.

Using cotton linters, cellulose acetate bio-fibre is produced with a yield of 54%. This bio polymer was found to be biode-

gradable and less affected by acid compared to poly-propylene, and poly-styrene and can find application in food industry and medicine.

A bio-plastic made by hot pressing cellulose solution in alkali hydroxide /urea system resulted in a transparent and uniformly oriented sheet. Compared to common plastics, this biodegradable polymer sheet possessed higher tensile strength, flexural strength, thermal stability, and lower thermal coefficient. The advantage of this method is that the cellulose is not converted to pulp prior to treatment and hot pressing.

### (c) Hydrogels and Aerogels

Hydrogels and aerogels are gel structures prepared from cellulose that have high adsorptive / absorbptive power of oils, water etc., combined with bio compatibility and bio degradability. They are special porous materials, with low density, high porosity, large specific surface area, adequate surface chemical activity. They are prepared by various techniques such as acetylation, and cyano-ethylation of linters {51}.

Subjecting cellulose lint, MCC, or cellulosic powder with high impact mechanical pulses of various amplitudes and frequencies {52}, graft polymerization of acrylic acid in cotton linters {53}, and ultrasonic treatment or dispersion of nano-cellulose or modified cellulose and solvent exchange and drying process {54} are the various methods of preparation.

Hydrogels / aerogels prepared from cellulose possess high compressive strength than synthetic aerogels and are used in oil /water separation, oil absorption or as super absorbents.

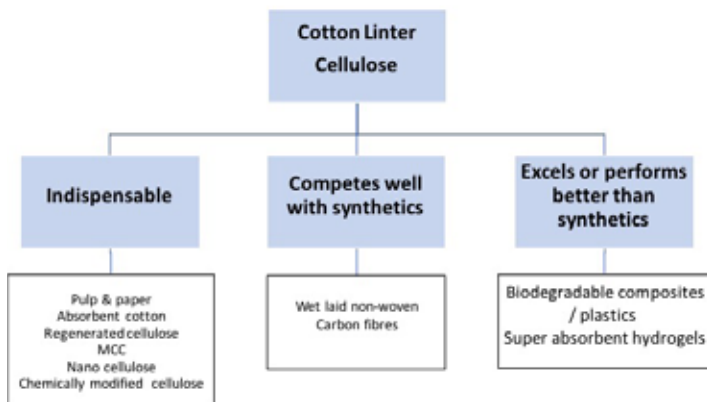
### (d) Carbon Fibres

Carbon fibres are fibres about 5-10 micrometer in diameter that are highly stiff, composed of carbon atoms. These fibres possess high tensile strength, low weight, high chemical resistance, high temperature tolerance, and low thermal expansion. Carbon fibres are generally produced from poly-acrylonitrile (PAN). They are used to reinforce composite materials, such composites known as graphite-reinforced polymers. The strength to weight ratio is much higher than steel or plastic.

Attempts have been made to prepare carbon fibres from cotton linters through a process of Carbonization and wet spinning technology {55}. The carbon fibres prepared had a smooth surface, and round compact morphology in cross section. The tensile strength was about 0.72 Gpa with carbon yield up to 36%, parameters compatible and highly favourable from bio mass material.

## 5. Is linter Cellulose an Effective Replacement for Synthetics?

From the discussions on value addition enumerated here, it is possible to decipher areas where linter cellulose competes well or sometimes even excels synthetic fibres. The diagram below illustrates the point.



## 6. Entrepreneurship Development in Cotton Linters

Although there are several value addition technologies and products where successful business ventures could be set up, manufacture of Micro Crystalline Cellulose (MCC), is one of the fairly simple techniques where both big as well as medium and small entrepreneurs could invest and reap the benefits. This product has an ever growing clientele and market. Even in new and unexplored regions, the MCC is finding its foot hold.

As already noted a CAGR of 4.71% is expected between 2018-2028, to this already burgeoning market.

A project report /feasibility report and plant lay out prepared by NIIR project consulting services [56] is available for consultation. A snap shot of the report indicates the following details:

The figures below would entail revision in values depending on the place, availability of raw materials, labour and other incidentals. These figures are provided to give a rough idea of estimated investment.

### Estimated Investment and returns

Plant Capacity = 8 MT/day  
 Plant and Machinery = US\$ 0.2 million (Approx.)  
 Working Capital = US\$ 1.1 to 1.2 million (Approx.)  
 Return on Investment = 45%  
 Break even = 36%

## 7. Future Out Look on Cotton Linters

The discussions and observations made in this report clearly bring out the versatility of cotton linter as a raw material for use in many varied applications.

The crucial point at this juncture would be the availability of raw material. Although global potential for cotton linter production is around 5 million metric tonnes (based on available ginned seeds), one report estimates the availability at 1 million metric tonnes, whereas as another survey states that the current availability of linter worldwide could be as much as 2.5 million metric tonnes. Be that as it may, this clearly points out to the lack of prevalence of scientific processing of cotton seeds in many regions of the world.

Going by the Indian experience, there is hardly 10% of ginned seeds that undergo the rigorous processing to extract invaluable

constituents (linter, hulls etc.), and the rest 90% seeds are directly crushed for oil extraction. The impediment in large scale adoption of linter extraction is cited to be high recurring cost. It is known that more than 50% of the incidental expenses go in power to run huge saw machines for extraction.

An urgent need to devise a highly energy efficient or an alternate novel mechanism to extract linters is felt seriously. Just like ginning, if delinting is also made a way of life, by introducing an appropriate sized delinter capable of serving a ginning industry year- long for extraction of linters from its seed, the situation could improve for the better.

However the fact remains undisputed that there exists a huge untapped potential for creating, value adding and establishing successful business ventures world over by using this veritable cellulosic raw material.

### References Cited

1. Development and Evaluation of a novel Bench Top Mechanical Cotton Seed Delinter for Cotton Breeders: G. Holt. *Journal of Cotton Science*, 21, 18-28, (2017).
2. Design for a Measurement and Control System for Delinting Machine: L. Zhou, Y. Yuan, J. Zhang and X. Dong. *8 th International Conference on Computer and Computing technologies*, China, 2014, p.646-652.
3. Evaluation of a mechanical Cotton seed Delinter for Breeders: Joel ARCE, *Thesis*, Texas A&M University, (2019).
4. Utilization of Cotton Seed Byproducts: R. H. Balasubramanya and A. J. Shaikh. *Model Training Course on ELS*, CICR, Coimbatore, pages 130-138, (2007). [www.cicr.org.in](http://www.cicr.org.in),
5. Cotton Linters: An Alternative Cellulose Raw Material: A. Sczostak. *Macro molecular Symposia* 280(1), 45-53, (2010).
6. Highly Biodegradable Cellulose Acetate: DAICEL Corporation, [www.daicel.com](http://www.daicel.com)
7. Cotton Linters Market, shares, strategies, and forecast World Wide 2019 to 2025: supriya@ factmr.com april, 2020
8. Bleached Linter Cellulose Market Size by Grade, By Application, Analysis report, Regional out- look, Growth potential, Price Trends, Competitive Market Share & Forecast 2019-2025: Kiran Pulidindi, Hemant Pandey. *Global Market Insights*, Pages 154, July (2019).
9. Evaluation of linter Cellulose as an alternative raw Material for tissue paper Production: Mustafa Cicekler, Drvna industriya, [www.academia.edu](http://www.academia.edu), 291-298, (2017).
10. Organo Solv Pulping of Cotton Linters: Nahed A., Abd-El-Ghany. *Cellulose chemistry and technology*, 43 (9-10), 419-426, (2009).
11. New Approach for Upgrading pulp and paper Quality: Mild Potassium Permanganate Treatment of already Bleached pulps: Fahmy, Tamer, Y. A., F. Mobarak, N. Kassem, and A. H. Abdel Kader. *Carbohydrate polymers* 74, no. 4, 892-894, (2008).
12. Unique Challenge of Making money From Cotton Waste: Maitreyee Handique. *Live mint*, e-Paper, (2010).
13. Electrical Insulated paper from Cotton linter: H. El- Saied, M. G. El -Meligy, S. H. Mohamed, and S. Abd El Mongy. *Carbohydrate Polymers*, 90 (1), 147-151, (2012).
14. Micro/nano fibrillated Cellulose from Cotton linters as Strength Additive in unbleached kraft paper: Experimental, semi-empirical and mechanistic Studies: A. K. Bharimalla, S. P. Deshmukh, P. G. Patil and N. Vigneshwaran. *BioResources*, 12 (3), 5682-5696, (2017).



15. Regenerating Cuprammonium Rayon from Various Cotton and Cotton-Polyester Mix Textile and Apparel Wastage: Riasat Zaman and Hosne Ara Begum. *Applied Chemistry*, www.academia.edu. 1-8. (1992). [https://www.academia.edu/download/58344288/paper\\_on\\_cuprammonium\\_rayon.pdf](https://www.academia.edu/download/58344288/paper_on_cuprammonium_rayon.pdf)
16. Regenerated Cellulose by the LYOCCELL process: A Brief Review of the Process and properties: S. Zhang, C. Chen, C. Duan, H. Hu, H. Li, J. li, Y. Lu, X. Ma, J. Stavik and Y. Ni. *Bio Resources* 13 (2), 4577-4592, (2018).
17. Preparation of Regenerated Cellulose Fibre Spun from cotton linter/ wood pulp Mixture and its Physical properties: Shamin Reza, Mi K Young and Kap Jim Kim. *Korea polymer Society Conference*, (2014).
18. Physical properties and Fibrillation Tendency Of Regenerated Cellulose fibre Dry-wet Spun From High Molecular weight Cotton Linter Pulp/ NMMO Solution: Mi Kyong Yoo, M. S. Reza, I. M. Kim, and K. J. Kim. *Fibres and polymers*, 16, 1618-1628, (2015).
19. Structure and properties of Regenerated Cellulose Films prepared from Cotton linters in NaOH/ Urea Aqueous solutions: L. Zhang, D. Ruan, and J. Zhou. *Industrial Engineering Chemistry Research*, 40, 5923-5928, (2001).
20. Structure Study of Cellulose Fibres- Wet Spun from Environmentally Friendly NaOH/ Urea Aqueous Solutions: X. Chen, C. Burger, F. Wan, J. Zhang, L. Rong, B. S. Hsiao, B. Chu, J. Cai and L. Zhang. *Bio Macromolecules*, 8, 1918-26, (2007).
21. Facile Preparation of Regenerated Cellulose Film from Cotton linter using Organic Electrolyte Solution (OES): D. Cheng, X. An, J. Zhang, X. Tion, Z. He, Y. Wen and Y. Ni. *Cellulose*, 24, 1130-1139 (2017).
22. Fabrication and Characterization of Regenerated Cellulose Films using Different Ionic liquids: J. H. Pang, X. Liu, M. Wu, Y. Y. Wu, X. M. Zhang, and R. C. Sun. *Journal of Spectroscopy*, Special Issue, (2014).
23. Micro Crystalline Cellulose PH 101, PH 102, CAS 9004-34-6: Chuangyingchem.com
24. Preparation of Micro Crystalline Cellulose from Cotton linter Ethanol pulp: S.S. Lih, G. P. Fang, Y.J. Deno, and Q. Wang. www.Scientific.net, (2011).
25. Structure of Cellulose and Micro Crystalline Cellulose from various Wood Species, Cotton and Flax Studied by X-ray Scattering: L. Kirs, A. Seppu, T. Mika, K. Matti, Kotelnikova, Nina, and S. Ritva. *Cellulose*, 16 (6), 999-1015, (2009).
26. Some physical characteristics of micro Crystalline Cellulose Obtained from raw Cotton of Cochlospermum planchonii: F. O. Ohwoavworhwa, and T. A. Adelakun. *Tropical journal of Pharmaceutical Research*, 4 (2), 501-502, (2005).
27. Overview on native Cellulose and Micro Crystalline Cellulose Structure Studied by XRD: Comparison Between Measurement Techniques: N. Teriate, R. Ibbete, and K. C. Schuster. *Lenzing*, 19, 118-131, (2011).
28. Prospects of Micro Crystalline Cellulose: *Cellulose* ether.com, (2014).
29. A simple process of Isolation of micro Crystalline Cellulose Using ultrasonic Irradiation: E. Y. Warchlono, N. Kanani, and A. Alfrano. *Journal of Dispersion Science and Technology*, (2019).
30. Synthesis of Micro Crystalline Cellulose from pre- treated Cotton obtained From Bombax Ceiba L and its Characterization: S. M. Haque, A. A. Chowdhury, A. A. Rana, S. M. Mausam, T. Ferdous, M. A. Rashid, M. Sarkar, and M. M. Karim. *Bangladesh Journal of Science and Industrial Research*, 50 (3), 199-204, (2015).
31. Extraction and Characterization of Nano Cellulose Structures from raw Cotton linter: J. P. S. Moraris, M. F. Rosa, M. M. S. Filho, L. D. Nascimento, D. M. Nascimento and A. R. Cassales. *Carbohydrate polymers*, 91, 229-235, (2013).
32. Zinc Chloride Pretreatment of MCC for preparation of nano Cellulose by Homogenization Process – Low Energy Method for the Preparation of Nano- Derivatized nanoCellulose (WO 2014/029517 AI), *Patent*, (2018).
33. Increasing yield of nanocrystalline cellulose preparation process by a cellulase pretreatment: B. Facundo, R. M. Blanca, V. Teresa, T. Antonio L and V. Christina. *Bioresource technology*, 192, pp.574-581, (2015).
34. Homogeneous Isolation of Nano Cellulose from Cotton Cellulose by High Pressure Homogenisation: Y. Wang, X. Wei, J. Li, Q. Wang, F. Wang and L. Kong. *Journal of Materials Science and Chemical Engineering*, 1, No 5, 49-52, (2013).
35. Energy Efficient Production of Nano Fibrillated Cellulose (NFC) from Cotton Linters by Tri-disc Refining and its Characterization: A. K. Bharimalla, P. G. Patil, S. P. Deshmukh, and N. Vigneshwaran. *Cellulose Chemistry and Technology*, 51, 395-401, (2017).
36. Assessing the Enzymatic Effects of cellulases and LPMO in Improving mechanical Fibrillation of Linters: C. Valls, F. I. J. Postor, M. B. Roncero, T. Vidal, P. Diaz, J. Martinez, and S. V. Vallenuela. *BioTechnology for BioFuels*, 12, 161, (2019).
37. Cotton linter Nano Fibres as the Potential Reinforcing Agent for Guar Gum: V. S. Karande, A. K. Bharimalla, N. Vigneshwaran, P. G. Kadam and S. T. Mhaske. *Iranian Polymer Journal*, 23, 869-879, (2014).
38. Preparation of Anti microbial hybrid nano materials using Regenerated Cellulose and Metallic Nano Particles: S. Shanker, A. A. Qun, and J. W. Rhim. *International journal of Biological Macromolecules*, 107, 17-27, (2017).
39. Preparation of Cotton linters Nano Whiskers by High Pressure homogenization Process and Its application in Thermoplastic Starch: N. R. Sarvadekar, V. S. Karande, N. Vigneshwaran, P. G. Kadam and S. T. Mhaske. *Applied Nano Science*, 5, 281-290, (2015).
40. Studies on the Homogeneous Acetylation of Cellulose in the Novel Solvent Dimethyl Sulfoxide / Tetra butyl Ammonium Fluoride Tri Hydrate: B. A. P. Ass, E. Frollini and T. Heinz. *Macromolecular Bio Science*, 4 (11), 1008-1013, (2004).
41. Unconventional Methods in Cellulose Functionalization: Thomas Heinze, Tim Liebert. *Progress in Polymer Science*, 26 (9), 1689-1762, (2001).
42. Production and Evaluation of High Yield Cellulose Acetate Using Iodine as Catalyst and Purification of Cotton linters: R. Yadollahi, M. D. Fircuzabadi, H. Resalati, H. Mahdavi and A. Saraeyan. *Journal of Forest and wood product, Iranian Journal of Natural resources*, 70, 671-679, (2018).
43. Carboxy Methylation of Cotton linter in an Alcoholic Medium: Z. A. Nagiels, M. E. O. Sakhawy and Samir Kamel. *International Journal of Polymer Materials*, 50 (2), 163-173, (2001).
44. Homogeneous Carboxy Methylation of Cellulose in NaOH/ Urea Aqueous Solution: H. Qi, T. Liebert, F. Meister, and T. Heinze. *Reactive and Functional Polymers*, 69, 779-784, (2009).

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45. The Origin and Type of Cellulose Utilized in the Manufacture of Nitro Cellulose Over the Last Thirty Years: W. J. F. Schimansky. [www.cranfield.ac.uk](http://www.cranfield.ac.uk), (1988).
46. Manufacturing Techniques of Non- Woven Composites- An Over View Textile Value Chain: [info@textilevaluechain.com](mailto:info@textilevaluechain.com), (2019).
47. Chemical Treatments of Cotton Linter Cellulose fibre for Composite Application: M. Rahman, G. M. A. Khan, M. H. Uddin, S. M. A. Razzaque and M. S. Aslam. *American Chemical Science Journal*, 16 (4), 1-7 (2016).
48. Development of thin Non- woven Cover Materials made of cotton Linters: Z. Haiquan, L. Shiylien, and C. Yunneng. *Technical Textiles*, (1999).
49. Production of Bio Degradable Plastic from Agricultural Wastes: N. A. Mostafa, A. A. Farag, H.M. Abo- Dief and A. M. Tayeb. *Arabian journal of Chemistry*, <http://dx.doi.org/10.1016/j.arabjc.2015.04.008>, (2015).
50. A Bio plastic With High Strength Constructed From Cellulose Hydrogel by Changing the Aggregated Structure: Q .Wang, J. Cai, L. Zhang, M. Xu, H. Chang, C. Hen, S. Kuja, J. Xiao, and R. Xiao, *J. Mater. Chem A*, 1, 6678-6686, (2013).
51. Chemical modification of Cotton Linter for Oil Spill Clean Up Application: D. Chattopadhyay, and K. Umrigar. *Journal of Institution of Engineers (India )*, Series E, 98, 103-120, (2017).
52. Hydrogels produced from Cotton Cellulose: S. M. Mirkamilov, and B. M. Sultanova. *Chemistry of Natural Compounds*, 36, 90-92, (2000).
53. Cellulose Fibre Supported pH Sensitive Hydrogels: J. O. Karlsson, and P. Galenholm. *Polymer*, 40, 379-387, (1999).
54. Cellulose Aerogels: Synthesis, Applications and Prospects: L. Y. long, Y. X. Weng, and Y. Z. Wang. *Polymers*, 10 (6), 623-651, (2018).
55. From waste Cotton Linter: A Renewable Environment Friendly Bio Mass Based fibres preparation: X. Zhou, P. Wang, Y. Zhang, X. Zhang, and Y. Jiang. *ACS Sustainable Chem. Eng.*, 4, 10 (2016).
56. Cellulose Powder from Cotton: Manufacturing Plant, Detailed Project Report, Profile, Business Plan, Industry trends, Market Research, Survey, Manufacturing Process, machinery, Raw Materials Feasibility study, Plant Lay out: NIIR Project consultancy Services, (NPCS). [www.niir.org](http://www.niir.org) (2020).
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## Part-3: Innovative interventions for Value creation in Cotton Lint

### 1. Introduction

Historical evidences provide credence to the fact that cotton has always been a part of human society. Since the very beginning of human civilization, cotton has been cultivated in various regions of the world and has remained a medium of exchange between cultures. Cotton has significantly contributed to the world history that early Buddhist and Hindu texts refer to cotton as being cultivated some 7000 years ago in India. Ancient Roman and Greek literatures also provide references to cotton from India. The physical attributes and varietal characteristics of Cotton have admirably supported commercial activities from early days. Evidences are available to show that small scale cotton farming has been in practice as a cash crop around 500 C.E. and that cotton weaving was practiced from early days as a house-hold activity by women {1, 2, 3} in Northern India.

Cotton has admirably lent itself as a creator of value in a composite economy. All the parts of the plant viz. the fibre, seed, stalks, and their processing produce and by-produce including the biomass generated during and after cultivation find use and application in different value-added products. Annexure-1 illustrates this point in a vivid manner by enumerating the value created by the various constituents of the cotton plant and the processing wastes / by-products generated during mechanical processing. It would suffice to add that these diversifications have enabled millions to engage in income generation activities and have remained a means for their livelihood.

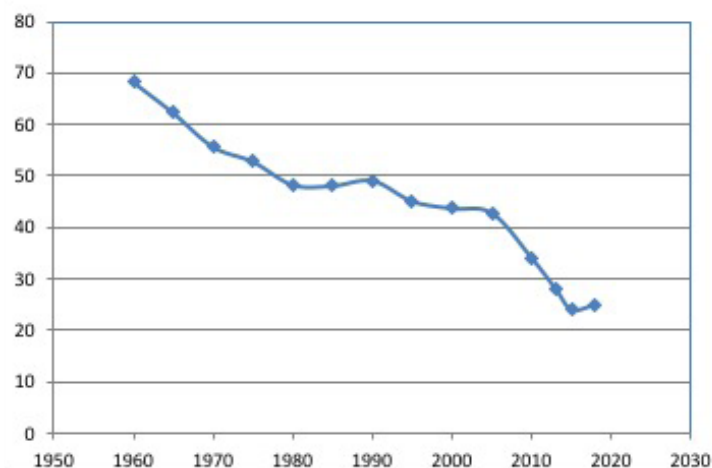
#### (a) Cotton in Comity of Fibres

Cotton is a prominent member of the family of fibres that comprise both natural and man-made. Till about 1950s, Cotton has remained the primary fibre for clothing. With the advent of Polyester and more recently, a host of chemical fibres, that are produced with tailored properties with petroleum as the base, Cotton is witnessing a serious competition and has seen an erosion in its prime position as a clothing material for mankind.

The share of cotton in global consumption of fibres has seen a gradual slide since 1960. Although the extent of decline varied from region to region in the global arena, the competition from synthetic fibres as well as man-made cellulose has been real. Figure-1 illustrates this decline graphically.

The factors that contributed to the decrease in share of consumption would be described in the ensuing section. Notwithstanding the fact that, over the years, cotton has lost its sheen in global fibre basket, it remains the single most fibre known for its softness, comfort attributes, mass appeal and as a rejuvenating clothing material

Figure-1. Global Consumption of Share of Cotton (%) Over the Years



Available from the shortest length (15 mm) to the longest (40 mm) and finest (Micronaire 2.5) to coarsest (Micronaire >8.0), these fibres can be used to produce finest fabrics (60 G.S.M.) to coarsest (300 G.S.M.) satisfying the diverse requirements of clothing. Another significant aspect is that over centuries these fabrics have been part of human well-being (Ayur Vastra) as a promoter of health, particularly in India. Cotton fabrics impregnated with plant-based medicinal oils and concoctions have been in use for treatment of many ailments.

### 2. Strategies for promotion of Cotton

World over efforts are being made by various organizations associated with cotton to strengthen its base among clientele. The United Nations as part of promotion of natural fibres celebrated the year 2009, as the "Year of Natural Fibres". The aim was to create awareness and take up promotional activities for natural fibres as bio-degradable, environment -friendly, and annually- renewable resource, that could sustain livelihoods of millions of lower income and dis-advantaged people in the entire world. Since 2009, concerted efforts are in place to promote the use of natural fibres and cotton in particular as a clothing material, by projecting its virtues through interactions, visual-media publicities etc.

Promotion of cotton could comprise two independent activities (1) efforts to create an economic advantage in the marketplace due to its virtues of cotton as a natural fibre and (2). Finding innovative ways and means to add value to the fibre to satiate the demands made in its application in both traditional and modern areas where it has never been put to use earlier.

### **(a) Efforts to Convert the Virtues of “Renewability” “Environment Friendliness” and “Bio-degradability” into an Economic advantage at the Market place vis-à-vis Competing Synthetic Fibre**

As already noted, the shrinking share of cotton consumption world over among fibres for over the last fifty years is a matter of concern, at a time when serious efforts are being made to promote cotton. One of the major reasons for loss in market share has been the high prices of cotton relative to the market price of polyester since the 1980s {4}. Contributing to this downfall has also been the stagnancy in productivity of cotton in comparison to the expanded production of chemical fibres including polyester. In fact, over the last two decades, the production of all chemical fibres has nearly doubled. While the share of polyester in the consumption of fibres in 1990 was about 45 %, it stands at around 77 % in 2015 {5}. It is also worthwhile to note that while cotton was 1.3 times costlier than polyester in 2007-08, it became costlier by 1.8 times in 2014-15.

James K. Boyce {6} in the context of Jute vs polypropylene notes that, this price advantage for the synthetic fibre is not essentially due to lower production cost of the fibre but rather due to an absence of a mechanism to internalize the environmental costs in the market price of the fibre. This view has been supported by others while dealing with the competitive advantage of the synthetic fibre with that of Jute {7}. It has been noted that, major environmental impacts in Polypropylene production comes from air pollution and energy consumption. Air pollution comprises particulates, Sulfur oxides, Nitrogen oxides, carbon monoxide and volatile organic compounds. Also other toxic pollutants such as ammonia, benzene, ethyl benzene, methane, lead, toluene etc. also contribute. The energy use in PP production is estimated to be at least six times that of production of Jute. As PP is not biodegradable and the recycling potential is limited to only the additives in production, its disposal incurs landfill storage. On the other hand, the environmental impact of Jute production is minimal. If the cost for reclaiming the environment in a synthetic fibre production is added to the cost, while fixing the market price, then the market price of Jute would be at least 20-25% lower than the competing synthetic Polypropylene fibre.

The above discussion brings in the need to internalize the environmental cost in fibre production in its market price. Since Natural fibres are environment friendly, annually renewable, and totally biodegradable (no landfill cost during disposal); the market price would automatically earn a premium lowering its selling price compared to the corresponding synthetic fibre. This rationale should be applied in Cotton-polyester case as well.

While calculating the Carbon footprint of a Knitted T shirt made of both polyester and Cotton {8}, it has been established that, the carbon footprint of Cotton T shirt has been calculated at 2.1 Kg CO<sub>2</sub> as against 3.8 Kg of CO<sub>2</sub> for a polyester T shirt. The water footprint {9} estimated for Polyester has been also found to be the highest compared to Viscose and Cotton, not - withstanding the fact that excessive pesticide use and protection

chemicals enhance the water foot print of Cotton, but even then much lower than Polyester.

Many experts argue that Cotton cultivation is beset with excessive water & chemical usage and in a large farm mechanization even the energy use is prohibitively higher indirectly adding to the ecological damage. While these facts may not be disputable, in a subsistence cultivation of Cotton with minimal resources in a fragmented land holding and more surely in an organic cotton cultivation set up with no chemical use and no mechanization or minimal use of electrical power, the environment cost could be expected to be minimum. In such a scenario, which is more common in many Afro-Asian situations. A rigorous analysis of environment cost of Cotton vis-a vis polyester needs to be conducted and efforts should be made to internalize these costs in the market price of the respective fibres. Unless and until, the virtues of biodegradability, renewability and environmental friendliness of cotton are converted into a market advantage, a substantial revival of the fortunes in terms of enhanced consumption of the fibre in the comity of fibres seems impossible to achieve.

### **(b) Introducing Cotton for Product Manufacture after Suitable Modifications/Finishing in Unconventional/Non-traditional Applications**

Another constructive approach to enhance the consumption of cotton and promote its use is to create value in cotton lint in innovative ways so that the fibre could find its application in areas where it has never been put to use earlier and also in places where synthetic fibres rule the roost. In the following section, an attempt is made to identify such areas and add value to cotton so that the fibre performs well in such demanding environment.

## **3. Innovations in Value Creation in Cotton lint**

Traditionally cotton fibre is used for clothing. Textile products include yarns, fabrics, garments, made ups, etc. In terms of segmenting the textile industry raw material wise, cotton dominated the sector with a US\$ 378.6 billion in 2019, out of a total turn- over of US\$ 950 billion. This sector is expected to grow at a CAGR of 4.4% during the next five years.

Innovations in value creation could be through mechanical processing of the fibres by using the newer technologies (Hydro entanglement, Electro spraying, Non- woven etc.) or through finishing with chemical agents or microbes (multi - functional finishes) to impart capability to perform in specified situations where synthetic fibres generally dominate. In the following section, a few selected applications of cotton are discussed where apart from conventional textiles, cotton is expected to be consumed in ample quantities in the coming decade. In many of these areas the high absorbency, excellent feel, dermatologically superior behaviour of cotton is exploited to further its use.

### **(a) Well Being and Health Textiles**

Textiles contribute to the health and well- being of humans. Japanese researchers in 1990s and around 2000s, could show



that fine cotton sheets worn over the body or covered during sleep, could help in rhythmic inhaling –exhaling process, contribute in maintaining heartbeat and blood pressure. Cotton fabrics impregnated with certain cosmetic ingredients and oils, could ensure optimum exchange with outside and improve skin health and appearance. Using pad-dry-cure method, cotton fabrics could be loaded with melamine –based capsules, essential oils, certain substances and even vitamins for improving skin health {10}.

Cotton textiles respond better to the environment. In the field of temperature- resistant clothing, cotton treated with hydroxides {11} was found to perform better at higher temperatures where the synthetic fibre – fabrics melt and are rendered unsuitable. In addition, breathability of cotton fabrics significantly helps in encountering successfully high temperatures in fire services. Smart textiles, another class of fabrics, are used in health care. As a class, these textiles sense the stimuli from the environment and react accordingly to adopt to the situation, if that functionality is embedded in their structure. Passive smart textiles are those that can only sense the environment, whereas, active smart textiles can sense and react effectively as per the situation. Very smart textiles adopt to the circumstances by changing their behaviour. In the field of medicine and health care, cotton fabrics suitably endowed with finishes respond better to the environment {12}.

### (b) Moisture Management

The “comfortability” of cotton fabrics is derived from its high moisture absorption capacity, but this very same attribute renders it a slow- drying system. Thicker fabrics take longer time to dry than thinner ones. As an “active wear”, the fabric should dry out faster making the wearer feel dry in a quick time. Polyester fabrics absorb very less moisture due to its hydrophobic nature and dries in a shorter time. As a ‘high activity wear’ “synthetic –fibre fabric fare better. In such a situation “moisture management” is of paramount importance than moisture absorption *per se*.

Moisture management refers to the transport of both moisture vapor and liquid away from the body. This can be achieved either by using a fibre that absorbs less or by a thin fabric made of hydrophilic fibre like cotton. How quickly a fabric dries is more relevant here than how much a fabric absorbs? The drying time and energy required to evaporate water from a wet garment depends on the amount of water absorbed rather than the fibre type. To maximize comfort in an apparel used for “high activity”, the fabric must allow vapor and liquid water to pass to the surface of the fabric for evaporation {13}. It is essential to maintain wicking in apparel designed for “brisk activity” where perspiration is expected to be maximum.

It is important to note that, a very thin cotton fabric has been shown to dry faster than a conventional polyester fabric when equal amounts of water are applied to both the fabric. Cotton fabric can be felt dry to touch even when it contains significant amount of moisture due to its hydrophilic nature, whereas the polyester fabric feels clammy even when it contains only a few traces of perspiration.

A wide variety of technologies and chemistries are available to modify the moisture management of cotton fabrics, without

sacrificing its moisture vapor transport, regain and air permeability. Physicochemical methods such as electro spraying of a hydrophobic polymer on cotton surface {14}, application of moisture management finishes {15}, preparing a skin-like fabric with suitable moisture management finishes {16}, preparing a multilayer/double face fabric with inner layer of a hydrophobic fibre and outer layer of hydrophilic {17}, applying herbal concoctions on the cotton fabric {18} to modulate the moisture management are some of the techniques employed for fabrics before putting to use in “high activity” regime. More innovative methods employed for moisture management were grafting a thermo- responsive polymer on cotton surface {19}, embedding Micro Crystalline Cellulose (MCC) particles by spraying on cotton surface {20}, and blending cotton with another bio-degradable polymer having different regain {21}.

Moisture management in a fabric meant for use in “vigorous activity” leading to “high sweat” would be constructed in such a way that, liquid moisture would be wicked away directly to the outer surface of the fabric for evaporation. The inner of this multi-layered assembly could be made up of a hydrophobic fabric from synthetic material or from untreated cotton having special channels for wicking. The outer layer would be high moisture regain cotton fabric with buffering capability. The absorbent capacity of the multilayered system is thus reduced significantly leading to quick drying.

By electro spraying a hydrophobic polymer on the inner surface of the fabric close to the skin and the outer surface with cotton an architecture is created. The Nano scale roughness is brought about by spraying a fluorocarbon. Thus, moisture movement is directed / restricted to a single direction towards the outer surface and to the environment. Here the moisture management index is significantly improved from 2.5 (untreated fabric) to 4.0 (fluorocarbon coated). Another effective way has been to generate in- situ nano zinc oxide on the fabric surface and simultaneously to finish with a non-fluorocarbon chemical. This multiple finish provided significant improvement in the moisture management {22} of the cotton fabric without detrimental to the permeability of air and water vapor through the fabric.

### (c) Wound Dressing Fabric

In medical parlance, a wound is defined as a disruption in the continuity of the skin lining resulting from a physical or dermal damage. Wound healing is a dynamic and complex process of tissue regeneration and growth process. Therefore, selection of a dressing material for a particular wound is paramount to achieve quicker healing. Since the dressing is different from a bandage, as it is designed to be in close contact with the wound, unlike the bandage, whose function is to hold the dressing in place.

Modern wound dressings are intended to perform a host of functions such as preventing the entry of any infection from outside, facilitate in the process of healing rather than just to cover the wound and also do not adhere to the wound so as to prevent sticking into the young granulating/ freshly growing tissues {23}.

In order to contribute to healing the wound, the dressings are functionalized by special treatments such as hydrogels

to maintain moisture environment and improve the drug delivery ability of cotton {24}. Another variant is to coat cotton fabric with Chitosan and Polyethylene Glycol to create a porous structure. Here cotton fabric is used as a support layer {25}, and the entire dressing is thin and light weight structure. The fabric is supported by a layer of hydrogel and the fabric as a reinforcement provides the strength to the dressing. Such drug-loaded dressings offer precise control to the drug-release mechanism.

Non-adhering dressings offer help by not interfering with the granulating tissues during regeneration. Using an in-vitro approach such dressings were investigated {26} for their healing efficiency. A vaseline-impregnated cotton dressing was found to have the potential to prevent damage to newly formed tissues during dressing changes and positively influenced wound healing.

A composite dressing is a versatile system having multiple layers intended to perform different, yet crucial, functions in healing a wound. While the outer layer usually protects the wound from infection, middle layer comprising a highly absorbent cellulose material (cotton) maintains a moist environment and assists in healing. The inner-most layer consists of a non-adherent material which prevents from sticking to young granulating tissues {23}. Composite dressings have less flexibility due to their compact form.

#### (d) Flame Retardant Textiles

With Changing lifestyle and impetus given to out-door activities and preference to socio-cultural engagements in human life, flame retardant textiles have become an integral part of the society. Natural fibres inherently are prone to fire with a trigger activating it. Therefore, flame proofing is an absolutely essential process for a safe life. Traditionally, flame-retardant cotton fabrics are prepared by treating with flame-retardant agents such as those containing halogens and phosphorous. Burning of halogen flame-retardant produces large amounts of poisonous gas leading to pollution. Due to absence of any anchoring groups in phosphorous-based flame retardants, these have poor surface adhesion and therefore are not fixed firmly on the surface of cotton. Efforts were on to find innovative fixing mechanisms of reagents to cotton surface that could provide excellent retarding of flame and simultaneously imparting high durability. The last decade has provided many interesting solutions to this problem.

Since phosphorous-based flame retardants have poor fixing due to lack of anchoring, FR treatments with modified phosphorous compounds have been attempted. These include non-halogenated organo-phosphorous compound of Propyl with substitution compounds {27}, Di-ammonium phosphate/urea combination {28}, Ammonium salt of diethylene glycol {29}, mixture of inorganic and organic salts and phosphate {30}, Piperazine derivative containing phosphorous {31}, combination of nitrogen and phosphorous compound {32}, etc. for better fixation in cotton fabric. Also, various methods of fixing phosphorous compounds on to cotton fabric such as ad-micellar polymerization {33}, was also tried for improving FR treatment. Use of nano-zinc oxide {34}, Meta, Borate compounds {35}, Plasma Radiation {36}, and herbal extracts {37} were

also tried as FR agents. All the above treatments on cotton fabrics, brought significant improvements in LOI index, and char yield indicating better flame-retardant finish application, without significantly altering the bulk fabric properties. Most of the treated fabrics self-extinguished the flame and showed high durability of the finish

#### (e) Cotton as a Super Hydrophobic Textile

Cotton is one of the few natural fibres apart from Wool, possessing high moisture absorption capacity, lending thereby admirably to imparting and enhancing comfortability in the wearer. Coupled with high moisture regain, a slow transmission of liquid/moisture within the body of the fabric and gradual evaporation to the environment, quite often enhances the discomfort in the wearer especially after a vigorous activity. In order to overcome this deficiency and build capacity for cotton as a high-activity wear, hydrophobicity is introduced either in the surface or in the bulk of the fabric.

Super-hydrophobicity is a trait imparted to the fabric using a bio-mimicking technology trying to replicate the dew drops in a lotus leaf. The drop horizontally floats on the surface without wetting the surface making the contact angle obtuse (more than 140°) and a sliding angle less than 10° due to the rough surface encountered by the water droplet. In an innovative approach, the “hydrophilic-cotton” is turned into a “super-hydrophobic” by treatment either in a physical process or more commonly by using certain chemical reagents.

Various methods have been attempted in recent times to impart “super-hydrophobicity” in cotton fabrics. These include physical methods to bring in surface roughness in cotton {38, 39}, applying fluorocarbon/fluoro-polymer on the surface {40, 41}, using nano zinc oxide {42}, and coating of TiO<sub>2</sub> coupled with surface hydro-phobization {43} Also simultaneously treating one surface of the fabric to hydro-phobicity by spraying a mixture of bio-composite commercial materials that contain Nano particles and a glue and retaining the hydrophilicity on the other side {44}.

All the treatments discussed above could bring in surface roughness in cotton fabrics, making the water droplet to float, reduce/modulate the water holding/absorption capacity without significantly affecting the mechanical properties, colour fastness to washing, rubbing and perspiration. Additionally, many of the treated fabrics showed antibacterial, water-repellent and quick-drying attributes after the treatment.

#### (f) Self-cleaning Textiles

When fabrics are to be used continuously for long durations, they should possess the property of maintaining cleanliness without the need to use water and detergents. This self-cleaning property has to be incorporated in the fabric by functionalization coupled with a photo-induced catalytic activity under ultraviolet light that helps in removing stains. Invariably hydrophobicity also plays a significant role in this process. Cotton fabrics in its natural form does not possess this attribute, hence needs to be imparted by appropriate finishing protocol.

Cotton fabrics are made self-cleaning in several ways. Nano particles such as TiO<sub>2</sub>, SiO<sub>2</sub>, etc. help in the process of impart-

ing the stain removal property. These particles more often in presence of manganese or ZnO<sub>2</sub> {45} decompose the organic stain in to water and CO<sub>2</sub> in presence of ultra violet light {46, 47}. These particles are deposited on the fabric surface in a medium containing water and a polymer immobilized on the surface by coating. By a dip-dry-cure process, a transparent layer of Nano crystalline TiO<sub>2</sub> coating showed also excellent photo – catalytic –self –cleaning property {48}. Cotton fabrics pre-treated with plasma radiation, upon anchoring TiO<sub>2</sub>, could effectively remove persistent coloured pigment stains {49}. A novel method of developing self –cleaning property under photo – catalytic activity even in visible light was introduced by Afzal et al {50}, by assembling mono layers of Porphyrin compounds on Anatase- coated cotton fabric. This technique has great scope as it avoids use of UV light and was effective in removing dogged stains of Coffee.

### (g) Non- Woven Textiles

Non-woven textiles are fabric structures that are prepared without the conventional route of yarns being woven into fabrics. Fibres are subjected to bonding by different means such as needle punching, thermal bonding or bonding using chemicals to form a fabric, used mainly for industrial applications. Cotton as a fibre material has been employed in recent years for manufacture of non- woven. In the thriving non-woven sector, where synthetic fibres dominate, cotton had only a symbolic presence in the beginning of this century. Recently many products and innovation in spun –lace technology has given impetus to use of cotton in non-woven production.

Many conventional techniques of Non- Woven preparation such as needle punching and thermal bonding were used to prepare non-woven for the use of chemical de-contamination {51}, oil clean -up {52}, acoustic absorption {53}, particulate filtration {54}. Composites made up of cotton with bio-degradable binders {55}, for moulded products, for oil and gas application and compression moulded products with PLA are also prepared. The multi-layer chemical de-contamination was found to perform better than carbon granules conventionally used for the purpose. For oil sorption, needle punched cotton non-woven was found to perform better than polypropylene non-woven employed for the said purpose.

Cotton reinforced composites performed better in both on-shore and off-shore gas applications due to their light weight and carbon dioxide sequestration capacity. Also cotton and Poly Lactic Acid (PLA) composites prepared using compression moulding with and with-out Lignin as a binder, behaved like a textile fabric with tensile strength and Young's modulus comparable to woven fabrics {57}.

A set of cotton specific non-woven has been developed in recent years using the hydro-entanglement technology where water jet under pressure acts on the cotton fibres to lay a fabric structure. Hydro-entangled cotton non-woven fabrics or spun-laces as they are called have found innovative uses and probably made cotton as one of the raw materials, indispensable for non-woven preparation. Non-woven wipes {58} with cotton and polyester as blend with acceptable whiteness and absorbency could be prepared using the hydro-entanglement process. Even untreated cotton after a pre needling could be

converted to hydro-entangled non-woven with acceptable absorbency and wicking Capability {59}. Fluid handling attributes matching to polypropylene sheets could be made with mechanically cleaned raw cotton non-woven prepared by hydro-entanglement with matching wettability, swelling and surface polarity. These fabrics had the softest feel as well {60}.

### (h) Cotton as a Protective Textile

Textiles are put to use in certain situations where they had to perform the role of a protector be it sun rays, or rain or against toxic gaseous fumes and many such difficult situations.

**(i). Anti- Microbial textiles:** Cotton fabrics devoid of the protective wax cover often becomes a carbon source for microbes to get attached to its surface. Anti-microbial protection, therefore, becomes highly essential requirement. Several methods are in vogue to impart anti-microbial property to cotton fabrics. Several physical methods such as plasma irradiation {61}, and application of herbal extracts {62, 63, 64} have been carried out to suppress the affinity of both gram –positive and gram- negative bacteria. Many chemical methods have been developed by incorporating nano particles either alone {65}, clusters of Nano particles {66}, mixture of nano particles {67, 68}, Nano particles in combination with finishing agents {69-74}. etc.

Most of the treated fabrics showed anti –microbial activity against *staphylococcus aureus* *Escherichia* and *Klebsiella Pneumoniae*. The wash durability of the finish was also found to be good even after a large number of washing cycles, many times up to 50 washes. Nano particles of zinc oxide, silver, copper oxide, chitosan and its derivatives and a few herbal extracts of nettle leaf, turmeric, and aloe gel also imparted anti-microbial activity in cotton textiles.

Chitosan –based hydro-gel preparations along with some essential oils {75} showed very good anti-microbial activity for long durations with controlled release of the finishing agent viz. the oil. Use of non-toxic bio-compatible starch with improved adhesion properties for ZnO<sub>2</sub> Nano particles and also mixture of ZnO<sub>2</sub> and Silver Nano particles gave excellent protection against microbes.

The anti-microbial market is a vibrant sector with a market size of US\$ 9,468 million in 2019 and is projected to grow at a CAGR of 5.4 % during 2019-2024 and expected to reach a size of US\$ 12,313 million as per trade reports {76}.

**(ii). Pesticide Protection:** Protection from pesticides is a crucial requirement for laborers involved in spraying of these chemicals using knapsack sprayers. Inhaling as well as spilling during handling causes severe breathing and dermatological problems and hence, protection from pesticide is a crucial safety essentiality.

Cotton fabrics finished with chemical derivative of Imidazoline and followed by chlorination to trap and de-toxify whatever pesticide absorbed by the fabric, were found to perform well {77}. The finished fabric reduced pesticide penetration through the fabric. Fabric construction also helped in the process such that twill fabrics performed better with their raised fabric structure. Carboxy methylation of cotton fabric, trapped pesticides essentially on the outer layers of the fabric {78}.

This effect remained even after laundering of the fabric. Fluorocarbon finishes applied on cotton fabric showed significant improvement in pesticide repellency {79}.

**(iii). Protection from Chemicals:** Workers in chemical factories particularly those handling hazardous chemicals need to wear a protective gear during their work schedule for more than 8 hours. The fabric here has to perform the twin jobs of protecting human life from hazardous substances, simultaneously, keeping the wearer comfortable. Here cotton fabrics in some form offers great advantage.

Carbon granules/ fibres in some form impregnated or intimately blended with the fabric satisfy the requirements of offering protection from chemicals. A multi-layer fabric in which the outer layer had polyester and carbon for low absorption, inner layer made up of cotton fabric for good absorbency and comfort, and the middle layer of carbon fabric sandwiched spun-bonded Non-woven. This multi-layer combination {80}, gave good protection under hazardous environments.

An activated carbon non-woven along with cotton fibre gave a morphological structure in which the pores of the cotton fabric has agglomerated carbon granules embedded and held firmly. This lightweight fabric {81}, had higher surface area and gave protection to the wearer from chemical hazards.

**(iv). Protection from Pathogens/ Particulate Matter:** Workers in spinning mills or in areas where fibres are opened and cleaned, often suffer from a disease "Byssinosis" resembling a respiratory infection. Continuous exposure to particulate matter of the "breathable fraction" also leads to breathing related problems. An ingeniously designed cloth mask can help relieve/ control this infection entering the lungs. In the current pandemic times, a well-designed face mask would save from virus containing particulate matter /fluid fraction in exhaled breath of an infected person. Two ways in which this can be achieved are (1) by proper design of the mask with appropriate fibre and in a layered form (2) by incorporating Nano particles that would provide the twin benefit of lower/ poor absorption coupled with introducing a poor adhesion capability of particles on the surface of the cloth. Efforts have been continuously made by researchers to design and functionalize a face mask made of cotton that would perform satisfactorily in the present circumstances.

Face masks designed to fit around the face and made water resistant also with higher number of threads and finer weave to make it full provided reasonable protection {82}. Increasing the number of layers also improved the filtration performance. Among the many fabrics tested for protection against aerosol particles of Nano size, cotton performed better. In comparison, synthetic fibres fared poorly in filtration efficiency {83}. Experimental results further pointed out that multiple fabric layers could improve cotton's effectiveness further. Tighter woven fabrics performed filtration better than knitted structures. If cotton fabrics had many raised fibres, they formed a web-like structure and improved the filtration of particulates more efficiently.

**(v). Protection from Ultraviolet Rays:** Ultra-violet rays from the Sun are often found to create dermatological problems if continuously exposed to, due to the ultra-violet component in

the sun's rays. Protection from ultra-violet forms one of the important functions of a clothing fabric. Conventional cotton fabric provides very low ultra-violet protection, evaluated by an index known as Ultraviolet Protection Factor (UPF).

The protection efficacy can be improved by various means. The fabric structure plays a crucial role in this. Fabric weight is the single most important parameter that decides the UPF value {84}. The type of fibre and weave structure are factors other than weight that influence the UPF. It was noted that to reach a minimum level of protection, cotton fabrics are to fall in the heavy category. The structural, physical and surface characteristics of the fabric also decide the level of ultraviolet protection {85}.

In addition to the cover factor, the dye used in the fabric has a significant influence on the Ultraviolet protection. A deep red dyed fabric was found to provide stronger protection than a black-dyed fabric {86}. A naturally coloured cotton fabric could provide enhanced protection may be due to the fact that the pigments and lignin are natural UV absorbers {87}. From the UPF value of 7 for a conventional cotton, the value was 28 to 29 for a naturally coloured cotton. It was pertinent to note that while high humidity slowed down the protection, perspiration played a positive role in protection.

Apart from the positive influence of fabric weight, density, and type of weave and dyes, titanium dioxide in a nano particle form was found to have a very high influence in enhancing the UV protection {88}.

TiO<sub>2</sub> displayed strong chemical stability at higher temperature, non-toxic and permanent stability under UV light. A thin coating of TiO<sub>2</sub> over the fabric surface enhanced UPF significantly reaching up to value of 50 {89}. This protection efficacy was maintained even after 50 laundering cycles.

The chemical protective clothing market is witnessing a robust growth. A CAGR of about 5% is anticipated during 2020-2025. The overall protective clothing market was valued at 8 billion US\$ in 2018 and expected to reach US\$ 12.1 billion by 2026 with a CAGR of 6.2%.

## (i) Multifunctional Textiles

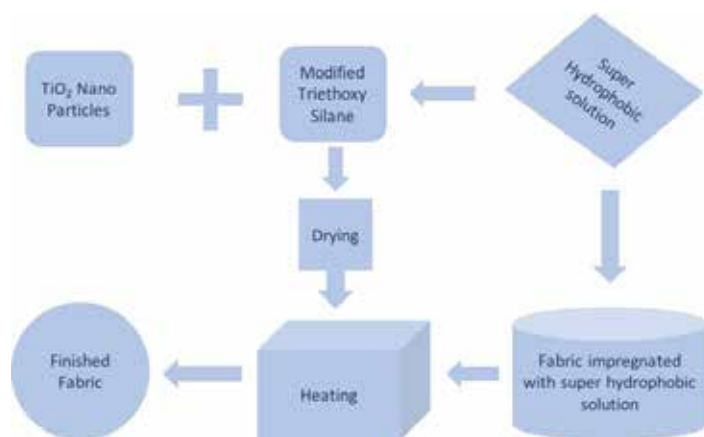
Certain finishes impart multifunctional attributes in cotton fabrics. An example is how a simple coating of TiO<sub>2</sub> Nanoparticles on the surface of a cotton fabric followed by immersion in a modified Ethoxy- Silane solution. This combination treatment was to provide primarily hydro-phobic finish to the cotton fabric.

The coating had excellent stability both mechanically and chemically as well as thermal stability {90}. This finish also brought in excellent self-cleaning, stain – resistance, rust and stain –resistance, anti –water absorption and anti-bacterial properties. The coated fabric had reliable anti –microbial activity.

A judicious choice of the finishing chemical either alone or in combination can impart multi-functional attributes in a single step that would save on chemicals and energy and perform well in multi-various situations. The figure below illustrates this finishing clearly.



Figure 2. Multi- Functional finishing in Cotton Fabrics



#### 4. Can Cotton in the field Grow with Engineered Fibre attributes?

A close look at both cotton and polyester brings out the following facts clearly as illustrated in the following Table-2.

| Cotton                                                                                                                                                                                                                                                                              | Polyester                                                                                                                                                                                                   |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Advantages:</b> Fine, soft, high moisture absorption, skin-friendly, eco-friendly, renewable, hygienic, biodegradable, easy dyeability, good air permeability                                                                                                                    | <b>Advantages:</b> Strong, high elongation, uniform fibres, no trash, dust or foreign matter, tailor-made fibre properties, high easy-care value, vigorous promotional efforts and good marketing strategy. |
| <b>Disadvantages:</b> High trash and dust, weak and immature, less elongation, high variability in fibre length, fineness and strength, poor easy-care property, very poor productivity, poor promotional efforts, lack of coordination amongst different segments in the industry. | <b>Disadvantages:</b> Poor moisture absorption, not so skin friendly, non-biodegradable, static electricity generation, dependent on petroleum reserves, microfibre pollution.                              |

Research is directed towards correcting the deficiencies in the cotton-fibre systems to enable better performance by the fibre and in that process provides stiffer competition to all other fibres. As far as polyester is concerned, its poor absorption is one of the major drawbacks as a performing fibre. Extensive research is directed towards improving the moisture absorption of the fibre by treatments to the surface by etching the surface by using alkali treatments and by creating crevices in the surface to enable holding moisture in those crevices to enhance absorption.

In the case of cotton, the deficiencies are made good with appropriate chemical finishing techniques. Although, the possibilities are immense and even endless, and serious efforts are

going on with innovative approaches, a limiting factor in these efforts has been the use of complex synthesis of new chemicals and use of expensive reagents. Not to speak of fulfilling stringent eco-norms as well as effluent management treatments in carrying out such chemical finishing treatments on a large scale.

On the crop production side, extensive research is going on since a long time to improve the quality of cotton fibres. Through conventional breeding, any effort to enhance the fibre quality of cotton generally results in adverse effect on the yield of the fibre. The association between fibre quality and yield is negative and hence, any effort to improve the quality of fibre has always resulted in reduction in yield. Earlier researches at PUSA, New Delhi and elsewhere in India {91} to improve the quality of cotton gave encouraging results leading to improved strains with better fibre at the expense of cotton fibre yield.

With the advancement of science and technology and modern tools to apply them, interventions to improve both the quality and yield of cotton have been timely and appreciable. At the beginning of this century, it was thought worthwhile to apply modern technologies to improve the quality of fibre without sacrificing the yield. Using bio-technological tools and by gene-transfer mechanisms, many researchers took up incorporation of genes from other plant sources with special emphasis to improve a particular fibre character in cotton. However, success was hard to come by, due to the inherent complexity of cotton genome and the difficulties faced in applying those modern tools. During the current decade, some positive results are emerging. Apart from gene-transferred plants, some field experiments have been also successful. A brief description of the achievements made in this regard is presented here.

Use of a DNA encoding Sucrose Phosphate Synthase in transforming a cotton plant to improve fibre qualities like strength, length, fineness, and maturity has met with some success {92}. By allowing over-expression of sucrose synthase in cotton, it was shown that {93}, the poorer length and other fibre traits could be improved. Another study in genetic modification of cotton employed *Calotropis Procera* genes in the transformation. Three years of field experiments revealed {94} that, while fibre length increased by 10%, fibre strength improved up to 12-38%, and micronaire value up to 8-12%. Another interesting research published in the National Academy of Sciences {95}, reports that inserting a gene into the cotton plant would make cotton fibres appear like polyester and wrinkle-free. A laboratory experiment has shown that a bacterium gene that makes a polyester-like substance can be inserted into the cotton plant and cause it to grow a fibre that has the texture of cotton with the warmth and insulation like polyester. The above research reports summarise part of the research efforts to improve fibre quality of cotton using gene transfer mechanism. Some of these have reached up to field trials after successful research at the laboratory. In a few years down the line, on a large scale, cotton with improved traits would be produced in the field and then this premier fibre would stand tall and face the competition squarely from that posed by the synthetic fibre counterpart.

## 5. Cotton as Comfort Fibre in a Competitive, Performance-oriented Synthetic Fibre Environment

What has been described in this report is how a traditional fibre like cotton essentially employed for clothing, has transformed itself to perform in non-apparel applications and also in various industrial environments by adopting to changes based on modern scientific and technological expertise. Efforts are still continuing to incorporate various facets of modern technologies such as plasma radiation, nano particles and improved chemical technologies and combination of these in imparting traits so far not thought of or experimented with. All these interventions are essentially to face the challenge provided by synthetic fibres with tailored properties and consistent quality.

Being a biological system, subjected to vagaries of weather and input resources, cotton fibre inherently has lot-to-lot, bale-to-bale variability in fibre attributes which more often than not do not get completely negated / made good by mechanical processing. As noted earlier, many of the polyester-like characters can be brought about in cotton by appropriate chemical finishing, but here too, the mechanical strength and other basic attributes take a beating in the process.

Not with-standing the above mentioned deficiencies, cotton stands tall in the comity of fibres, as the only fibre that could be labelled as “comfortable”, “soft”, “Skin-friendly”, and “hygienic”. Coupled with “bio-degradability”, “environmental-friendly” and “annually renewable” characters, this natural fibre has all the attributes in place to perform efficiently as the “clothing provider” for human kind. Continuous improvements in yield and performance traits would enhance its value immensely and render the fibre indispensable and make it a way of life for generations to come.

### References Cited

1. J. Lewis in “Cotton” in Encyclopedia of World Environment History, ed. Shepard Krech III, J.R. McNeill, *Carolyn Merchant*, (2014).
2. Cotton Manufacture in Ancient India: D. Schlingoff. *Journal of Economic and Societal History of the Orient*, 17, no. 1, March (1974).
3. Big Cotton: How a Humble Fibre Created Fortunes, Wrecked Cultivations and Put America on the Map: Stephen Yafa, N. Y. Viking, (2005).
4. Town Send, International Cotton Advisory Committee (ICAC), 1998.
5. Policy Driven Causes for cotton’s Decreasing Market Share of Fibres: Dean Ethridge, *33<sup>rd</sup> International Cotton Conference*, Bremen, (2016).
6. Jute-Polypropylene and the Environment: A Study in International Trade and Market Failure: James K. Boyce. *The Bangladesh Development Studies*, 23, No ½, 49-66, (1995).
7. Redefining Competitive Edge Through Integration of Ecological Foot Prints- *Jute vs Synthetic Fibre*: Mandeep Chandra
8. Sustainable Apparel Materials: R. Kirchain, E. Clivetti, T. Reed miller and Suzanne Grene, *A Report by Material Systems laboratory, Massachusetts Institute of Technology*, Cambridge, (2015).
9. State of Analysis of water footprint Assessment in Polyester, Cotton & Viscose: Ruth Mathews, Alexandra Freitas, Ertug Ercin. *Water Footprint net Work*, Stockholm www, August, (2017).
10. Essential Oil Microcapsules Immobilized on Textiles and certain Induced effect: M.S. Stan, L. Chirila, A. Popescu, D.M. Radulescu, D.E. Radulescu and A. Dinischitotu, *Materials*, 12 (12), 2029, (2019).
11. The Impact of Technical Textile on Health and Well Being: Current Developments and Future Possibilities: E. Diane. *Journal of Textile Science and Engineering*, 7, Issue 3, 4 pages, (2017).
12. Textile Sensors for Health Care: L.V. Langenhove, C. Hertleer, P. West brock and Priniotakis. Smart Textiles for Medicine and Health care Materials, Systems and Applications, *Wood Head Publishing Series in Textiles*, 106-152, (2007).
13. 100 % Cotton Moisture Management: Michelle Wallace. *Journal of Textile and Apparel Technology and Management*, 2, 1-11, (2002).
14. Moisture Management Finish on Cotton Fabric by Electro-Spraying: G.T.V. Prabhu, S.K. Chattopadhyay and P.G. Patil. *Textile Res. J.*, 87, 2154-2165, (2017).
15. Analysis of Moisture Management Parameters in the Woven Cotton Fabric after Chemical Treatment with Moisture Management Finishes: D. Sai Sarika and M.K. Shakya. *International Journal of Science and Research*, 6, no. 8, 1159-1162, (2017).
16. Skin-Like Fabric for Personal Moisture Management: L. Lao, D. Shou, Y. S. Wu, and J. T. Fan. *Science Advances*, 6, No. 14, 1-11, (2020).
17. Moisture Management Evaluation in Double Face Knitted Fabrics with Different Kind of Constructions and Fibres: F.B. Vasconcelos, L.M.M. Barros, C. Borelli, and F.G. Vasconcelos. *J. Fashion Technol. Textile Engg.*, 50, No. 3, (2017).
18. Effect of Herbal Extract Treatment on the Moisture Management Properties of Cotton Knitted fabrics: K. Chandrasekaran, and M. Senthilkumar. *Journal of Natural Fibres*, 17, 557-572, (2020).
19. Smart Moisture Management and Thermo- Regulation properties of Stimuli-responsive Cotton Modified with polymer brushes: X. Liu, Y. Li, J. Hu, J. Jiao, and J. Li. *RCS Advances*, 4, 63691-63695, (2014).
20. Micro-Crystalline Cellulose Particles for Surface Modification to Enhance Moisture Management Properties of Polyester and Polyester/ Cotton Blend Fabrics: M. Messiry, A. Ouffy and M. Issa. *Alexandria Engineering Journal*, 54, 127-140, (2015).
21. Development of cotton-rich /Poly lactic Acid Fibre Blend Knitted fabrics for Sports Textiles: R. Guru Prasad, M.V. Vivekanandan, A. Arputh Raj, S. Saxena and S.K. Chattopadhyay. *Journal of industrial Textiles*, 45, No.3, 405-415, (2015).
22. Development of Multi-functional Cotton Surface for Sports Wear Using Nano Zinc Oxide: A. ArputhRaj, N. Vigneswaran and S. R. Shukla. *Journal of Natural Fibres*, (2018).
23. Wound Dressings: A Review: R. Dhivya, V.V. Padma, and E. Santini. *Biomedicine (Taipi)*, 5 (4), 22, (2015).
24. Functionalization of Cotton Cellulose for Improved Wound Healing: D. Pinho and G. Soares. *Journal of Materials Chemistry B*, 6, 1887-1898, (2018).
25. Textile Based Smart Wound Dressings: B. Gupta, R. Agarwal and M. S. Aslam. *Indian Journal of Fibre and Text. Res.*, 35, 174-187, (2010).
26. Effect of Non-adhering Dressings on promotion of Fibroblast Proliferation and Wound healing In Vitro: A. Wiegand, M. Abel, U. C. H. Pier, and P. E. Uner. *Scientific reports*, 9, 4320, (2019).
27. Preparation of a Reactive flame Retardant and its finishing on Cotton Fabrics Based on Click Chemistry: L. Xu, W. Wang and D. Yu. *RCS Advances*, 7, 2044-2050, (2017).

28. Flame Retardant cotton Blend High lofts: D. V. Parikh, N. D. Sachinvala, A. P. S. Sawhney, K. Q. Robert, E. E. Graves and T. A. Calamari. *Journal of Fibre Science*, 21, 383, (2003).
29. Synthesis of a Formaldehyde-free Flame Retardant for Cotton Fabric: P. Tian, M. Liu, C. Wan, G. Zhang and F. Zhang. *Cellulose*, 26, 9889-9899, (2019).
30. Formaldehyde-free and Halogen-free Flame Retardant Finishing on Cotton Fabric: Z. O. Basygit, D. Kut. *Tekstil Ve Konfeksiyon* 28 (4), 287-293, (2018).
31. Fire Self Extinguishing Cotton fabric: development of Piperazine Derivatives Containing Phosphorous-Sulfur-Nitrogen and their Flame Retardant and Thermal Behaviour: R. Nagayuen, S. Chang, B. Condon, and J. Smith. *Materials Science and Applications*, 5, 789-802, (2014).
32. Synthesis of a New N-P Durable Flame retardant for cotton Fabrics: P. Tian, D. Wang, G. Zhang and F. Zary. *Polymer Degradation and Stability*, 165, 220-228, (2019).
33. Enhancement in Flame Retardancy in Cotton Fabric by Using surfactant-aided Polymerization: S. Nehra, S. Hanuman Setty, E.A. O. Rear and J. B. Dahiya. *Polymer Degradation and Stability*, 109, 137-146, (2014).
34. Fabrication of High Nano-ZnO Doped with Boric Acid assembled on Cotton Fabric with Flame retardant Properties: C. Ling and L. Guo. *Fibres and Textiles in Eastern Europe*, 27, 65-70, (2019).
35. Facile Flame Retardant Finishing of Cotton fabric with Hydrated Sodium Metaborate: Tawaiah, B.Yu, W. Yang, R.K.K. Yuan, and B. Fei. *Cellulose*, 26, 4629-4640, (2019).
36. Study of the Effect of Plasma modification on the Change of Fire-Resistant Properties of Textile materials Imported by Flame retardants: S. Ilyushina, M. Antonova, I. Krasima, A. Hinayazova, A. Parsenov, and R.Mingaliev. *J. Phys. Conf. Ser.* 1328012037, (2019).
37. Fire Retardant Property of Cotton Fabric Treated with Herbal Extracts: S. Basak, K.K. Samanta and S.K. Chattopadhyay. *Journal of Textile Institute*, 106, 1338-1347, (2015).
38. A Brief Review of Surface-functionalized Cotton Fabrics: B. Cortese, D. Caschera, G. Padeletti, G.M. Ingo and G. Gagli. *Surface Innovations*, 1, 140-156, (2013).
39. Surface Modifications of Cotton Textile Using Low Temperature Plasma: V. D. Gotmare, K. K. Samanta, V. Patil, S. Basak, and S. K. Chattopadhyay. *International Journal of Bioresource Science*, 2 (1), 37, (2015).
40. Hydrophobic Thin Fluoro Polymer Coating on Cotton Surfaces: S. Mondal, S. Pal and J. Maity. *International Journal of Polymer Analysis and Characterization*, 23, 376-382, (2018).
41. Development of multi-functional Cotton using fluorocarbon Resin: A. K. Jain, A. F. Tesema and A. Haili. *Journal of Textiles and Fibrous Materials*, 1, 1-8, (2018).
42. Production and Characterization of Super hydrophobic and Anti-bacterial Coated Fabrics Utilizing ZnO Nano Catalyst: M. Shaban, F. Mohammad, and S. Abdallah. *Scientific Reports*, 8, 3925, (2018).
43. Super Hydrophobic Cotton Fabrics prepared by Sol-gel Coating of TiO<sub>2</sub> and Surface hydrophobization: B. Xue, S.T. Jia, H.Z. Chen, M. Wang. *Science and Technology Advanced Materials*, 9 (3), (2008).
44. Asymmetric Super hydrophobic/ Super Hydrophilic Cotton Fabrics Designed by Spraying Polymer and Nano particles: K. Sasaki, M. Tenjimbayashi, K. Manabe, and S. Shiraton. *ACS Appl. Mater. Interfaces*, 8, 651-659, (2015).
45. Design and Characterization of Self- cleaning Cotton fabrics Exploiting zinc Oxide Nano-particles –triggered photo-catalytic Degradation: B. Zhu, J. Shi, S. XU, M. Ishimori, J. Sui and H. Murikawa. *Cellulose*, 24, 2657-2667, (2017).
46. Self- cleaning Technology in Fabric: A Review: S. R. Saad, N. Mohamed, M.M.A. Abdullah and A. V. Sandhu. *IOP Conference Series Material Science and Engineering*, 133 (1), (2016).
47. Facile Preparation of Multiscale Nano Architecture on Cotton fabric with Low Surface Energy for High Performance Self-cleaning: S. Tian, J. Zhao, J. He, H. Shi, B. Jin, S. Qin, Y. Xia, and C. Xiao. *J. Textile Instt.* (2020).
48. Self-cleaning Cotton: K. Qi, W. A. Daoud, J. H. Xi. C. L. Mak, W. Tang, and W. P. Cheung. *Journal of Material Chemistry*, 47, 1-8, (2006).
49. Self-cleaning of Modified Cotton Textiles by TiO<sub>2</sub> at Low Temperature Under Day Light Radiation: A. Bozzi, T. Yuramova, I. Gusaquillo, D. Laub, and J. Kiwi. *Journal of Photo Chemistry and Photo Biology A: Chemistry*, 174, 156-164, (2005).
50. Self-cleaning cotton by Porphyrin –sensitized Visible light Photocatalysts: S. Afzal, W. A. Daoud, and S. J. Longford. *Journal of Materials Chemistry*, 22, 4083-4088, (2012).
51. Development of cotton Non-woven composite fabric for Toxic Chemical De-contamination and Characterization of its absorption Capabilities: U. Sata, E. Wilusz, S. Mlynarek, G. Gopal, R. Kendall and S. S. Ram Kumar. *Journal of Engineered Fibres and Fabrics*, 8, 94-106, (2013).
52. Needle Punched Cotton Non-wovens and Other Natural fibres as oil Clean-up Sorbents: H. M. Choi. *Journal of environmental Science and Health: Part A, Environmental Science and Engineering and Toxicology*, 31, 1441-1457, (1996).
53. Acoustical Evaluation of Carbonized and Activated Cotton Nonwoven: N. Jiang, J. Y. Chen, and D. V. Parikh. *Bio Resource Technology*, 100, 6533-6536, (2009).
54. Multi- layer Non-woven Fabrics for Filtration of Micron and Sub-micron Particles: G. Nallathambi, S. Evangelin, R. Kasthuri, and D. Niveditha. *Textile Eng. Fashion. Technol.* 5 (2), 81-84, (2019).
55. Cotton fibre Non-woven for Automotive Composites: M. G. Kamath, G. S. Bhatt, D. V. Parikh, and D. Muller. *International Natural Fibres journal* (2005). [www.jeffjournal.org](http://www.jeffjournal.org)
56. Engineered Natural fibre composites for oil and Gas application: A Review: T. A. Briggs, and N. Obinichi. *International Journal of Application or Innovation in Engineering and Management*, 6, 113, (2017).
57. Application of lignin as Natural adhesion promoter in Cotton fibre Reinforced poly Lactic Acid Composites: M. Graupner. *Journal of Material Science*, 43, 5225-5229, (2008).
58. Whiteness and Absorbency of Hydro-entangled Cotton- based Non- woven Fabrics of Different Constituent Fibres and Fibre Blends: P. Sawhney, C. Allen, M. Reynolds, and R. Slopek. *World Journal of Engineering*, 10 (2), 125-132, (2013).
59. Advent of Greige Cotton Non-woven Made using a Hydro – entanglement Process: A. P. S. Sawhney, B. Condon, M. Reynolds, R. Slopek and D. Hui. *Textile Res. J.*, 80, 1540-1549, (2010).
60. Fluid Handling and Fabric Handle Profiles of Hydro- entangled Greige Cotton and Spun- bond Polypropylene Non-woven Top Sheets: J. V. Edwards, N. Mao, S. Russell, E. Carus, B. Condon, d. Hinchliffe, L. Gary, E. graves, A. Bopp and Y. Wang. *J. Materials: Design and Applications*, 1-13, (2015).

61. Regenerable Anti- microbial Finishing of Cotton with Nitrogen Plasma Treatment: C. E. Zhou, C. W. Yuen, C. M. Lo, K. C. Ho, C. P. Ken, K. R. Lau. *Bio Resources*, 11 (1), 1554-1570, (2016).
62. Anti-bacterial finishing of Cotton Fabric using Nettle Plant Extract: A. Ketema and A. Worku. *Hindwai Journal of Chemistry*, 1-10, (2020).
63. Experimental Study on Anti- microbial Activity of Cotton fabric Treated with Aloe gel Extract from Aloe Vera Plant for Controlling Staphylococcus aureus: D.Jothi. *African Journal of Microbiology Research*, 3 (5), 228-232, (2009).
64. Anti-microbial Finishing of Cotton fabric with Turmeric and Chitosan: B. Adehena, D. Zereb, B. Fissiha, and Brahaneknfe. *Textile learner.blog spot.com* (2018).
65. Investigation of Anti-bacterial Activity of Cotton Fabric Incorporating Nano Silver Colloid: N. V. K. Thanh, and N. T. P. Phong. *Journal of Physics: Conference series* 187, (2009).
66. Anti-microbial Functionalization of Cotton Fabric with Silver Nano-particles / Silver Composite coating via RF Co-sputtering Technique: M. Irfan, S. Perero, M. Miola, G. Maina, A. Ferri, M. Ferraris, and C. Balagna. *Cellulose*, 24, 2331-2345, (2017).
67. Preparation and Anti-microbial Activity of ZnO-NPS Coated Cotton/starch and Their functionalized ZnO/Ag / Cotton and Zn (ii) Curcumin/ Cotton Materials: Issa M. El Nahhal, J. Salim, Rawan Ambar, F. S. Kodeh, and A. Elma Nama. *Scientific Reports*, 10, 5410, (2020).
68. Anti- bacterial and Anti –mycotic Activity of Cotton Fabrics Imprgnated with Silver and Binary Silver/ Copper Nano Particles: A. M. Eremenko, L. S. Petrik, N. P. Smirnova, A. V. Rudenko and Y. S. Marikvas. *Nano Scale Research Letters* 11 (1), 28, (2016).
69. Durable Anti-microbial Cotton Textiles Coated Sono –chemically with ZnO nano particles Embedded in an in-situ Enzymatically Generated Bio-adhesive: M.Salat, P. Petkova, J. Hiyo, I. Pereclshtein, A. Credanken, and T. Tzanov. *Carbohydrate Polymers*, 189, 198-203, (2018).
70. Anti- bacterial Effect of Cotton fabric reared with Silver nano particles of Different Sizes and Shapes: K. H. E. Yunusov, S. V. Mullajnova, A. A. Sarymsakov, J. Z. Jalilov, F. M. Turakulov, S. S. H. Rashidova, and R. Letfullin. *International Journal of Nano Materials, Nano Technology and Nano Medicine*, 5 (2), 16-23, (2020).
71. Anti-microbial Finishing of Cotton Textile Based on Water Glass by Sol-Gel Method: Y. Xing, X. Yang, and J. Dai. *Journal of Sol- Gel Science and Technology*, 43, (2), 187-192, (2007).
72. Anti-bacterial Efficacy of Cotton fabrics Chemically modified by Metal Salts: S. Nakashima, Y. Sakagami, and M. Matsuo. *Bio Control Science*, 6, 9-15, (2001).
73. Application of a Fibre –reactive Chitosan Derivative to Cotton Fabric as an Anti-microbial Textile Finish: S. H. Lim and S. M. Hudson. *Carbohydrate Polymers*, 56, (2), 227-234, (2004).
74. Innovative Dual Anti –microbial and Anti –crease Finishing of Cotton Fabrics: A. S. Aly, A. B. E. Mostafa, M. a. Ramadan and A. Hebeish. *Polymer-Plastics Technology and Engineering*, 46, 703-707, (2007).
75. Proactive release of Anti-microbial essential Oil from a “Smart” Cotton fabric: B. Stular, M., Sobak, M. Minelesc, E. Sest, I. G. Ilic, I. Jerman, B. Simoncic and B. Tomsic. *Coatings*, 9, 242, (2019).
76. Global Anti- microbial Textile Markets Forecast 2024: *Globe News Wire, Research and Markets*, (2019).
77. An Imidazoline derivative functionalized Cotton fabric for Pesticide Clothing: R. Abirami and N. Selva Kumar. *Asian Journal of Chemistry*, 25, 6036-6038, (2013).
78. Carboxy -methylated Cotton Fabrics for Pesticide Protective Work Clothing: I. Racz, J. Borsa, S. K. Obendorf. *Textile Res. J.*, 68, 69-74, (1998).
79. Development of protective Clothing for pesticide Industry: Part I. Assessment of Various Finishes: M. Suri, D. Rastogi, K. Khanna, and M. Chakrabarty. *Ind. J. of Fibre and Text. Res.*, 27, 85-90, (2002).
80. Development of chemical protective Clothing Using Multilayer Fabric for hazardous Chemical Handling: N. Sukumar, P. Gnanavel, R. Dharmalingam, and S. Aruna. *Journal of Natural Fibres*, (2020).
81. Activated carbon non-woven as Chemical Protective Materials: Y. Chen, N. Jiang, L. Sun and I. Negulescu. *Research Journal of Textile and Apparel*, (2006).
82. Effectiveness of Cloth Masks for Protection Against severe Acute respiratory Syndrome Corona Virus 2: A. A. Chughtai, H. Seale and C. R. Macintyre. *Emerging Infectious Diseases*, 26, (2020).
83. Filtration Efficiencies of Nanoscale aerosol by Cloth Mask Materials Used to Slow the Spread of SARS. COV-2: C. D. Zangmeister, J. G. Radrey, E. P. Vicenzi and J. L. Weaver. *ACS Nano* (2020).
84. Correlation Between the Ultraviolet Protection factor and the weight and Thickness of Undyed Cellulose Woven Fabrics: Algaba M. Pepio and A. Riva. *Fibres and Textiles in Eastern Europe*, 16, 85-89, (2008).
85. A Study on Ultraviolet Protection of 100 % Cotton knitted Fabric: Effect of Fabric Parameters: A. W. Kan. *The Scientific World Journal*, 24, 1-10, (2014).
86. Improving the Ultraviolet Protection Factor of Cotton Fabric: M. Gorensek, F. Sluga, and R. Urbas. *AATCC Review*, 7 (2), 44-48, (2007).
87. Ultra Violet Radiation Protection of Naturally Coloured Light Weight Cotton Fabric: J. C. Yu, and S. C. Wang. 2016, *Proceedings ITAA*, British Colombia, (2016).
88. A Review on Ultra Violet Protection of Textiles: K. M. Aslam, and M. T. Aslam. *International Journal of Engineering, Technology, Science and Research*, 4, (2017).
89. A New approach to UV Blocking Treatment for Cotton Fabrics: J. H. Xin, W. A. Daoud and Y. Y. Konj. *Textile Res. J.*, 74, 97-100, (2004).
90. Surface Modification of Cotton Fabric Using TiO<sub>2</sub> Nano Particles for Self Cleaning –Oil-water absorption, Anti Stain, Anti Water Absorption and Antibacterial properties: B. K.Tudu, A. Sinhamahapatra and A. Kumar. *ACS Omega*, 5, 7850-7860, (2020).
91. An Update on Conventional and Molecular Breeding Approaches for Improving Fibre Quality Traits in Cotton- A Review: J. Ashok Kumar, K. Senthil Kumar, and R. Ravi Kesavan. *African Journal of Biotechnology*, 13, 1097-1108, (2014).
92. Transgene Cotton plants with Altered fibre Characteristics Transformed with a Sucrose Phosphate Synthase Nucleic acid- Patent
93. Sucrose Synthase genes: A Way Forward for Cotton Fibre Improvement: K. Ahmed, A. A. Shahid, A. Q. Rao, M. S. kiani, M. A. asraf, A. A. Dahab, A. Bakshih, A. Latif, M. A. U. Khan, A. N. Puspito, A. Latif A. Bashir and T. Husnain. *Australian Journal of Crop Science*, 7 (2), 206-212, (2013).
95. Genetic Implant Allows cotton to Grow Polyester-like Fibre: *Tulsa World News*, February, (2019).

## ANNEXURE-1

| Process     | Product/ By-product/ Waste                                                                   | Value added products                                                                                                                             |
|-------------|----------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|
| GINNING     | Ginning waste                                                                                | Soil application, Livestock Feed, Fuel, Extruded Products                                                                                        |
| GINNING     | Cotton Fibres                                                                                | Textile Yarns, Fabrics, garments, Non-woven, Industrial Textiles, Medical Textiles                                                               |
| DELINTING   | Linters extracted from fuzzy seeds                                                           | Absorbent Cotton, Pulp & Paper, Regenerated Cellulose, Micro Crystalline Cellulose, Nano Cellulose, Modified Cellulose, non-woven, Carbon Fibres |
| SPINNING    | Carding- waste, Droppings & Fly Fibres (from twisting), Comber Noil (by-product of spinning) | Absorbent Cotton, Micro Crystalline Cellulose, Viscose, LYOCELL, High Tenacity Rayons, Non-woven, Pulp & Paper, Nano Cellulose                   |
| OLD FABRICS | Garments, fabric & yarn Waste                                                                | Recycled Yarns, Insulation Products, Horticulture Mats, Compost                                                                                  |
| DEHULLING   | Hulls                                                                                        | Animal Feed, Peptone                                                                                                                             |
| DEHULLING   | Kernels                                                                                      | Oil                                                                                                                                              |
| CRUSHING    | Seed-meal                                                                                    | De-oiled Cake                                                                                                                                    |
| UPROOTING   | Cotton stalks                                                                                | Particle Boards, Hard/ Fibre Boards, Pulp & Paper, Extruded Products, (1). Briquets, pellets, (2). Compressed Blocks                             |

## GLOSSARY

**Alpha cellulose:** It is the major component of wood and paper pulp. It is separated from the other components by soaking the pulp in a 17.5% solution of Sodium hydroxide. The pure white, alpha cellulose is insoluble and can be filtered and washed prior to use in the production of paper or cellulosic polymers.

**Batt:** a piece of felted material used for lining or insulating items such as quilts and sleeping bags.

**Card waste:** Carding is a mechanical process that disentangles, cleans and intermixes fibres to produce a continuous web or sliver suitable for subsequent processing. It breaks up locks and disorganised clumps of fibre and then aligns the individual fibres to be parallel with each other. The waste arising from this process is called card waste.

**Card:** A machine used to separate, align, and remove of short fibers from cotton.

**Carded yarns:** A cotton yarn which has been carded but not combed. This type of yarn contains a wide range of fibre length. As a result, carded yarn is not as uniform as combed yarns and are considerably cheaper.

**Cellulose:** It is an organic compound, a polysaccharide consisting of a linear chain of several hundred to many thousands of  $\beta(1-4)$  linked D-glucose units. Cellulose is an important structural component of the primary cell wall of green plants, many forms of algae and the oomycetes. Some species of bacteria secrete it to form biofilms. Cellulose is the most abundant organic polymer on Earth. The cellulose content of cotton fiber is 90%.

**Cleaned Card Strips:** The waste fiber removed by the revolving flats of a card during the carding process.

**Combed yarns:** Yarn that has undergone the combing process so that all the fibers are straight and parallel. This process creates a smoother, stronger, and more compact yarn that is excellent for weaving. Combed yarn is extremely soft and is stronger than other yarns and is more expensive.

**Comber Noil:** Comber noil is a by-product of the yarn spinning process, produced when cotton is combed in comber machine to remove short fibers. Noil consists of shorter fibers and neps.

**Cotton Classing:** A High-Volume Instrument (HVI) measures fiber properties including fiber strength, length uniformity, micronaire, trash, and color. These values are attached to each bale, and fiber is priced and purchased based on these properties.

**Cotton Gin:** Short for engine, all fiber from the field flows through the cotton gin. Today's modern cotton gins dry and clean the cotton – removing field trash and plant parts like sticks and stems – before performing the primary job of removing fiber from the seed.

**Cotton purification:** Removal of oils, waxes, and color bodies from cotton fibers.

**DP (Degree of polymerization):** DP determines chain length. The degree of polymerization, or DP, is the number of monomeric units in a macromolecule or polymer or oligomer molecule.



**Fibre length:** The length of cotton fiber is an important indicator of spinnability, physically, the individual cotton fibers consist of a single long tubular cell. Its length is about 1200-1500 times than its breadth. Length of cotton fiber varies from 16mm to 52 mm depending upon the type of cotton.

**Flat-strip waste:** Cotton flat is a by-product of the yarn spinning industry produced in the first carding machine. The fiber has higher trash compared to comber Noil. It is mostly used in OE spinning for blending with good quality cotton.

**Gin Motes:** Small, broken, or immature seeds with attached fibers. The gin removes the motes at a different stage from the mature, whole seeds.

**Hydro-entanglement:** It is a bonding process for wet or dry fibrous webs made by either carding, airlaying or wet-laying, the resulting bonded fabric being a nonwoven. It uses fine, high pressure jets of water which penetrate the web, hit the conveyor belt and bounce back causing the fibres to entangle. Hydroentanglement is sometimes known as spunlacing, because the early nonwovens were entangled on conveyors with a patterned weave which gave the nonwovens a lacy appearance.

**Linter:** The fine silky fibres left behind on the cotton seed after ginning are called linters that is use in the making of paper and cellulose.

**Lyocell fibres:** A form of rayon, it consists of cellulose fibre, made from dissolving pulp and then reconstituting it by dry jet-wet spinning. The fibre is used to make textiles for clothing and other purposes.

**Maturity:** A fibre characteristic which expresses the relative degree of thickening of the fibre wall. it is the measure of primary and secondary wall thickness.

**Micronaire:** A measurement of airflow resistance through a standard weight of cotton compressed to a specific volume. The higher the value, the larger the diameter of the fibers. Micronaire range is normally 2- 5, although there are some fiber types that produce fibers with micronaire as high 8.

**Nanocellulose:** Refers to nano-structured cellulose. This may be either cellulose nanocrystal (CNC or NCC), cellulose nanofibers (CNF) also called nano-fibrillated cellulose (NFC), or bacterial nanocellulose, which refers to nano-structured cellulose produced by bacteria.

**Nep:** A small tangled bundle of fibers.

**Organosolv pulping:** In industrial paper-making processes, organosolv is a pulping technique that uses an organic solvent to solubilise lignin and hemicellulose.

**Pulp paper:** Pulp is a lignocellulosic fibrous material prepared by chemically or mechanically separating cellulose fibers from wood, fiber crops, waste paper, or rags. Pulp is the major raw material used in papermaking and in the industrial production of other paper products.

**Regenerated cellulose:** Is a class of materials manufactured by the conversion of natural cellulose to a soluble cellulosic derivative and subsequent regeneration, typically forming either a fiber (via polymer spinning) or a film (via polymer casting).

**Reginned mote fiber:** Fiber removed by re-ginning machines from the gin motes.

**Viscose:** is a type of rayon. Viscose is the generalized term for a regenerated manufactured fibre, made from cellulose, obtained by the viscose process, it is neither truly natural (like cotton, wool or silk) nor truly synthetic (like nylon or polyester) – it falls somewhere in between. Viscose is a low-cost fabric, which is popular and can be found in cotton end uses such as feminine hygiene products, in tyre cords as well as in velvets and taffetas.

**Yarn:** It is a long continuous length of interlocked fibres, suitable for use in the production of textiles, sewing, crocheting, knitting, weaving, embroidery, or ropemaking. Thread is a type of yarn intended for sewing by hand or machine.

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