Natural and Man-made Evolution of Sustainability of Cotton Production and Processing over the Centuries in the World

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Abstract

Cotton is a premier textile fiber and one of the most competitive crops in global agriculture. Though primarily considered as fiber crop cotton is also an important source of oilseed and livestock feed besides providing several other by-products. In fact all parts of the cotton plant are used. Cotton is in harmony with the environment today than ever before. Invention of gin, development of *Bt*-cotton, etc. are man-made evolution which helped cotton to sustain productivity and global competitiveness. The success story of cotton is that of natural and man-made evolution of sustainability of cotton production and processing over the centuries in the world. The article provides a fascinating glimpse into the evolution and sustainability of cotton crop over the centuries around the world.

1. Current Status of Cotton in Textiles

Cotton is a premier textile fiber and one of the most competitive crops in global agriculture in 35-36 mha annually and the commodity enjoys a share of 35-40% in the total fiber use in clothing textiles, apart from 9-10% in technical textiles. In the global textile markets, cotton enjoys high patronage. After China, India commands the status of being the second largest textile industry that is a strong and growing power on the world stage. The biggest challenge facing the textile industry is not only the high price of cotton for not merely the large cotton producing countries, but much more so for the importing countries for conversion into textiles and garments for export after ingenious value additions in color, texture and style. The other problems for the importing countries is also dependence on more than a few suppliers of raw cotton to use in their industry for spinning, weaving and garmenting before shipping textile goods to global markets, where competition has to be faced on the basis of superiority of the brand in terms of quality as well as price. This will require new initiatives and incentives from the governments to promote the global competitiveness in the textile world and it also depends on the ability of the spinners in textile producing countries to outsource and secure the best raw material that will give the greatest advantage. In addition, the other factors are the availability of labor, energy, water and other infrastructural support to huge textile industries in India and China as well as other textile manufacturing countries. Due to escalations in cotton prices and other cost escalations in Industry, the yarn cost of various categories also gets accentuated leading to higher price of textile goods to the end-user customers. The prevailing business environment as a result of various factors mentioned above is impacting sustainability, survival and profitability of the industry. The affordability of the common man to continue using cotton clothing textiles may also be affected driving the users to polyester and other fibers, which may be more durable in relation to cost comparisons.

2. Cotton Production Factors for Reckoning

This scenario in the cotton and textile front throws a number of challenging questions such as the likelihood for planting higher hectares of area under cotton, the status and share of cotton in the national and global fiber market, future mechanisms and facilitations for proper price discovery of cotton, cotton

as a preferred raw material in certain categories of technical textiles and continued preference of cotton growers in case the raw cotton price boom subsides sooner or later. But given the escalations in cost of production due to increase in the various components of cotton production and having enjoyed comfortable price margins and profitability levels, the higher enthusiasm in growing more area under cotton in preference to next level of profitable crops may not be sustained unless incentives exist in various ways.

In fact there are countries in Africa and Asia (Afghanistan), where cotton production has not received enthusiastic interest or have become unattractive and unsustainable in the globally competitive era in which accusations of unfair play have been made against certain countries deliberately causing price distortions. African countries have better potential for cotton growing in enhanced area and securing enhanced yield levels with upward mobility of total share to global production levels, but many factors so far known and still un-spelt require consideration by all those who hold a stake in the cotton and its rising consumption in future.

3. Cotton Yield Potential and Scope in India

Also there are cotton majors like India, which is just half way mark in reaching the yield levels of USA, China, Turkey, etc. and far below that of Australia and Israel, and immense possibilities of boosting or achieving great leaps in overall production is possible. If one takes into consideration, the yields reported under a telephone system of cultivation with hybrid H-4 in late 1980s at 8970 kg ha^{-1} seed cotton (almost equal to 2990 kg lint ha^{-1}), or the competitive and progressive Indian farmers in Gujarat, Madhya Pradesh, Andhra Pradesh, etc. obtaining 1600-2000 kg lint ha^{-1} on more or less regular basis, the fact that cotton yields can be maximized by superior management techniques and special attention could be understood. However, the national average yield is low for various reasons particularly inefficient means of cultivation by majority of farmers and also certain constraints imposed by nature. From an average yield of 300 kg lint ha^{-1}, less than a decade ago, the average yield has jumped to 560 kg lint ha^{-1} first and now in 2011-12 estimated to be only 31.2 m bales or 5.304 mt working out to an average yield of 510 kg lint ha^{-1} and 1020 kg seeds ha^{-1}.

4. Era of New Gene Technologies

The cultivation of BG-I and BG-II versions of hybrids on almost same pedigreed hybrids has definitely lifted the average lint yield from 300 to 510-560 kg ha^{-1}, but a further beneficial increase in yields with same technologies in the years to come depends on questions of favorable monsoons, prevailing bonanza of high prices and demand-supply equations in the textile industry in global markets coupled with the possible competition strengths from man-made and synthetic fibers, and non-occurrence of new pests or diseases or other problems. But India expects that the third generation *Bt*-hybrids with BG-III with more efficient check over the bollworms complex and stacked versions with Round-Up Ready Flex system for herbicide tolerance are likely to be offered in 2012 or 2013, scope for further leap forward in production and average yields can be expected.

A mere 100 kg average yield increase ha^{-1} from the present 10.6-11 mha can bring about a production increase of one mt lint over the existing level, making up for a new national average of 610-660 kg lint ha^{-1}. India with better extension approach in the new circumstances can aim to get a jump in present average by 200 kg lint ha^{-1} by 2015-16 by achieving saturation of the entire area under cotton with the newly coming gene technologies leading to a production of 7.20 mt and average yield of 720 kg ha^{-1}. This would also enhance the production of cotton seed to 14.4 mt and cotton seed yield to 1440 kg ha^{-1}. India will add to global production of cotton lint by 2-2.4 mt and without taking any consideration of other countries, through India's contribution alone, global output will touch within the range of 29-30 mt. Some basic data are presented in table 1 and 2.

Table 1: Top ten countries in global production (2009-10)

Country	Million bales of 480 lb each (227 kg)
China	32
India	23.5
USA	11.7
Pakistan	9.8
Brazil	5.5
Uzbekistan	4.4
Australia	1.8
Turkey	1.7
Turkmenistan	1.2
Syria	1

5. Positive Expectation from National and Global Scenario

Thus cotton production, consumption in textile industry and export for 2011-12 are projected higher than ever so far by the ICAC release of March 2011. There are seven segments that make-up global cotton industry- farms, gins, warehouses, merchants, cooperatives, cottonseed oil mills, and textile mills and a plethora of sub-sectors for further processing and delivery to consumers and also take back used textiles for reconversion or for other uses. The cotton industry contributes significantly to global economy besides in top ten major cotton producing

Table 2: World demand and supply situation of cotton (mmt) (year beginning August, 2001)					
1	2	3	4	5	6
2003-04	10.48	20.96	21.74	7.24	8.71
2004-05	8.71	27.00	23.58	7.75	11.62
2005-06	11.89	25.68	24.99	9.73	12.65
2006-07	12.65	26.79	26.45	8.10	12.91
2007-08	12.91	26.05	26.38	8.36	12.68
2008-09	12.68	23.43	23.48	6.55	12.75
1: Year; 2: Beginning stock; 3: Production; 4: Consumption; 5: Exports; 6: Ending stock					

countries and 90 other minor countries apart from non-cotton producers, but cotton-user countries. The massive crop of 35-36 mha of cotton in the world and nearer to 11 mha in India provides livelihoods for many and affluence for the most entrepreneurial in the business of cotton production, trade, processing, textiles and finished goods distribution apart from cotton seed utilization industries.

6. Sustainability of Cotton Production

The success story of cotton is one of natural and man-made evolution of sustainability of cotton production and processing over the centuries in the world.

'Cotton: King of Crops in Georgia, USA' provides an interesting insight into cotton crop and the products of the cotton plant in the course of its evolution and crop adaptation. 'That Fluffy White Stuff' that is cotton, one of the world's leading row crops- farming, ginning, cottonseed oil milling, and textile mill processing, warehousing and selling of cotton has a special fascination for all sections of people.

The entire cotton chain consisting of various sub-sectors including textile industry crossing beyond apparels and garments and even technical textiles contributes significantly to global economy and provides employment for sizable proportion of the global population. Cotton also contributed to growth of a more civilized society. Cotton has an interesting history in the global economic scenario and yet continues to serve us in many surprising ways. Cotton has behind its steady growth 'a richly textured history'. For more than two centuries, from the time the upland (*G. hirsutum*) cotton was first planted in several parts of USA and elsewhere until the middle of last century, it was the most successfully grown commercial crop in the USA. The people especially in USA loved their 'homespun' cotton fabric. It was also an important export commodity from USA and India, especially to the textile mills in Europe and elsewhere; and later to China, Bangladesh, etc.

7. Evolution of First Cotton Gin

Eli Whitney, a Massachusetts teacher, revolutionized the cotton industry when he invented the labor-saving cotton gin while visiting Georgia in 1793. He called it a 'gin'- short for engine, and he claimed it. The gin replaced the work of 50 men! The gin simplified the process of separating the seeds from the cotton fiber or lint. The invention was considered so significant to cotton economy that the patent issued to Whitney was signed by the President of the United States of America- George Washington! It was learnt that he was witness to small poultry birds playing in the backyard happened to squeeze through narrow window pane rods leaving behind fallen feathers and the bird reaching the other side and it gave him an idea to develop a device for separation of the lint and seed from the seed cotton. Today we have developed large number of gin types for use in various situations and also on a commercial basis. One should understand the manual separation of lint from the seed to appreciate the importance of evolution of mechanical ginning technology.

8. Effect of Wars and Food Security Concerns on Cotton

The Civil War in USA and first and second World Wars and World Food Famines at different times severely had impaired cotton production in USA and other major countries. When peace returned after different wars, the scramble was on to find the increased lands, funds, livestock, seed, labor, and equipment to intensify cotton production again. Georgians in USA within fifteen years reached its first million-bale harvest of cotton in the state. In India also, after attainment of freedom from the British and losing an important cotton growing territory to Pakistan in 1947, the central and state governments started intensive plans to extend the area under cotton and increase the outputs unit^{-1} ha in successive Five-Year Plans. This is with two intentions namely to increase the cotton production to meet the demands of highly established textile industry and also to provide a commercial crop to farmers to ensure adequate farm income for sustainability apart from fiber security. In recent past, bio-fuel producing crops have encroached into the normal cotton area in USA, etc. but with soaring price levels for cotton in the last three years such diverted areas and some new areas are also brought under cotton.

9. Promotion of Cotton Use

Cotton fabric became America's favorite. Part of cotton's comeback popularity can be attributed to the demand for denim jeans or 'levis', as work clothes for miners during the 1849-1860 California Gold Rush. The denim culture also spread rapidly among the Indian youth both men and women gradually in the 1980s. Mahatma Gandhi influence and the first generation congress leaders' culture and the rural preferences for cotton dresses for a hot and humid country like India also

enhanced the popularity of cotton use, its preference and prestige. American governments, their people and later the Cotton International USA have always promoted the production of cotton and encouraged its consumption as a result of which in the last 20-30 years alone cotton use has been maintained at a sustainable high level with various cotton promotional programs and activities. For the third time in history, the demand for cotton products, especially denim and other cotton clothing and household goods, has returned cotton to the status of most popular American fabric. Today in USA, China and India, the domestic cotton production and consumption are increasing and in addition, overseas sales of yarn, denim and other cotton value-added products are in the billions of dollars and rising.

10. Cotton as a Tool for New Inventions

Inventors used cotton to produce their big ideas and inventors turned to cotton when searching for materials to produce their inventions. There are several examples. Thomas Edison lit up the country by using cotton filament for the light bulb; Samuel Morse communicated with people all over the world by insulating the telegraph with cotton; Wright brothers stretched cotton muslin over the wings of their airplanes that made the first sustained flights; cotton was the magic cord for tires that put America on wheels; and cotton linters- the short fuzz on cottonseed- were the important source of cellulose, which is used to make smokeless gun powder.

11. Boll Weevil Occurrence and Eradication in USA

Of all the dreaded, destructive insects in North America, none was more feared in the cotton belt than the boll weevil. It first entered the United States from Mexico around 1900, through Texas, and made its way across the US to Georgia. The little grey beetle, with its long snout, feeds on the newly-developed cotton boll, destroying its growth. In Georgia, the boll weevil was responsible for millions of dollars worth of damage. Historians believe the weevils' destruction was one of the major causes of the beginning of the economic depression in the South. Consequently, it is considered one of the reasons for mass migrations of laborers to Northern cities. By 1978, Georgia's cotton production was at an all-time low. Cotton's destruction by the boll weevil and the onset of synthetic fibers, especially polyester- (remember the leisure suit) almost brought the cotton industry to its knees. But for the third time, the industry fought back. The Boll Weevil Eradication Program, begun in 1987, made it possible for Georgia to declare the boll weevil an economically insignificant pest in 1994. A vigilant maintenance program is in place today and it guards against the return of the boll weevil. The sustainability of cotton production was again ensured by man-made efforts and interventions.

12. Cottonseed Oil and Protein with other By-products

Cotton though primarily considered as a fiber crop is also an important oilseed (made edible by refining) and livestock feed crop besides several other by-products. In fact 100% cotton, 100% usable! All parts of the cotton plant are used. After harvest, the lint is separated from the seeds and baled for use in textiles. Cottonseed is crushed to make oil, which is used in shortening, margarine, cooking oil and salad dressing. Cottonseed meal and hulls are used to make livestock feed. Cellulose from cottonseed linters (linters are the short fuzz left on the cottonseed hulls after the ginning process) is used to make ice cream, paper currency, photography papers, plastics, and mattress and auto cushion coverings. The remaining crop residue, stalks, and leaves, are plowed under to enrich the soil. Nothing is wasted. In India, where it was primarily used for thatching rural households and also for use as fuel for cooking food, CIRCOT, Mumbai in the last two decades has demonstrated more economically attractive uses by growing mushrooms of the dibble kind and also making wooden (timber) boards virtually for any construction work especially attractive conference halls and furniture. Over all, if every cotton farmer in cooperation with various stake-holders makes sincere efforts and effective utilization, cotton production is highly sustainable and competitive with most crops in ensuring better returns.

13. Evolution of Technology for Gossypol-free Edible Cottonseed Oil

Although, cotton is mainly cultivated for its lint, the cottonseed is one of the important by-products. Processed cotton fiber consists of more than 99% cellulose, after the refining and processing of cotton lint through chemical and thermal means. Cotton lint contains no detectable nitrogen, and hence contains no DNA or protein. In fact, because of its very low allergenicity, it is widely used in pharmaceutical and medical applications as well. On the other hand, cottonseeds can be toxic if ingested in excessive quantities because of the presence of anti-nutritional and toxic factors including gossypol and cyclopropenoid fatty acids including dihydrosterculic, sterculic and malvalic acids. Cottonseed is processed to obtain four major products, namely oil, meal, hulls and linters. After extensive processing to remove toxicants, especially gossypol and its derivatives, the oil and linters are used as premium vegetable oils and as cellulose dietary additives for human consumption, respectively. Traditionally, whole cottonseed is used as cattle feed in India. However, the increase in demand of edible oils has necessitated processing of cottonseed for its oil. Therefore, cottonseed oilcake/meal after extraction is now used as cattle feed. The extraction process also helps in removing gossypol to a large extent.

Bt-cotton cultivation is a major recent discovery for the protection of yields from serious pests, and adoption of this new gene technology in India has resulted in a production increase by approximately doubling the total cottonseed output to cross some 10-11 mt and in the global level to cross 55-60 mt of cottonseed. This is another case of sustainability of cotton through possibilities for income enhancement to the farmer.

In the Texas AMU, USA efforts are on to breed cottons using RNAi technology to remove gossypol development in seeds and therefore oil without gossypol can be extracted without resorting to chemical removal of gossypol and saving costs. Further, the plants will have gossypol in other plant parts ensuring its excessive non-vulnerability to certain pests, while keeping the seed only free of gossypol; this would ensure better sustainability and providing safe source of cottonseeds for snack foods.

14. Sustainability through Ingenious Pest Management

Cotton is now in harmony with the environment, even though it has acquired a name for its notoriety to spoil the environment by becoming the largest user of poisonous pesticides to quell the extreme harm caused by insect-pests, diseases and rodents in the USA, India, Pakistan, China and elsewhere. Earlier, the boll weevil became a great menace in certain important cotton growing states of USA and growers had to use high amount of pesticides. Sustained eradication program was carried out in 1960s through 1970s as a result of which, the occurrence was highly controlled by various means and the cotton growers used 40-90% fewer pesticides thereafter.

Subsequently, the *Helicoverpa armigera* known as the American bollworm was the 'robber no.1' of the cotton plant eating away a major part of the economic product- the developing bolls of the cotton plant that carries the seeds with lint. The aggressive use of very toxic pesticides by the USA farmers, Chinese farmers and to abusive levels by the Indian farmers created pollution problems affecting the environment seriously. The excessive use of pesticides caused resistance in *Helicoverpa*, which has several instars and large number of alternate hosts resulted in emergence of secondary pests such as the white fly in India causing grave threat and concern for continued cotton cultivation. Tamil Nadu state cotton area has declined by more than 60% compared to 1970s. In Punjab also there was decline in cotton area and production. However, some other states like Gujarat, Andhra Pradesh, etc. recorded rise in area after the adoption of IPM practices popularized in all states and under the Technology Mission on Cotton operated by the Government of India jointly with all the cotton growing states.

15. Genetic Modification

Genetically modified (GM) cotton was developed to reduce the heavy reliance on pesticides. *Bacillus thuringiensis* (*Bt*) bacterium naturally produces a chemical harmful only to a small fraction of insects, most notably the larvae of moth and butterflies, beetles and flies, and harmless to other forms of life. The gene coding for *Bt*-toxin has been inserted into cotton, causing cotton to produce this natural insecticide in its tissues. In many regions, the main pests in commercial cotton are Lepidopteron larvae, which are killed by the *Bt*-protein in the transgenic cotton they eat. This eliminates the need to use large amounts of broad-spectrum insecticides to kill Lepidopteron pests some of which have developed pyrethroid resistance. This spares natural insect predators in the farm ecology and further contributes to non-insecticide pest management. In 2002, the *Bt*-cotton BG-I with cry1Ac and subsequently BG-II cry2Ab + cry1Ac were released putting a great relief system to the cotton farmers and in fact the transgenics became popular and widely adopted in most major countries making the attack on cotton by *Helicoverpa* and even other bollworms including pink bollworm into a rarity in cotton crops. Thus cotton acquired a new fame as the much reduced user of pesticides so far in this century. *Bt*-cotton hybrids in India have covered over 9-9.5 mha or about 90% of the total area under cotton.

16. Sustainability from New Pests

Now the new problems of sucking pest resistance in certain areas and the mealy bugs particularly and also the whitefly-induced leaf curl virus of cotton in the north zone states require similar attention so as to make cotton cultivation more profitable with the least environmental pollution. The R&D units of various seed companies of MNCs are intensively researching to find out a gene technology for sucking pest resistance as in the case of bollworms so that further sustainability against new pests could become a reality.

17. Integrated Soil, Water and Nutrition Management

In cultivation also, farmers in USA have adopted tillage practices to minimize soil erosion. Cotton takes few nutrients from the soil because it is grown primarily for the fiber found in the boll part of the plant. As noted before, the stems and leaves are ploughed back into the soil in USA and many countries. Even the meal produced from cottonseed, as feed for livestock, finds its way back to the soil as fertilizer. The cotton plants' deep-rooting pattern makes it very efficient utilizing moisture from the soil and makes it possible to produce top yields with half the water required by many other crops. Drip and sprinkler irrigation systems apart from other agro-techniques of rainwater harvesting and reuse for cotton, etc. have added to the sustainability of production. Cotton truly is in harmony with the environment today better than ever.

18. Rare Events in the Evolution of Cottons

Occurrence of the First and Rare Linted Mutant in *Gossypium*: first the evolution through discovery of an early spontaneous mutant with spinal lint fibers in *Gossypium* species and further manipulation by humans at the very early stage of evolution and development of cultivation-worthy cotton plants probably occurred in the diploid level leading to the Asiatic or old world cotton species, *G. herbaceum race africanum* and its subsequent race development in the species and also divergence into *G. arboreum*. The wild species remained lint-less except for fuzz and therefore the very rare event of a mutation in a remote place and its resultant mutant with spinnable lint and spread all over Asia from African origin is of great significance in the art of plant breeding.

19. Spinnable Lint Hairs and Charka

The cotton lint hairs are unique without a parallel in the plant kingdom being made of one of the purest forms of cellulose (95% and above) in nature. The discovery of the property of twist in lint hairs of cotton making it fit for spinning is due to human ingenuity in discovering ways and means for leading towards higher order civilizations through the use of hand spinning and again with Charka, which is an invention of ingenuity.

20. Rare Inter-specific Hybridization and Subsequent Events

It was another miracle that the early African version of the Asiatic diploid cotton *G. herbaceum* race *africanum* by chance hybridization with an American wild species *G. raimondii* and produced a sterile hybrid. Another chance event of doubling of the chromosome number of the diploid inter-specific hybrid led to the emergence of the allo-tetraploid cotton. This hybrid polyploidy in due course evolved into *G. hirsutum* and *G. barbadense* species with mutual introgressions over time in West Indies, South and North Americas and also Egypt-Sudan region and they were named as American upland cotton and Egyptian cotton, respectively. Together, they are considered as New World cottons. The monophyletic emergence of the two allo-tetraploid cottons was also proved by researchers in the last century through experimental proof and hypothesis. With genomics of *Gossypium* species being explored intensively under the influence of the International Cotton Genome Initiative USA, there will be further applications of biotechnology and genetic engineering to make cotton production and use more competitive, sustainable and popular. The *hirsutum* cotton has become the predominant global cotton today contributing to as much as 94-95% of total world cotton production and only about 1% comes from the Asiatic cottons and the balance of 4% may be from the extra-long staple *barbadense* cotton. These events resulted in the evolution of cottons with superior staple and other fiber properties in present day cottons.

21. Evolution of Spinning System and Fiber and Yarn Testing System

From the hand spinning and manual weaving to machine spinning and modern weaving practices, what it is today is a great and successful story by itself. In the last five to six decades, the yarn manufacture using synthetics has revolutionized the spinning technologies and speed of machinery. In keeping with such developments, apart from improved versions of ring spinning, newer machinery such as open-end or rotor spinning, air jet spinning, friction spinning, compact spinning, etc. have been developed and used in large measure. Consequently, from individual instrument testing of different fiber and yarn properties, integrated fiber quality testing machines like the HVI and user testing machines and fiber classing techniques have been developed and used in tune with fastness and perfections in spinning technologies. Fiber parameter requirements for newer spinning technologies have also undergone considerable changes and precision and so also the determinants of yarn perfections for various end-uses.

The yarns spun on the compact spinning system are characterized by higher tenacity, higher elongation at break, smaller mass irregularity measured at short segments, and significantly lower hairiness in comparison with yarns spun on the conventional ring spinning frame. For the long-staple Egyptian cotton varieties, the breaking force or single yarn strength of the compact yarn (with a nominal linear density of 15 tex spun from long-staple cottons) was 17.63% higher than the conventional ring spun yarn, while for the extra-fine carded yarns spun from extra-long staple varieties (around 7%). This means that, the compact spinning system is more useful for long-staple cottons and coarse and medium counts than for the extra-long staple cottons and finer counts, as per a report of the Cotton Research Institute in Egypt.

22. New Developments in Ginning

Although Eli Whitney's 1793 invention to remove seeds from cotton revolutionized the economy of southern states, today's standard gin equipment still ejects some valuable fiber along with the trash- leaf particles, sticks, stems, seed coat fragments, grass, and bark that must be removed. Most cotton is processed with the same machine sequence regardless of its needs, and as a result, good fiber is sometimes wasted. To resolve this problem, Anthony developed and patented several equipment and software technologies. The research culminated in a process-control system known as 'IntelliGin', patented by Anthony and

Richard K. Byler, an ARS agricultural engineer. The research unit's best-known invention, it is now found in about 80 gins. With this technology, ginners can prescription-process cotton, improving its quality and increasing its value and profitability. An independent study found that IntelliGin can increase the net value of a bale of cotton by US$ 8 for farmers.

The ginning equipments and machinery have also undergone many modifications including pre-cleaning systems so as to provide cleaner cotton to the spinning industry for better yarn and fabric production. Thus the competitiveness of cotton with synthetics and other man-made fibers has been sustained by all these developments, establishing the superiority of cotton as a premier textile fiber.

23. Plagued by Diseases and Evolution of Management Techniques

Diseases like bacterial wilt, black arm and fungal diseases posed a threat to successful cotton cultivation. In 1901, Peru's cotton industry suffered because of a fungus plague caused by a plant disease known as 'cotton wilt' or more correctly, 'Fusarium wilt', caused by the fungus *Fusarium vasinfectum*. The plant disease, which spread throughout Peru, entered plant's roots and worked its way up the stem until the plant was completely dried up. Fermín Tangüis, a Puerto Rican agriculturist who lived in Peru, studied some species of the plant that were affected by the disease to a lesser extent and experimented in germination with the seeds of various cotton plants. In 1911, after 10 years of experimenting and failures, Tangüis was able to develop a seed which produced superior cotton plant resistant to the disease. The seeds produced a plant that had a 40% longer (29-33 mm) and thicker fiber that did not break easily and required little water. The Tangüis cotton, as it became known, is the variety which is preferred by the Peruvian national textile industry. It constituted 75% of all the Peruvian cotton production, both for domestic use and apparel exports.

The New Wilt or Adilabad wilt (quick wilt and slow wilt) that caused panic among cotton growers and hybrid developers in about the 1970s-1980s in certain hybrids and certain germplasm in India was traced to specific genotypes, which under certain adverse environments and physiological constitution succumbed to the wilt and is still of unknown etiology. The loss was tremendous and the damage to fiber quality was immense. The identification of avoidable or susceptible parents and germplasm resulted in confidence building measures to overcome the disease incidence thereby ensuring the sustainability of cotton production.

24. Weeds as Serious Pest and Management

There are a large number of weeds affecting cotton in various regions in India and all over the world. Under weed infested conditions and their competition to cotton for water, nutrients and growth, cotton yields are suppressed significantly and weed management by various means cost anything from 20 to 30% of cost of production of cotton in various soils. Manual, cultural, mechanical and chemical weeding had been adopted singly and in combination to remove the weeds and enable higher cotton production. In the last one decade or more in many advanced cotton growing countries, genetically modified Glyophosate resistance that is Round UP Ready herbicide tolerance technology has been adopted to kill weeds and protect cotton plants. The newer technology that is termed as Round UP Ready Flex is likely to be adopted in India in the next couple of years or so. This technology promises cleaner cotton fields free of all weeds with flexibility of applications of the herbicide all through the crop season at lower cost, circumventing labor shortage for otherwise manual weeding and also better cotton crop yields and returns. This is a man-made effort for sustainable cultivation of cotton.

25. Organic Farming of Cotton

This is also gaining prominence in India and several parts of the world, but for various reasons, its contribution to production is very insignificant and not even 1% of total world output. If all cotton could be produced completely adopting 100% organic methods to the present level of production, it will be the most preferred by all sections, the producer, manufacturers and consumers alike. However, as we see it today, this is an unlikely event. It may be better useful for sustaining cotton use, but not for sustainability of production of the order of 27-30 mt of lint coupled with 54-60 mt of cottonseed by adopting only organic methods of production and processing.

26. Cotton Genome Sequencing Effort

A public genome sequencing effort of cotton (International Cotton Genome Initiative, 2002) was initiated in 2007 by a consortium of public researchers. They agreed on a strategy to sequence the genome of cultivated, tetraploid cotton. 'Tetraploid' means that cultivated cotton actually has two separate genomes within its nucleus, referred to as the A and D genomes. The sequencing consortium first agreed to sequence the D-genome relative of cultivated cotton (*G. raimondii*, a wild Central American cotton species) because of its small size and limited number of repetitive elements. It is nearly one-third the number of bases of tetraploid cotton (AD), and each chromosome is only present once. The A genome of *G. arboreum* would be sequenced next. Its genome is roughly twice the size of *G. raimondii*. Part of the difference in size between the two genomes is the amplification of retrotransposons (GORGE). Once both diploid genomes are assembled, then research could begin sequencing the actual genomes of cultivated cotton varieties.

This strategy is out of necessity; if one were to sequence the tetraploid genome without model diploid genomes, the achromatic DNA sequences of the AD genomes would co-assemble and the repetitive elements of AD genomes would assemble independently into A and D sequence, respectively. Then there would be no way to untangle the mess of AD sequences without comparing them to their diploid counterparts.

The public sector effort continues with the goal to create a high-quality, draft genome sequence from reads generated by all sources. The public-sector effort has generated Sanger reads of BACs, fosmids and plasmids as well as 454 reads. These later types of reads will be instrumental in assembling an initial draft of the D genome. In 2010, two companies (Monsanto and Illumina), completed enough Illumina sequencing to cover the D genome of *G. raimondii* about 50x. They announced that they would donate their raw reads to the public. This public relations effort gave them some recognition for sequencing the cotton genome. Once the D genome is assembled from all of this raw material, it will undoubtedly assist in the assembly of the AD genomes of cultivated varieties of cotton, but a lot of hard work remains.

The cotton breeders are waiting for new information based on this project for directed improvement of cotton productivity, novel attributes, the fiber quality and also probably the edible oil quality so that further sustainability of cotton production is ensured for the future and also manipulate cotton to compete equally with synthetic fibers. The scope for breeding cotton as a further man-directed evolution as an exclusive oilseed plant with naked seeds, without gossypol and higher content of oil (35-40%) or higher oil and protein than at present since the energy going for lint development can be channelized for the fat and protein.

27. Future of Cotton Breeding for Superior Sustainability

The following are considered essential in R&D and extension to ensure superior sustainability of cotton:

a. Genetic modification for drought tolerance without sacrificing yield since globally 50-60% of the cotton is grown in dry land conditions all over the world with predominance of unfavorable soils and aberrant weather conditions.

b. Genomic information should be generated that can be relied upon for genetic modification of fiber properties and ginning out-turn.

c. Genomic information should be generated that can be relied upon for genetic modification of oil content in seed and its quality profile, and also quality of protein.

d. Lasting solutions against sucking pests especially the jassids, whitefly and mealy bugs and also the whitefly-vector mediated leaf curl virus disease.

e. Though large cotton growing countries like USA, Australia, etc. have been successfully adopting mechanized harvesting of cotton for long, India, Pakistan and China would be befitted by developing suitably modified plant conformations and evolution of harvesting machinery suited to their respective conditions would help in reducing the cost of production and improving the productivity to higher levels.

f. Breeding work on plant types like short sympodia *hirsutum* and short season cottons with stable performance for reproductive attributes, boll weight and staple length with high ginning out-turn may also be given priority.