INTERNATIONAL COTTON ADVISORY COMMITTEE
1629 K Street NW, Suite 702, Washington, DC 20006 USA
Telephone (202) 463-6660 • Fax (202) 463-6950 • e-mail: rafiq@icac.org

Cotton Tomorrow[1]

M. Rafiq Chaudhry
Head, Technical Information Section

Cotton production and research has not been the same ever and neither it is going to stay as it is today. Efficient management and as well as the most economical use of resources demand that research efforts be planned today to meet tomorrow's needs and challenges. This is what this paper is all about. However, there are many areas of research and production where significant changes are expected to occur but only five areas of high priority are discussed here with emphasis on the current situation and how they will look like in the long run. The five areas of research discussed are yield, breeding, insects control, genetic engineering and fiber quality.

Yield

Real yield in cotton is an outgrowth from the epidermis of the seed coat. Components of yield determination are very complex. The most commonly used variables to determine yield are number of plants/unit area, number of bolls per plant and boll weight which is again composed of seed and lint. Heavier bolls may not produce higher quantity of lint due to bigger and heavier seeds. Weight of lint produced per unit area is a better estimate of yield which may not be strongly affected by any single above mentioned components of yield. Such a complex nature of yield estimation and poor understanding of its genetic control makes it difficult to improve yield.

Cotton yields have undoubtedly increased in the world particularly since 1950 to 1991. In this period, the average increase in yield is estimated at 2% or 8 kg/ha/year. But since 1992/93, the world average yield has shown slow growth and the increase is also not steady. In fact, increase in the world average has come from a few countries; mainly Brazil, China (Mainland) and Turkey. Most other countries do not show any increase in yield since 1992/93.

The cotton plant is indeterminate in nature and thus has a huge potential to produce higher yield. Genetic potential and recoverable potential remain apart and it is the ultimate target of all cotton production research in the world to improve recoverable potential and move it closer to the genetic potential. Recoverable potential is not a heritable character while genetic potential is. Higher yields achieved in the world have come from agronomic and protection improvements and not from the ability of the plant to produce higher yield. Indeterminate nature of the cotton plant awards this plant with the potential to produce much higher yield than achieved today.

All over the world, breeders have claimed that increases in yields have come from breeding high yielding varieties which is not true. Breeders are the largest team of researchers in most countries and commonly claim the credit of increasing yields. In fact, it is the agronomic management which has brought increases in yields. Breeders' achievements are no doubt tremendous in many areas like heat tolerance, short stature, fiber quality, etc., but their claim to develop higher yielding varieties is questionable.

The data shows that the average yields in most countries are not increasing. One should not expect any significant increases in yields unless a new technological development (of the magnitude of previous ones) is achieved. The focus should be to reduce cost of production and improve quality of cotton already produced.

Breeding

Breeding should be a science based practice but so far it has been generally employed as an art of selecting the most suitable plant that ultimately becomes a variety for any set of growing conditions. With the advent of

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genetic engineering becoming more accessible, the art of breeding is going to change and become more scientific. Breeders will have to share the credit for the so called development of higher yielding varieties with biotechnologists. Contributions from genetic engineering will be undeniable. Conventional breeding will continue to play the dominant role but specific changes through insertion of specific genes, molecular marking of characters, enhancing the expression of a particular gene, blocking the expression of a particular gene, etc., will be so prominent that breeding will have to acknowledge contributions from the science of genetic engineering. Breeding for new varieties will change from a field work to field plus lab work.

The other major change which is going to happen is the privatization of breeding for suitable varieties. The breeding work has already been privatized in the USA and the USDA breeders are responsible for only developing germplasm material. Private breeding is also practiced in India where commercial cotton hybrids are developed and distributed by many private companies. Almost four million hectares have been planted under hybrid cotton in India in 2003/04 and all the planting seed was developed, multiplied and distributed by private companies. Breeding must go to the private sector and countries who are in the process of strengthening their breeding programs should not make the mistake of federalizing their breeding programs.

Future changes in breeding also require closer working with seed production systems. The latter may be successful without the former but breeding cannot stand-alone as has been the case in Colombia. Good varieties developed by breeders are easily lost in the poor seed production system. This fact is better realized today than it was yesterday. The privatization of breeding will automatically take care of the amalgamation of both disciplines. It is going to happen and the sooner we do it the better it is.

Colombia depends entirely on the varieties developed outside and a large quantity of the planting seed is still imported. Local breeding program must be strengthened to develop new varieties locally which are suited to the local conditions. But, the breeding program will fail to achieve suitable varieties if the seed production system is not fixed accordingly. Both have to go together and only then Colombian growers can have Colombian varieties.

Insect Control

Insecticides have become an integral part of the cotton production systems in the world. One cannot think of having a successful cotton crop without the extensive use of insecticides. Without going into the history of introduction and adoption of insecticides, one must admit two important facts about insecticides.

1. Insecticides were quick in action and they killed insects as they were sprayed.
2. Insecticides were cost effective.

These two factors encouraged governments to promote the use of insecticides. It is also true that consequences of insecticides use have been severely underestimated. Many countries, where Australia and China (Mainland) are on the top of the list, have suffered due to these consequences. Both were able to contain the problem and have successfully recovered from the problem. The cost of insect control continues to increase to unacceptable levels. The already slim margin between the cost of production and the price received by farmers cannot bear this increase for a long time.

Was it a right decision to adopt insecticides? No, it was not. If governments had a chance to go back and decide once against that whether or not to use insecticides, they will decide differently. This is what has been experienced in the adoption of transgenic cotton. Strong cautions regarding development of resistance to the toxin and impact on the environment emerge from the lessons learnt from insecticides use.

The cotton production systems cannot afford continuous increase in the cost of insecticides use for many reasons. But, the most fundamental reason is the cost of insecticides including their spraying. Guatemala used to produce more than three times the area Colombia now plants to cotton production. Guatemala was also one of the highest yielding countries in the world during 1970s and early 1980s. But, it had to quit cotton production due to high insecticides use.

Many countries can still afford to produce cotton at a yield level of less than 300 kg/ha because low insect control costs permit them to do so. Syria is the best example on insecticide use in the world. In Syria, cotton is grown on the average on 200,000 hectares and the average lint yield has been over 1,000 kg/ha since 1991/92. The average yield in 2002/03 was 1,402 kg/ha and the latest ICAC forecast suggest that the average yield from 206,000 hectares will be 1,387 kg/ha in 2003/04. And, yet only 2% of the total area is sprayed with insecticides, 98% area does not get any insecticide treatment. The average number of sprays across the border in Turkey in the Cukurova region is 8-10 sprays per season. If Syria can grow cotton without insecticides, why not other countries?

The successful future of cotton lies in the elimination of insecticides. How to achieve that is a challenge but it is certainly not impossible. Ultimately, cotton will be grown without insecticides. Farmers cannot grow cotton and expect to make money if they continue to use insecticides as has been during the last 3-4 decades. The good thing is that the problem has been realized and now the issue is to find ways and means to achieve it. The growth in insecticide use has already slowed down in most cotton producing countries. Insecticides will be eliminated and ultimately cotton production systems in the world will be insecticide free or will have the least use of insecticides.

Genetic Engineering

Bt Gene in Cotton

Breeding of crops has being going on even before the recognition of genetics as a science. The breeding principles are still the same as were prior to the discovery of the fact that genes control characters and they are inherited under certain principles. Discovery of the DNA structure opened the field of gene manipulation. In the early 1980s, scientists discovered how to transfer a piece of genetic material from one organism to other. The first transgenic tobacco plant was developed in 1983. A gene conferring resistance to herbicide (glyphosate) was transformed into cotton for the first time in 1987. The first transgenic cotton (cotton having non-cotton gene) with a Bt gene in it was developed in 1989. The Bt gene was extracted from the soil bacterium *Bacillus thuringiensis* and inserted into cotton. However, commercial production of Bt cotton started in Australia and the USA in 1996/97.

Once the Bt gene is inserted into the cotton plant, it is automatically transmitted to the subsequent generations. The presence of Bt gene enables the cotton plant to produce a toxin, which is as toxic to lepidopterans (scale-winged butterflies and moth) as an insecticide. The Bt toxin affects only those bollworms and budworms that have receptors in the midgut. The affected worms stop feeding and consequently die.

Cotton is one of the many crops that have been transformed. According to the International Service for Acquisition of Agri-Biotech Applications (ISAAA), transgenic crops were planted on 58.7 million hectares in the world in 2002/03. This shows 12% increase in the transgenic crops area over 2001/02. In 1996/97, all transgenic crops including cotton were planted on 1.7 million hectares. The area increased to 11 million hectares in the next year and 52.6 million hectares in 2001/02. The genetic engineering technology has been accepted in the world at a rate faster than any other technology in agriculture.

Transgenic Cotton Area

The transgenic cotton has been commercialized in 8 countries. They are Argentina, Australia, China (Mainland), India, Indonesia, Mexico, South Africa and the USA. Colombia also had some experimental plots in 2002/03. Indonesia planted only a few thousand hectares for the 2nd year in 2002/03 and India planted Bt hybrids for the first time in 2002/03. In India, the Bt gene (Cry1Ac-Bollgard) has been introduced only through commercial cotton hybrids and it is estimated that the three Bt hybrids were planted on 42,200 hectares in 2002/03. Herbicide resistant transgenic varieties are permitted for commercial cultivation in Argentina, Australia, South Africa and the USA. In other countries only Bt cotton has been approved for commercial production. 2002/03 was the first year of herbicide resistant transgenic cotton in Argentina, Australia and South Africa.

It is estimated that 22% of the world total cotton area was planted to transgenic varieties in 2002/03. Over 50% of the total area in China (Mainland), Mexico, South Africa and the USA was under Bt or herbicide resistant varieties in 2002/03. Australia had decided to cap the transgenic varieties area at 30% of the total area but the restriction will be lifted from 2004/05. Thus, the genetically engineered varieties area will not increase in Australia until 2004/05. South Africa and the USA seem to have utilized their potential for area to be planted to transgenic varieties. The same may be true for Mexico but China (Mainland) still has a potential to increase area under Bt varieties. In fact China (Mainland) has two types of genes available for resistance to the bollworms and budworms, Bt gene from Monsanto and a gene of local origin. Area under the locally developed transgenic cotton is increasing. Argentina commercialized Bt cotton in 1998/99 but, contrary to all other countries, the area under Bt cotton has not increased more than 10%. It seems that a higher technology fee compared to savings in insecticides and expected increase in yield is limiting the Argentinean cotton growers to expand area planted to Bt cotton. India planted Bt cotton only for one year and the trend in the increase is yet to be seen but similar problems could limit the adoption of Bt cotton in India where the cost of the planting seed is already high due to its hybrid nature. Indian growers may hesitate to make high initial investment on the Bt technology fee without looking at the crop condition and expecting significant increases in yields.

A number of characters have been transformed in many crops however; insect resistance and herbicide resistance are the most utilized among all crops. It is estimated that 75% of the 58.7 million hectares planted to genetically engineered varieties were under herbicide resistant character, 17% under Bt gene crop varieties, 8% under Bt + herbicide resistant (stacked form) varieties and less than 1% under other forms of genetically engineered characters. However, in cotton most countries have adopted Bt varieties and not the herbicide resistant varieties. U.S. is an exception, where 50% of the transgenic cotton area was planted to herbicide resistant varieties, 48% to stacked gene herbicide and insect resistant varieties, while only 2% was planted to Bt varieties in 2002/03.

Many more countries are interested to adopt Bt gene varieties. But, they cannot do so because a private company owns the genes inserted into cotton and countries are legally bound not to insert the Bt genes into their own varieties and starting using them. Countries have to pay the technology fee to owners of the genes, which is limiting the spread of the technology particularly to developing countries.

Bollgard II Cotton

In addition to the transgenic Bt cotton and herbicide resistant transgenic cotton, two new technologies are on the way to be commercialized, Bollgard II from Monsanto and VIP from Syngenta. Monsanto received the regulatory clearance for its Bollgard II insect-protected cotton technology on December 23, 2002 clearing the way for large-scale use of the second Bt gene. The crop season 2003/04 will be the first year that Bollgard II will be available to growers in Australia and the USA. The Bollgard II gene has been inserted in the existing transgenic Bt varieties so the Bollgard II varieties will have a dual gene resistance mechanism. The technology fee in the USA for Bollgard II will increase to US$99/ha as against US$79/ha in case of Bt or only Bollgard gene.

The Bollgard II technology has used the same soil bacterium as in the case of Bollgard but the gene is different. However, the Bollgard II technology has some additional objectives to achieve over the Bollgard technology.

- The basic objective of finding the 2nd Bt gene has been to delay the development of resistance to the Bt toxin. Insects could develop resistance to one gene faster compared to two genes working in the same genotype.
- The Bollgard II gene is effective against more pests compared to the Bollgard cotton with one Bt gene. The quantity of the toxin has increased in Bollgard II thus providing better protection against the target pests.

The two Bt genes are inherited independent of each other and there is no negative interaction between the two genes. Bollgard varieties will continue to be available but plans are to replace them with Bollgard II varieties.

VIP Cotton

The VIP cotton is an alternate technology to control insects that are controlled by Bollgard or Bollgard II. The difference is that the VIP cotton contains a vegetative insecticidal protein (VIP) that controls target insects through a novel mode of action. The Syngenta Group Company discovered the VIP protein in 1994. The VIP protein is an exotoxin, but still derived from the same soil bacterium *Bacillus thuringiensis*. As an exotoxin, the VIP protein is structurally, functionally and biochemically different than Bt d-endotoxins. The VIP protein is expressed in the entire cotton plant, including the floral parts, to provide protection against the target species. When pest larvae feed on VIP cotton, the protein is ingested and causes the larvae to stop feeding and die soon.

The trials conducted in 2002/03 revealed that the VIP cotton is able to resist a variety of lepidopterans and produce significantly higher yield over its respective non-transgenic variety. The VIP cotton is not currently registered for use in any country, but may become available for commercial sale in 2004/05.

Dow AgriSciences has announced their dual Bt gene product called WideStrike which contains Cry1Ac and Cry1F. Bayer has announced their Liberty Link cotton which has an expanded tolerance to herbicides. Both could also be released at the same time.

Future

Genetic engineering has a very bright future. The products developed involving the genetic engineering technology may come and go but the technology is going to stay. Unlike many other technologies, it is not a consumable technology. Currently, the nature of products coming out of this technology are focused only in one direction which is resistance to insect pests but the technology has tremendous applications. The Technology Protection System was not commercialized due to known reasons but the ability of researchers to activate and inactivate gene expressions at will for the plant to produce seeds which may or may not germinate is a proof that technology has uses beyond ransgenic traits already utilized.

The current system of expression in the whole plant, while satisfactory for the current transgenic traits, may be replaced by regulated expression for other transgenic traits. Methods of regulated expression include: tissue specific, temporal specific, generation specific, etc. The tissue specific transgene expression derives from the use of tissue specific promoters that allow gene expression in specific tissues. These will be highly useful with output traits such as fiber, oil or protein modification that improve the value of the harvested product, since gene expression in non-seed tissue would be superfluous and may be even deleterious.

After the first commercial production of transgenic cotton in 1996, a limited number of new products have been adopted on commercial scale and also not many new products have been announced. This reflects the industry's reluctance to generate farmer enthusiasm for products when commercial approval is years away. It is estimated that US$4.4 billion were spent on biotechnology research in the private and public sectors in 2001. Work is going on in the field of drought tolerance, salt tolerance, cold tolerance and many other areas. Lately, work has also begun to increase yield through different approaches including to increase the number of fibers grow/seed (increase fiber density on the seed coat) and by delaying the leaf shedding process.

Fiber Quality

Fiber quality is the least researched area in cotton. Lately, the emphasis has increased and it is expected to increase further. The ginning mechanism has not improved since the invention of the saw gin by Whitney in 1793. Higher efficiency and cleaning were no doubt achieved, but the process remains the same, harsh pulling and beating action. Many efforts have been made including differential ginning, cage ginning and Templeton ginning, but none of these could be commercialized. The need is there but changes are not expected for many years to come. The soft fiber has to bear the harsh treatment of sharp metallic saws.

Measurement of fiber quality characteristics is slow, stickiness has no standards, maturity and fineness are not separated, short fiber contents not defined, interlaboratory variation for many characters is poor, repeatability of the data also needs improvements and so on. Machine testing of quality characteristics is improving and sooner or later all cotton in the world will be tested on machines like the High Volume Instrument.

The need for real qualitative value of fiber is becoming recognized and fiber quality testing has become one of the fastest growing areas in cotton. Not only the measurements on the currently measured quality characters will improve, but the industry will start measuring new characters which have affect on processing and products.