The ICAC Recorder

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.

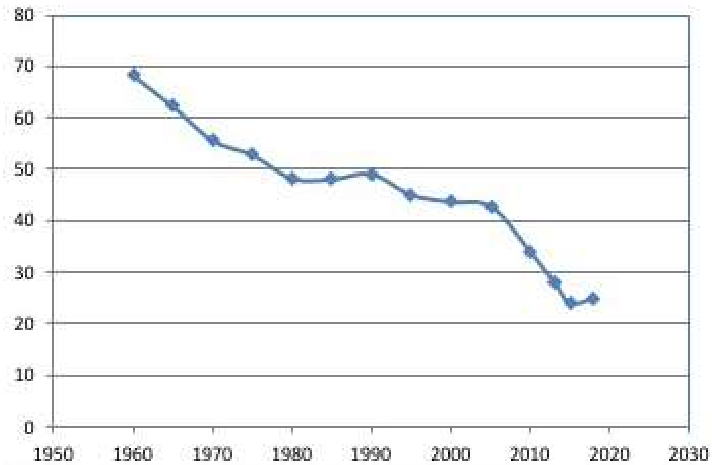
(a) Cotton in Comity of Fibres

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_2 as against 3.8 Kg of CO_2 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_2 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 with - out 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 with-out 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_2, SiO_2, etc. help in the process of imparting the stain removal property. These particles more often in presence of manganese or ZnO_2 {45} decompose the organic stain in to water and CO_2 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_2 coating showed also excellent photo – catalytic –self –cleaning property {48}. Cotton fabrics pre-treated with plasma radiation, upon anchoring TiO_2, 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_2 Nano particles and also mixture of ZnO_2 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 sand witched 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_2 displayed strong chemical stability at higher temperature, non-toxic and permanent stability under UV light. A thin coating of TiO_2 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%.

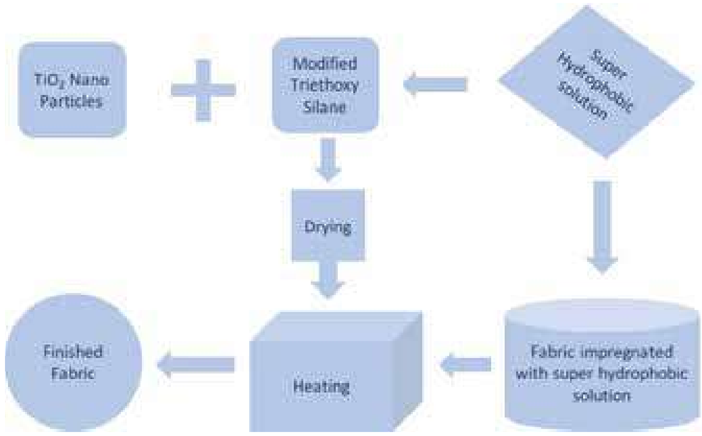
(i) Multifunctional Textiles

Certain finishes impart multifunctional attributes in cotton fabrics. An example is how a simple coating of TiO_2 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
Advantages: Fine, soft, high moisture absorption, skin-friendly, eco-friendly, renewable, hygienic, biodegradable, easy dyeability, good air permeability	**Advantages:** 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.
Disadvantages: High trash and dust, weak and immature, less elongation, high variability in fibre length, fineness and strength, por easy-care property, very poor productivity, poor promotional efforts, lack of coordination amongst different segments in the industry.	**Disadvantages:** 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. Al 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.

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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 in 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 β(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.