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Update on Cotton Production Research

Contents

Introduction

The ICAC Secretariat estimates that 36% of world cotton are was planted to biotech varieties in 2006/07, and this area will account for about 45% of production. Over the last eleven years, since commercialization of biotech cotton in 1996, the world yield has increased by 2.6% per year, or 29% in 11 years. Over the five decades prior to 1996/97, the world yield rose at an average annual rate of 1.6% per year. Thus, with the introduction of Bt varieties, the rate of increase in the world yield has been 1% per year higher. Increases in yields come from multiple factors, but the use of biotech varieties resistant to insects has contributed a significant portion of the recent increase. However, in addition to raising yields, the use of biotechnology has other impacts that are usually not reported. Most reports about biotechnology are positive; nevertheless, there are genuine concerns about biotechnology in cotton. It is also true that there are some apprehensions that have not been proven, but there are others concerns that have been verified and need to be watched/monitored carefully. This includes issues such as the Technology Protection System, resistance to Bt toxins, changes in weed patterns and resistance to selected herbicides, changes in the pest complex and a set back to organic cotton production. There are other issues, like illegal spread of biotech varieties and awareness about the technology that require particular attention. These concerns are discussed in the first article on Biotechnology Applications in Cotton: Concerns and Challenges.

It is estimated that pesticides worth $32.9 billion were used in the world in 2005/06, and cotton accounted for 9% of all pesticide sales. Insecticides worth $1.6 billion were sprayed on cotton in 2005/06. Thus, on the average, US$47/ha were spent to control insects on cotton in 2005/06. Data on cost of production shows that the cost of insecticides ranges from almost nothing in countries like Syria to over US$400/ha in Spain. Insecticides have become an integral component of the production system, but insecticides affect farmers' incomes. It is not only the cost of insecticides but also the consequences that cotton producers have faced. There are indications that the adoption of insecticides was not a wise decision. Recent trends in pest control in cotton are driving growers and countries away from insecticide use. Insecticide use is on the decline in most countries, and cotton production is heading toward least dependent on insecticides. More information about insecticides use on cotton is given in the 2nd article on Insecticides: A Costly Mistake.

Dr. James McD Stewart of the University of Arkansas, USA, has contributed the third article in this issue. He presented this paper at the 'Regional Consultation on Genetically Modified Cotton for Risk Assessment and Opportunities for Small-Scale Cotton Growers,' March 6-8, 2007, Faisalabad, Pakistan. The Consultation was held under a project CFC/ICAC 34FT sponsored by ICAC and funded by the Common Fund for Commodities. According to Dr. Stewart, biotechnology should be able to shift existing production systems to more environmentally friendly systems. Small growers in developing countries can benefit the most from biotechnology. Biotic resistance is just one of many traits needed to provide cotton crops that will yield more on less land. Some of the traits that are currently receiving attention are 1) increased light harvesting efficiency, 2) drought tolerance, 3) high, 4) low temperature tolerance, 5) salt tolerance, and 6) fiber quality. Each of these are steps toward producing more and better cotton in a sustainable way. Also, one could hope that the output traits derived from biotechnology will be viewed favorably by the general public, since they will not imply the plant is producing a "toxin," as now is the case.

World Cotton Research Conference-4 (WCRC-4)

The World Cotton Research Conference-4 will be held in Lubbock, Texas, USA from September 10-14, 2007. The last date to submit papers is April 6, 2007. The full registration package and instructions to submit papers are available at http://www.wcrc4.org. Requests on specific questions may be addressed to the WCRC4 Secretariat at wcrc4secretariat@gmail.com. Also see an insert in this publication.

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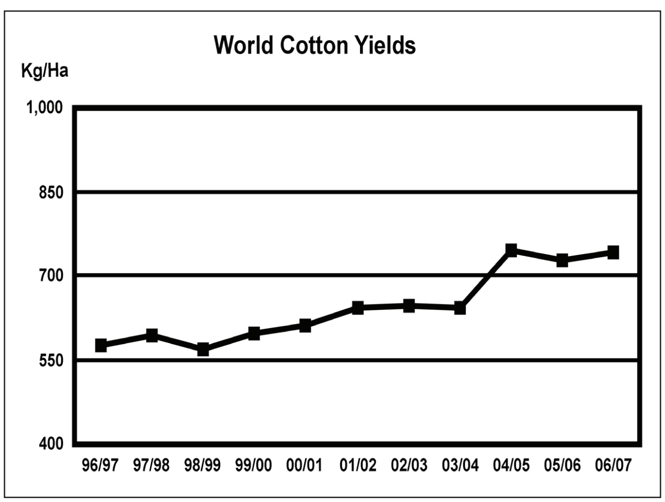
The US Organizing Committee has arranged with the US State Department and announced WCRC-4 on their web page. Once a researcher pays the registration fee, his/her name will be passed on to the US State Department web page for posting under WCRC-4. US Embassies in all countries will have access to this list, which will help researchers to get US visas. All potential participants who need a visa to enter the USA are advised to start their visa formalities at the earliest.

Biotechnology Applications in Cotton: Concerns and Challenges

The use of genetic engineering in agriculture, including cotton is new. Genetically engineered cotton resistant to insects was commercialized in 1996/97, and so far nine countries have allowed commercial production of biotech cotton. The ICAC Secretariat estimates that 36% of world cotton area was planted to biotech varieties in 2006/07, and this area is expected to account for 45% of world cotton production in 2006/07. India commercialized biotech cotton in 2002/03, Colombia in 2003/04, and Brazil only in 2006/07. The area planted to biotech varieties in these countries is still increasing. The requirement for a refuge crop is limiting biotech cotton area in some countries. Nevertheless, biotechnology is the fastest adopted technology in the history of agriculture. If the adoption of biotechnology did not require regulatory approval and, if the technology was freely available, as was the case with other technologies like short stature wheat and rice, many more countries would have adopted biotech cotton by now. However, the biotechnology has proved to be the most controversial technology in the history of agriculture.

Impact on Yield

Over the last 30 years, the world yield rose on average at the rate of 2% or about 8 kg/ha per year. There have been periods of slow growth and similarly there were periods of faster growth. The world yield rose to a new record of 600 kg/ha in 1991/92, but there was no increase in yield for the next six years until 1997/98. Since then, the world yield rose to 742 kg/ha in 2004/05. The average yield in 1996/97, the first year of adoption of biotech cotton was 575 kg/ha. The average yield in 2006/07 is expected to be 742 kg/ha. Not all, but a significant proportion of this increase, comes from the use of biotech varieties providing better protection against pests. The 29% increase in world yield over the last 10 years is un-precedent in the recent history of cotton.



To estimate the role of biotechnology in increasing the world yield, many assumptions are required. A comparison of yields in Bt area versus non-Bt adopted areas is presented here. Cotton producing countries were divided into two groups; countries that produce Bt cotton (Argentina, Australia, Brazil, China (Mainland), Colombia, India, Mexico, South Africa and USA) and countries that do not yet produce Bt cotton.

Performance of Yield in Bt Producing Vs Non-Bt Producing Countries

	Bt Producing	Non-Bt Producing	World
Area in million ha 2005/06	20.4	13.6	33.9
Average annual increase in yield			
1966/67 to 1975/76	1%	1%	1.10%
1976/77 to 1985/86	6%	2%	3.50%
1986/87 to 1995/96	1%	1%	0.80%
1996/97 to 2005/06	3%	1%	2.70%

The data above indicates that there are variable rates of yield increases, and the period of 1986/87 to 1995/96 was slower than the previous two decades. Further analysis of this decade indicates that slower growth was due to no increases for four years from 1992/93 to 1995/96. The two groups of countries, Bt and non-Bt, showed similar behavior for two decades but not for the decades from 1976/77 to 1985/86 and from 1996/97 to 2005/06. The higher increases in yield in Bt growing countries from 1976/77 to 1985/86 can be attributed to the adoption of insecticides. The other countries adopted insecticides, but later and applications were often not done correctly, including use of threshold levels, spray machinery, proper chemicals, etc. The last ten-year differences in yield indicate that countries adopting Bt showed higher increases, which could be attributed to the new technology.

Biotech cotton has multiple advantages, and most papers and reports that have been published on this technology are favorable. However, the technology carries risks, and unfortunately the negative aspects of biotechnology have not been properly covered in scientific publications. This article is focused on the negative aspects of biotechnology in cotton, aiming mainly to make people aware and therefore more careful, rather than to diminish the positive aspects of this technology. This discussion does not mean that the ICAC Secretariat is opposed to this technology. Moreover, only issues related to biotech cotton as a fiber crop are discussed in this article.

Misuse of Gene Action Technology

Many biotechnological tools are available to utilize genetic variability from within species, across species and beyond species. Bt cotton was developed utilizing a gene from the soil bacterium *Bacillus thuriengenesis* and it is not the gene as such that actually gives rise to a new characteristic. All genes code for specific proteins, which actually do most of the work in the cell. The Bt gene codes for a specific protein, Cry 1Ac, in genetically engineered biotech varieties, the protein produced by the Cry 1Ac gene performs the function of killing Lepidoptera species. To ensure that the gene-coded protein is made in the right tissue at the right time, genes have switches, or promoters, that direct the cell when and where to make a particular protein. Genes present in the genome have these switches; the switches are turned on only in the right part of the plant. With genetic engineering tools, different switches can be attached to desired genes, directing them to work at a special tissue or remain dormant until they are activated.

Researchers in the private sector, in collaboration with the USDA, employed genetic engineering tools to develop the “Technology Protection System” in cotton (gene terminator). The technology protection system was not commercialized but it would have been if farmers and other segments of the cotton industry had not objected so much to the technology.

Researchers started to develop a self-sterile seed system in 1993, three years before biotech varieties were commercialized. The technology advanced well and received a patent in 1998. The technology protection system was a clever three-gene system that forced plants to produce a toxin that was fatal to their own seeds. The complex array of gene promoters, which in a normal state were inactive, proved successful at all experimental stages in the lab and in the field. The variety with a technology protection system was able to produce viable seeds only when needed. The sterile seeds were treated prior to sale so that they would germinate like normal seeds but the resulting plants would not produce viable seeds. The treatment triggered an irreversible series of actions rendering the produced seed non-viable for planting. The toxin was produced late in the season, so that the seed’s commercial value for oil extraction and livestock feeding was not lost. This technology protection system, as is evident from the name, was developed to stop the illegal spread of biotech seeds by making it impossible for farmers to plant the seeds the next year. This technology was not commercialized, but similar tools could be employed in the future in different forms that could work against growers, processors and even users.

Development of Resistance to Bt Toxins

Once a Bt gene is inserted into a variety, the Bt toxin is produced throughout the cotton plant during the entire growing season. Consequently, target pests are exposed to high levels of the toxin continuously, a situation likely to elicit resistance faster than intermittent exposure to conventional insecticides. All sectors of the cotton industry, including pesticide companies and biotech technology owners, agree that it is only a matter of time before cotton pests evolve resistance to the Bt toxin. However, it is possible to delay resistance if farmers incorporate resistance management strategies into their cotton production systems. Otherwise, without effective management plans, the effectiveness of Bt varieties could be lost in just a few growing seasons. Thanks to the lessons learned from the intensive use of insecticides, the resistance problem was identified even before biotech varieties were commercially introduced. Accordingly, appropriate measures in the form of refuge crop and gene pyramiding were undertaken and resistance has not become a problem so far. But the threat is real and acknowledged by everybody.

Change in Weed Control Systems

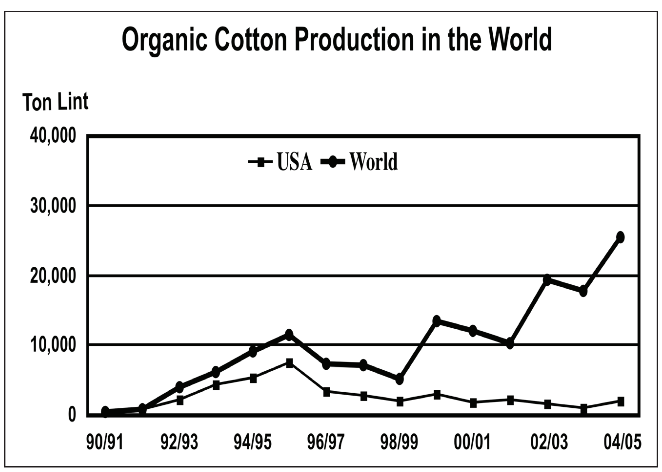
Herbicide resistant biotech crops encourage the use of herbicides. According to James (2006), the herbicide resistant character has consistently been the dominant trait since the commercialization of biotech crops. In 2006, the herbicide resistant trait occupied 70% of the 102 million hectares planted to biotech crops in 22 countries. 19% of the total area had only the Bt gene while the remaining area was devoted mostly to stacked traits of Bt and herbicide tolerance. The herbicide resistant trait in cotton is popular in Australia and the USA. In the USA, herbicide resistant biotech cotton was over 95% of the area planted to biotech varieties in 2006/07.

Herbicide resistant biotech cotton has changed the weed control systems in Australia and the USA. Weed control prior to Roundup Ready cotton involved multi-dimensional approaches from several angles to achieve the best control. These approaches involved preplant incorporation (PPI), applications at planting (PRE), postemergence-directed (PDIR) applications when the cotton reached 3 to 4-inches in height or once a height differential was established between cotton and weeds, cultivations, non-selective herbicides under hoods, layby applications, spot spraying, and hand weeding (Dotray and Keeling, 2006). Studies on weed biology and weed control effects on succeeding crops in a rotation were also considered.

The benefits of a herbicide resistant biotech system include broad spectrum weed control, convenience, simplicity, increased efficacy and crop safety and reduced labor, which is expensive in Australia and the USA. Increased use of herbicide resistant biotech cotton has resulted in fewer tillage operations, more narrow row cotton, larger spray booms, fewer herbicide modes of action, reduced application of herbicides in soils at planting (especially PPI), and reduced labor and machinery requirements. Other changes since the use of herbicide resistant technology include shifts in weed species and the emergence of herbicide (glyphosate) resistant weeds. New weed species and the development of ‘super weeds’ are the most serious among all effects. Resistance could deprive cotton growers from the most popular herbicide (Glyphosate due to its low cost, ease of use and its activity on a broad spectrum of weeds) used on cotton. Roundup Ready Flex cotton was introduced in the USA in March 2006. Roundup Ready Flex offers a wider window of application timing without the risk of possible yield loss. Applications can be made up to seven days before harvest, which is only going to aggravate the potential of resistance development.

Setback to Organic Cotton Production

Statistics show that 11,527 tons of certified organic cotton were produced in 1995/96. Organic cotton production declined for the next three years before picking up again. The USA was the leading organic cotton producer in the world. The U.S. National Organic Standards Board defines organic agriculture as ‘an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity.’ One of the prerequisites for organic production is certification from a recognized certifying agency that the cotton has been produced following the organic cotton producing requirements set under the U.S. National Organic Standards Act. The primary requirements for organic production are to use materials and practices that enhance the ecological balance of natural systems. Organic cotton production was never large, but it was increasing slowly until biotech cotton was introduced. However, the National Organic Standards Board in the United States, on the advice of producers of organic products, regards biotech varieties as not eligible for certification as organic. This decision negatively



affected the spread of organic cotton in the USA. With 88% of the U.S. cotton area under biotech varieties in 2006/07, there are fewer chances of producing organic cotton than there were prior to 1996/97. Currently, Turkey is the largest organic cotton producer in the world sharing 44% of organic cotton produced in the world in 2005/06 (Wakelyn and Chaudhry, 2007).

In addition, organic cotton growers face the challenge of keeping organic produce separate not only from conventional produce but also from biotech produce during handling, ginning, and processing. This is in addition to requirements for distances between fields that prevent biotech varieties from crossing over to non-engineered conventional varieties. The chances of out-crossing with wild species are extremely low, but the chances of contamination with another variety grown under organic conditions are much higher. As long as biotech varieties are grown in the same area as organic cotton, organic producers are at risk of their crops being exposed to background levels of biotech varieties.

Another of the many consequences of insect-resistant biotech cotton to organic cotton is the restriction not to spray microbial insecticides (insecticides also made from *Bacillus thuringiensis*) on biotech varieties. The market for Bt insecticide has been significantly decreased, and biotech use has proved to be a disincentive for producers to continue producing the microbial insecticide. This has had the result that the organic producers have lost one of their most valuable pesticides.

Organic cotton production is increasing lately in India and Turkey, where most cotton is still no-biotech. It is estimated that 23,200 tons of organic cotton were produced in the world in 2005/06 and close to half was produced in Turkey. Over 40% was produced in India and very little in the USA. The area planted to biotech cotton is increasing in India and it could affect organic cotton production.

Labeling and Consumers’ Rights

Cotton is a fiber crop, but approximately 40 million tons of cottonseed are also produced annually, most of which is used to make vegetable oil for human consumption in developing countries. In principle, farmers should have a choice of the variety they grow, be it biotech, conventional, or organic. This assures the availability of a variety of products in the market. However, like the producer, the consumer is also entitled to choose the product he or she likes. The introduction of biotech cultivars makes labeling imperative for all countries, and the world in general. Many European countries and environmental groups are concerned about biotech products in the food chain and advocate labeling produce from biotech varieties. Some people even see such labeling as necessary for biotech products to survive and compete successfully with conventional products.

Long Term Consequences

The use of biotechnology in crop plants is new and so far experienced by 22 countries. However, only five countries i.e. Argentina, Brazil, Canada, India and USA, shared 92% of the 102 million hectares planted to biotech crops in 2006/07 (James, 2006). Three other countries China (Mainland), Paraguay and South Africa shared another 6% of the biotech crop area in 2006. The remaining 2% of area was grown in 14 other countries. It means that only a few countries have extensive experience, which is a short experience. Most of the biotech cotton area outside the United States is in developing countries, including China (Mainland) and India. The most intensive use of biotech cotton has been in Australia and the United States, where biotech cotton varieties have been grown for the last eleven years. Eleven years is too short a time to assess long-term consequences of a new technology that is so different from long existing technologies; researchers admit that there is insufficient scientific data regarding the long-term effects biotech varieties may have on the environment or on human health. Even though the technology might not have long-term consequences, the concerns are there.

Percentage of Insecticides Applied to Target Pests in Australia (2004/05)

Pest	Helicoverpa	Mirids	Aphids	Others
Conventional cotton	92	1	4	3
Bollgard II cotton	3	55	21	21

Source: Pyke and Doyle (2006)

Illegal Biotech Cotton With All of Its Consequences

Biotech varieties in Australia, the United States and other countries are sold to cotton growers under an agreement to follow refuge requirements, not to spread the seed to other farmers and not to keep seed for self-planting in the following year. However, these conditions have been violated extensively in a number of countries. Farmers not only save seed for planting, but they pass it on illegally to others. Zoning of varieties has been violated, and varieties have been cultivated on a large scale in areas where they were not approved or recommended. Bt cotton has illegally traveled to many countries. Illegal use of biotech varieties is a blatant violation of biosafety regulations, and could spoil seed purity, performance, and safety as well as the credibility of legitimate biotech products and technology. Illegal sellers can afford to sell their products at a much lower price, as their investment on research is meager. Biotech pirating could affect the confidence and enthusiasm of genuine technology developers, who invest a lot of time, talent, and money in developing new products and getting approval through proper regulatory procedures. At the same time, pirating is misleading and confusing users, who do not observe refuge requirements and contribute to a bigger problem.

Biotech Cotton and the Pest Complex

Bt cotton is effective against a variety of budworms and bollworms, but it is not effective in controlling many secondary pests. The emergence of secondary pests in Bt cotton is by no means a random event. The experience in China (Mainland) showed that populations of secondary pests such as aphids, mites, thrips, lygus bugs, whitefly, and leaf hopper, increased in Bt cotton fields after the target pests—budworms and bollworms—had been controlled (Xue, 2002). It is known that the currently discovered Bt proteins Cry 1Ac, Cry 2Ab, VIP, and Cry1F do not control sucking pests; insecticides have to be used to control them. However, chemicals used to control budworm and bollworms have a relatively broad spectrum toxicity so when used against target insects they also kill sucking insects. The situation may vary from country to country, but data show that organophosphates comprised almost 90% of the insecticides used on cotton in 2000/01 in the world. Therefore, there is an additional advantage of insecticide spraying: partial control of non-target insects. When biotech varieties are used, there is a possibility of recording higher populations of pests that are not Bt targets during the period of no insecticide sprays. This is what has been observed in the work reported by Xue (2002), and this was expected to occur in nature. Wang *et al* (2006) observed that 'China provides strong evidence that secondary pests, if unanticipated, could completely erode all benefits from Bt cotton cultivation.'

In Australia Bollgard II® cotton has dramatically reduced the need to spray for *Helicoverpa* spp. and other lepidopteran pests. Sucking pests previously controlled by these broad-spectrum sprays are now a management issue in Bollgard II® cotton. Such pests include the green mirid, *Creontiades dilutus,* which has increased significantly in Australia and China (Mainland). In the USA, tarnished plant bug *Lygus lineolaris* has become a high concern.

Supporters and opponents of biotech cotton agree that Bt genes provide good control of target pests. But once the targets pests are controlled, minor and non-target pests may emerge as major pests. When minor pests become major ones, they may change the pest complex situation, and pests that are more difficult to control than the target pests may emerge as major pests, bringing new and difficult problems. The possibility of sucking insects gaining higher importance is always there.

Biotech Cottons and Beneficial Insects

The insect-resistant biotech cotton varieties provide resistance to a specific group of insects that includes most bollworms and budworms but excludes natural predators and parasites.

The active toxin binds to receptors in the insect's stomach cells. The binding creates pores in the wall of the insect's gut, allowing ions to equalize, ultimately causing the gut to lose its digestive function. Once the binding has taken place after ingestion, the insect's gut is paralyzed, forcing it to stop eating. After the stomach is immobilized, the cells break open and the pH of the stomach decreases as its fluids mix with the lower-pH blood. A lower pH allows the spores to germinate and colonize the rest of the insect's cells. The bacteria spread throughout the rest of the host by the bloodstream until complete paralysis of the insect occurs. This process takes anywhere from an hour to a week to kill the insect. Beneficial insects might feed on insects that have taken up the toxin but have not died yet, or might digest by-products of insects such as honeydew that are contaminated with toxin. No data show that biotech toxin kills beneficial insects, but the toxin could harm beneficial insects indirectly in the two ways described above. The third, indirect, effect could be in the form of poor quality food if the transgenes reduce the quality of the host or prey insects that are available for feeding. This could be true particularly in cotton of the third and later generations of insects towards crop maturity, when the amount of toxin is reduced and not all the target larvae will be killed.

Human Health and Environment

If a genetically engineered plant produces a new protein, there may be some risk that humans could be allergic to the new protein. Biotech products have been tested for their effects on non-target insects, human health, and the environment in their country of origin. No ill effects have been found, but a notion still persists among countries and the public reluctant to adopt biotech products that the new technology carries potential threats to the environment and non-target insects. This issue may be more relevant to food crops than cotton, which is grown as a fiber crop. Unfortunately, biotech cotton has been treated like biotech food crops, since its byproducts are used for food and feed. In addition, biotechnology applications have not reached their peak, and future products could create such problems, particularly if something such as an antibiotic gene is inserted into cotton or other food crops for ease of distinguishing transformed plants from non-transformed types, or for the production of pharmaceutical substances.

StarLink™ corn is grown on a commercial scale in a number of countries, but it is not approved for human consumption. Studies can be cited showing that an allergic reaction has occurred for some consumers who have eaten food products containing StarLink™ biotech corn. StarLink™ biotech corn carrying the Cry9C gene was commercialized in the late 1990s and since then it is approved only for animal feed. The Cry9C protein breaks down slowly in the digestive system, an indication that it might induce allergic reactions. StarLink™ is a corn variety genetically modified to be resistant to the European corn borer and tolerant of glufosinate herbicides such as Liberty™. Some growers in the USA ignored the agreement not to sell StarLink™ corn to mills using the flour for human food and StarLink™ corn ended up in the food chain. After the contamination of StarLink™ was detected in foods, Aventis petitioned the US Environmental Protection Agency (EPA) to consider allowing the "temporary approval" of StarLink™ corn for human consumption, based on new data provided by Aventis. The EPA reviewed the new data and deferred to the advice of its scientific advisory panel (SAP). The SAP published its analysis on December 5, 2000--concluding that StarLink™ does pose a moderate allergy risk. EPA ruled on July 27, 2001, that it would not accept Aventis' petition to allow StarLink™ for food use, and that its policy of zero tolerance would continue.

Technological Limitations

Breeding, the art and science of developing new varieties, has been untaken for centuries, and genotypes and cultivars drastically different from their wild ancestors and relatives have been developed. Developments have been achieved in agronomic performance, including higher yield and better fiber quality in cotton, contributing to productivity and quality improvements. While breeding can bring drastic changes, biotechnology applications, at least so far, have been limited to specific changes in existing genotypes and cultivars. Conventional breeding will always carry a large gene pool to exploit genetic variability according to an area's growing conditions, since, for example, certain varieties perform better under sandy soils while others perform better under rainy or drought conditions. Molecular genetic engineering breaks down the incompatibility barriers among different forms of life and makes it possible to transfer a gene or genes from one level of life to another. However, certain limitations will always apply to biotechnology, and sometimes conventional breeding will prove to be better.

Dominance of the Private Sector

Private companies have a major role in commercialization of biotech products. Certain issues like "international patent to transform cotton" have been of great concern to all countries. Companies own specific genes, which no one else can legally use without their permission. Such conditions are limiting the use of biotechnology applications in developing countries. In contrast, most of the developing countries benefited from the "green revolution" in a short time because the public sector acquired the technology quickly and spread it to farmers. The primary objective of the green revolution was to produce more food and alleviate poverty. Therefore, farmers were the primary beneficiaries and they produced more food without increases in the cost of production. This is not the case with biotechnology. The private sector views biotechnology mainly as a source of income and a way to compete with other companies, and only secondly as a tool to solve problems. The monetary intent is apparent from the technology fee, which is different in different countries for the same Bt gene. The fee is related not to the cost of development but to savings on insecticides used and the financial conditions of farmers. For this reason, the technology fee for the Bollgard gene is higher in Australia than in the United States. Also, the technology fee in Australia has been changed more than once.

Technology is Expensive

Agricultural technological innovations like the green revolution came at various stages, always bringing with them some cost in developing and acquiring that technology, but nothing like the cost of biotechnology products. Further, if the technology was acquired through seed, the cost was paid only once, except in the case of hybrid seed in corn or commercial cotton hybrids in India. This condition was not coming from technology developers but it was a genetic issue where nothing could be done except to produce planting seed every year. For biotech crops, farmers have to pay for insect- and herbicide-resistant technology every year, which makes the technology more expensive. Argentina commercialized Bt cotton in 1998, but so far Bt varieties cover less than 25% of the area. The high cost of biotechnology is limiting the use of this technology in many countries. The high cost also encourages the illegal use of technology products. Biotechnology research is expensive and if started, particularly under limited resources in developing countries, could be done at the cost of other research.

Search for Newer Genes

It has been 11 years since insect-resistant and herbicide-resistant cottons were commercialized. The only two new biotech cotton products commercialized since then belong to the same two categories. The search for additional genes may have been initiated even before the commercialization of biotech cottons, but new forms of biotech cotton (other than insect- and herbicide-resistance) are not expected to be released any time soon. New genes are needed but how far we can go to explore and utilize new genes is another consideration. The ICAC's Second Expert Panel on Biotechnology of Cotton observed that the difficulty in identifying new genes with classical traits is the most important limitation to the use of biotechnology applications (ICAC, 2004).

Biotech Cotton is not Suitable for all Production Systems

Cotton is grown under a variety of growing conditions and production systems. Cotton in general is a small growers' crop, as most farmers in developing countries own only a small piece of land. Private companies can sign direct contracts with large growers, something that is very difficult to do under small-scale farming systems. Additionally, insect- and herbicide-resistant biotech varieties are not suitable for all production systems. The target pests do not exist everywhere, and many countries just do not need them. The boll weevil *Anthonomus grandis* is the most serious pest in the Latin American region. Many Central American countries had to quite cotton production due to extremely high costs to control boll weevil. Argentina, Bolivia, Brazil, Colombia, Mexico and Paraguay would see a higher benefit in boll weevil resistant biotech cotton compared to lepidoptera resistant biotech cotton.

Opposition Due to Lack of Knowledge and Over Cautiousness

Genetically engineered biotech varieties resistant to insects have faced opposition from a number of organizations and individuals from the beginning, even before the technology was commercialized. The issues raised were mostly speculative, complex, and confusing. It was claimed that the Bt protein might be harmful to humans, farm animals, other beneficial organisms, and soil. In India, such groups threatened farmers with serious consequences if they were to seed Bt cotton. They also held repeated public demonstrations against this technology in India, the United States, and many European countries. Unfortunately, the year when biotech varieties were introduced in India coincided with a new disease. The disease, commonly named as "parawilt," was found on Bt as well as on non-Bt hybrids, but biotechnology was blamed for the disease's occurrence. Later, it was revealed that parawilt was a physiological disorder that occurred when Bt hybrids were exposed to prolonged dry spells or unusually high temperatures during boll formation, followed by heavy rains. A similar allegation occurred in the United States when excessive leaf/boll shedding was attributed to the herbicide-resistant gene. Biotechnology has faced enough opposition due to lack of knowledge and to unnecessary cautiousness, to create doubts and confusion in the minds of farmers and the public.

Need for Public Participation

The Cartagena Protocol was adopted in January 2000; it entered into effect in September 2003. One hundred eleven countries had ratified the Protocol by the end of 2004. The essence of the Protocol is "to ensure an adequate level of protection in safe transfer, handling and use of living modified organisms resulting from modern biotechnology that may have adverse effects on the conservation and sustainable use of biological diversity, taking also into account risks to human health, and specifically focusing on transboundary movements." Article 23 of the Protocol specifically addresses the issue of public awareness and participation, stating "The Parties shall: (a) Promote and facilitate public awareness, education and participation concerning the safe transfer, handling and use of living modified organisms in relation to the conservation and sustainable use of biological diversity, taking also into account risks to human health. In doing so, the Parties shall cooperate, as appropriate, with other States and international bodies; (b) Endeavor to ensure that public awareness and education encompass access to information on living modified organisms identified in accordance with this Protocol that may be imported." The Protocol also says that parties "shall, in accordance with their respective laws and regulations, consult the public in the decision-making process regarding living modified organisms and shall make the results of such decisions available to the public, while respecting confidential information in accordance with Article 21. Each Party shall endeavor to inform its public about the means of public access to the Biosafety Clearing-House." Public awareness and participation have become key in the acceptance of biotech products. The Food and Agriculture Organization of the United Nations has done elaborate work on public participation in the decision-making process regarding adoption of biotech crops. FAO's electronic forum on biotechnology at http://www.fao.org/biotech/Conf10.htm provides a lot of information on biotech issues.

New Products and New Concerns

Biotechnology in a broad sense includes genetic engineering, tissue culture, embryo rescue, marker-assisted breeding, and many more applications. There are two kinds of concerns about biotechnology: concerns about available products and concerns about biotechnology products in the pipeline or yet to come. Many people agree that many biotechnology applications are not always risky and dangerous, while transgenic biotech products carrying non-related genes could be harmful. Thus, even if researchers convince people of the safety of currently available products, new concerns will arise as new products are developed and commercialized. Biotechnology applications are technologies that will continue to be controversial for a long time.

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Insecticides: A Costly Mistake

The cotton plant is naturally vulnerable to a variety of insect pests, and more insecticide is used on cotton than on any other crop. It is estimated that world pesticide expenditures in 2005/06 amounted to $32.9 billion and cotton was responsible for 9% of all pesticide sales. Insecticides worth $1.6 billion were sprayed on cotton in 2005/06. Thus, on average, US$47/ha was spent to control insects on cotton in 2005/06. ICAC cost of production data from 30 countries shows that the cost of insecticides ranges from almost nothing in countries like Syria to over US$400/ha in Spain. Insecticides have drained cotton farmers' incomes and driven many countries in Central America to abandon cotton production. But it was not only the cost that led cotton farmers to the conclusion that the adoption of insecticides was not a wise decision. Other consequences that cotton producers throughout the world have had to deal with for almost three decades was the decisive factor.

The latest trends in pest control in cotton show that insecticide use is on the decline in most countries, and cotton producers are rapidly moving toward minimal insecticide-dependent cotton production systems. The current trend shows that this is possible, but it will take some time. While the total elimination of insecticides may not be feasible everywhere, it is certainly possible to drastically reduce their use, and countries like Syria have successfully eliminated insecticides from their cotton production systems without sacrificing yields. In fact, Syria's national yield is twice the world average.

Background

History can trace back the origins of the use of pesticides in agriculture for centuries, but the earliest record of insecticide use refers to the burning of "brimstone" (sulfur) and its application in the form of a fumigant. Subsequently, many more naturally occurring products were used commercially as insecticides. The results of some of these products, such as extracts of pepper and tobacco, soapy water, salty water, whitewash, vinegar, many oils in various forms, etc., were actually questionable, but they were commonly used in many countries. The worst part of the history of pesticide use started in 1940 with the outbreak of World War II. World War II ushered in the so-called 'Modern Era of Chemicals' with the introduction of a new concept of insect control in agriculture. The new chemical control era took off with DDT (dichloro-diphenyl-trichloromethylmethane), the first synthetic organic insecticide. DDT was so popular and appreciated that Dr. Paul Müller was awarded a Nobel Prize in 1948 for his work in developing DDT. It was observed then that thanks to DDT "a preventive medicine is now able to fight many diseases carried by insects in a totally different way from those employed heretofore. Your discovery, furthermore has stimulated throughout the world successful research into newer insecticides." Soon, DDT became the best-known insecticide in the world. DDT, a contact insecticide, was a highly hydrophobic, colorless solid with a weak chemical odor. It was nearly insolublre in water but had good solubility in most organic solvents, fat, and oils.

The first alert against DDT came in 1962, when it was alleged that DDT caused cancer and harmed reproduction in birds. Later, detection of DDT in the food chain and confirmation of its very slow degradation resulted in a large public outcry that eventually led to the banning of DDT for agricultural use in the USA. Subsequently, in the 1970s, DDT was banned for agricultural use in many countries. DDT is no longer used in agriculture, but it may still be present as a contaminant in food commodities because of its persistence in the environment.

Although DDT was totally banned in the early 1970s, by that time, the pesticide industry was firmly established and it started looking for a replacement for DDT. The industry successfully developed many new products that became equally or even more popular in agriculture. Today, the pesticide industry has evolved a great deal, and current insecticides can be categorized into following groups.

Inorganic Insecticides

These are manufactured from metals and include arsenates like copper and fluorine compounds, which are now seldom used. Sulfur seems to be the only commonly used product in this category.

Organic Insecticides

These are synthetic chemicals that nowadays form the largest number of compounds on the market. Organic chemicals can be either contact insecticides or systemic insecticides, depending on their mode of action.

Natural Insecticides

Natural insecticides such as nicotine and pyrethrum are produced by plants as a defense against insects.

Insect Growth Regulators

Insect growth regulators are chemical compounds that can alter growth and development patterns in insects. Growth and development can be altered in many ways, and three of them are among the most important.

Microbials

Microbial insecticides are made from microorganisms capable of controlling insects. Bacteria, fungi, protozoa, viruses, nematodes and transgenic organisms used to control insects belong to this category.

The Pesticide Market

A UK based company, Cropnosis, monitors the sale of agrochemicals around the world. Data for 2006 is not yet available but according to Cropnosis, agrochemicals worth US$32.87 billion were used in agriculture, in 2005/06. Herbicides make up the largest group of agrochemicals currently employed in agriculture, accounted for almost half of all agrochemicals. Herbicides are more popular in corn, wheat and soybeans and the area planted to these crops is almost 15 times greater than the area normally planted to cotton around the world. Among all agrochemicals, the sale value of fungicides approaches that of insecticides, but fungicides make up less than 3% of the agrochemicals used on cotton.

Cotton's share of all agrochemical sales in the world has remained steady at 9% for many years. In the last 20 years, the share of agrochemicals used to produce cotton has declined by only 2 percentage points, which is due to the enhanced use of herbicides in many countries. The share of insecticides in agrochemical sales in the world has been almost stable at 27-

Agrochemical Market in the World

Year	Pesticides Sales (Billion US$)	Share of Cotton (%)
1986	17.00	11
1988	20.45	11
1990	26.40	10
1991	26.80	11
1993	25.28	11
1995	30.27	10
1997	30.20	9
2000	29.18	9
2001	27.94	9
2002	26.56	9
2003	28.52	9
2004	32.35	9
2005	32.87	9

Source: Cropnosis, UK

28% for many years. The data for the last six years also show that sales of insecticides for use on cotton comprise 19% of all agrochemicals. It shows that, even with 29% of the cotton area planted to biotech varieties, there has been little impact on insecticide sales, and despite the fact that insecticide prices have increased, the share of insecticide sales going to cotton has not declined.

Insecticide Use in the World (By Sale Value)

Year	Share of Insecticides Among Agrochemicals (%)	Share of Cotton Among Insecticides (%)
2000	28	19
2001	28	19
2002	28	19
2003	27	18
2004	27	19
2005	27	19

Why are Insecticides Used?

Insecticides are dangerously poisonous chemicals, but they are still used in most cotton areas in the world. Syria is a special case where insecticides are applied on less that 1% of cotton area, and, therefore Syria will be discussed separately. In all other countries, all but a small portion of cotton area is treated with insecticides. In most cases, there may be a need to spray insecticides, but they are not applied for a number of reasons. The International Cotton Advisory Committee undertakes a survey of production practices every three years where countries are requested to provide information on the cotton area that is not treated with insecticides. According to the report published in September 2005, the following areas were reported as not treated with insecticides.

Cotton Area Untreated With Insecticides

Country	% Area
Argentina	20
Australia	< 1
Bangladesh	25
Brazil	< 1
Egypt	< 1
Mali	1
Mozambique	60
Pakistan	3
Syria	> 99
Tanzania	20
Turkey	8
Uganda	10
USA	21
Zambia	2
Zimbabwe	3

If we assume that not all but most of the 21% of cotton area reported by the USA as not treated with insecticides was planted to insect resistant biotech cotton, then only 2% of the area in the rest of the world was not sprayed with insecticides in 2004/05. If we include the USA, almost 5% of the cotton area did not receive any insecticide applications in 2004/05. This area may have received herbicides, as is the case in Syria, and other agrochemicals, but not insecticides. Most of the insecticide-free area in developing countries is not sprayed because of the inability of farmers to access insecticides or because prevailing agronomic practices are so poor that insect control alone cannot increase yields significantly.

Insecticides were eagerly adopted throughout the world. Governments in the developed and the developing countries not only undertook campaigns to popularize insecticides, but also provided subsidies for insecticides. In order to ensure that sufficient quantities of chemicals were available to growers at a reasonable price, many governments got directly involved in selling insecticides to growers. Researchers and extension workers also played their role in promoting insecticide use. Insecticide marketing quickly shifted to the private sector because of the flourishing business potential and the eagerness with which insecticides were embraced. Neither governments nor researchers realized that they were promoting something that would have serious negative consequences in the long run. Now all segments of the production chain are beginning to realize that the adoption of insecticides has harmed production systems. Insecticides have serious consequences but their most serious impact has been the shift from long-term environmentally sustainable insect control methods to quick fixes and heavy reliance on a single control method.

Why Were Insecticides Adopted?

Insecticides were adopted as a pest-control system in cotton with no long-term vision of the consequences. The following factors encouraged growers to adopt insecticides at much higher spread than the insecticides deserved.

- Insecticides were very effective. A severely damaged crop with clear symptoms of insect damage would start showing signs of improvement in just 1-2 days after treatment. After seeing the results of the first spray, particularly in the case of sucking insects, farmers were tempted to spray a second time, a third time, and so on.
- Insecticide prices at the outset were low and the pest pressure/damage was high. Consequently, the cost/benefit ratio was very high.
- No other alternatives were available. The conventional alternatives demanded a long-term commitment and growers were looking for a stronger and more efficient control method. It was even more difficult for large-scale growers to control insects. Insecticides were introduced at just the right time to make it easier for large-scale growers to handle their crops.
- Insecticides were promoted aggressively. Governments were convinced that it was a better option than the prevailing methods and provided subsidies for

insecticides to promote their use. The only source of information on production technology was the state/ provincial governments, which is still the case in most cotton growing countries. Other media like radio, TV and printed literature were not yet effective. Farmers trusted their government's advice.

- In the beginning, the number of sprays required was not as great as it is today or as it was 10 years ago, so farmers were able to buy insecticides for each spray separately. If they had to pay a single lump sum for the entire insecticide supply for the whole season, as is the case with the 'technology fee' charged for biotech cotton, farmers might have adopted insecticides more slowly.
- Opposition to biotechnology products and applications started even before biotech cotton was commercialized in 1996/97. Concerns and apprehensions were widely expressed in the media by governments and by the public. The campaign produced an indisputable impact on the spread of biotechnology applications to more countries. Insecticide use did not have to deal with that level of opposition, despite the fact that it was more noxious than biotech products.
- The long-term consequences of insecticide use were not known or were underestimated. Resistance to insecticides, a phenomenon that has affected developed, developing and underdeveloped countries alike, irrespective of farm size, was not properly understood until each country had to face the situation. The most convenient approach -- to spray more and more frequently, spray stronger insecticides and use spray mixtures -- worsen the situation.
- The private sector took over the pesticide industry rather quickly because governments wanted to offload some of their responsibilities. It entered the market with a strategy based on research, testing, promotion and marketing, all under a single umbrella. The marketing aspect played a key role. Companies hired experienced technical staff with backgrounds in agriculture and trained them extensively in cotton production technology. The company people were in a better position to reach growers and give them advice at their very doorsteps and in their fields. The companies' sales representatives, no doubt following a course of financial pragmatism, proved more effective than traditional extension staff in most countries.
- Pesticide companies understood the market very well and frequently came up with new products tempting growers to use those newer products to achieve higher levels of control.
- Pesticides were made available through a network of small dealers. Farmers not only had easy access to pesticides, but companies offered them liberal credit. Farmers had no reason to say no to insecticide companies. The few growers who did not want to apply insecticides could not survive in small-scale production systems when everybody around them was spraying.

What If Insecticides Had Not Been Adopted?

It may be inferred from the above that insecticides were actually imposed on farmers by creating circumstances in which the uninformed growers would welcome them. Growers are not researchers and they do not formulate policies, which are the domain of governments. Mistaken policies and misguided orientation led cotton growers to a disadvantageous situation of insecticide-dependent production technology. Cotton breeding programs around the world developed varieties consistent with insecticide-dependent production systems. Breeders developed varieties that would give higher yields only with perfect pest control, something that could be achieved only with insecticide applications. Insecticides had come to play such an important role in the success of the crop that cotton growers were forced to purchase products from pesticide companies.

Governments could have decided to use or not to use insecticides and some governments did decide not to use them. Many more governments could have done the same thing and spared farmers from the current situation or the similar situation faced by Australian and Chinese cotton growers 15-20 years ago. The success achieved by Australia, China (Mainland) and Israel in lowering the number of insecticide applications by more than 50% proved that governments could check the unlimited use of insecticides. One might suppose that the following scenario could have come about if insecticides had not been adopted in cotton.

- The world average yield increased by slightly over 1% during the decade of the 1970s and by 3.4% during the decade of the 1980s. This was the time when most countries were adopting insecticides. Sucking insects affect the ability of the plant to produce fruiting forms, while the fruit-eating insects cause a direct loss in yield. World yields would not have increased at the same pace if insecticides had not been adopted, and the world yield might be lower today if insecticides had not been adopted.
- Lower yields would have resulted in lower production but higher international prices. Higher international prices can also have a positive impact on local prices for farmers. Lower yields with higher prices might not have affected farmers' net income. However, higher prices would have resulted in lower cotton comsuption.
- Extensive entomological research and application of research findings was required to determine when, what and how to spray. Thus, entomological research received higher emphasis and attracted qualified manpower and financial resources depriving some other disciplines of their deserved shares.
- Insecticides could produce their full potential impact only if weeds were properly removed and fertilizers were applied on time and in the required doses. In an effort to

draw maximum advantage from insecticide applications, farmers also learned and improved agronomic management of their crops. Better agronomic handling of the crop in combination with insecticide applications improved yields.

- The complexities of insecticide use in combination with other inputs turned cotton into a technical crop, thus underscoring the importance of technology transfer. If insecticides had not been introduced, not only would agronomic practices have received less attention, but the transfer of technology would not have become so important.
- If insecticides had not been adopted, more attention would have been devoted to non-chemical control methods and integrated pest management. Dependence on insecticides lowered the importance of non-chemical control methods and the long-term sustainability of cotton was adversely affected.
- Environmental issues would not have become so important, and biotechnological research would have assumed a more leisurely pace.
- Differences in cotton yields among farmers within countries and among countries would have been lower in the absence of insecticides.

High Yields in Syria With No Insecticides

Syria, along with other countries, started using insecticides in the early 1970s. By the late 1970s, approximately half of the total cotton area was sprayed with insecticides. In 1979, the Government of Syria decided to reduce the use of insecticides and adopt a different form of pest control - not due to environmental concerns, but to the exorbitant cost of insecticides. The success of this logic has become one of the most serious criticisms leveled against the contemporary cotton industry.

While many other large cotton producing countries such as India and Pakistan were struggling with how best to promote the use of insecticides, researchers in Syria trusted their abilities to tackle the pest problem through non-chemical means. Thus, in 1979 they began to study the various predators and parasites that feed on pests in cotton fields. Researchers discovered 13 species of predators and 6-7 species of parasites that were very active in cotton fields. Unfortunately, spraying also resulted in the decline of the population of beneficials (predators and parasites). However, it was also observed that if the population of predators and parasites could be increased, they could overpower the pest population. Therefore, researchers increased the threshold levels (number of pests observed for initiating insecticide use) for various pests and correlated the number of pests with the predators and parasites at various stages of crop development.

The threshold for the American bollworm *Helicoverpa armigera*, the most persistently serious pest in Syria, was 1 larva per 100 fruiting plants. In other words, when 1 larva was found on a minimum of 100 fruiting plants, insecticides were applied. In an attempt to decrease insecticide use, researchers revised their recommendations to a higher threshold level - 10 larvae per 100 fruiting plants, an amount that is rarely reached. Experienced farmers began to observe early insect appearance and damage to their crops and became uneasy with the revised recommendations. Regardless, the government discontinued the supply of insecticides to farmers when experts did not recommend them. As researchers succeeded in bringing the predator/parasite populations up to levels consistent with the pests' increasing threshold levels, pests began to be eliminated naturally and cotton growers were more willing to delay their use of insecticides.

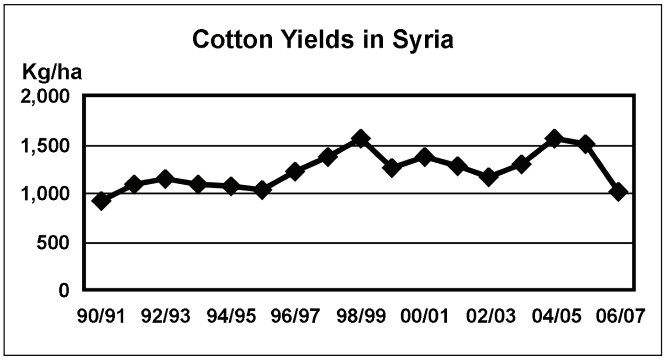
Cotton Area Sprayed with Insecticides in Syria

Year	Area Sprayed (%)
1985/86	25
1986/87	15
1987/88	29
1988/89	4
1989/90	8
1990/91	5
1991/92	3
1992/93	3
1993/94	3
1994/95	3
1995/96	1
1996/97	2
1997/98	< 1
1998/99	< 1
1999/00	< 1
2000/01	< 1
2001/02	< 1
2002/03	< 1
2003/04	< 1
2004/05	< 1
2005/06	< 1
2006/07	< 1

Historical yield data from Syria show that the average cotton yield did not increase during the 1950s and 1960s, then increased by almost 40% during the 1970s due to the use of insecticides. Syria has been able to maintain its high yields even without insecticides. The two most important steps that helped to eliminate insecticide use were: 1) raising the threshold level for key insects and 2) strict control of insecticide use. Raising the threshold level resulted in a buildup of biological control systems and that helped to reduce the need for insecticide sprays. More details on the success story of Syria can be found in the June 2004 issue of the ICAC RECORDER.

Average Yields in Syria

Year	Average Yield (Kg/ha)
1950/51	457
1955/56	360
1960/61	526
1965/66	609
1970/71	600
1975/76	705
1980/81	849



The Future of Insecticides in Cotton Production

Most people are beginning to realize that the adoption of insecticides was not a very wise decision. There was a time when countries were making efforts to popularize insecticides, but now all country are trying to cut back on insecticide use. Insecticide use on cotton is declining in most cotton producing countries, and insecticides do not have a bright future as far as cotton production is concerned. Pesticide companies have already realized that the future of insect control lies in in-build resistance and environmentally friendly control measures.

Acknowledging that same reality, pesticide companies are quickly buying seed companies. Pesticide companies are also investing in biotechnology so that they can market the built-in host-plant resistance directly to farmers in the form of seeds as a replacement for insecticide-dependent production systems. Cotton production technology in the world is successfully moving toward a system that is less dependent on insecticide use. It would be difficult to predict how long it might take to reach the stage where Syria is today. Syria achieved success in a short period of time because of centralized government control. It is likely, that it is going to take much longer for other countries to achieve this target, but promoting environmentally friendly sustainable production systems might accelerate the rate of progress.

Biotechnology: A Look into the Future

James McD. Stewart, University Professor,
Altheimer Chair for Cotton Research & Development, University of Arkansas, Fayetteville, AR 72701, USA

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*"…**perception is reality**." Malcolm Kane, Head of Food Safety, Sainbury's Supermarkets Ltd. (1980-1999)*

***-A person who does not learn the lessons of history is doomed to repeat them. However, "What experience and history teach is this – that nations and governments have never learned anything from history, or acted upon any lessons they might have drawn from it."** G.W.F. Hegel, German philosopher (1770-1831).-*

Two issues were covered in the regional consultation. The first, Genetically Modified Cotton for Risk Assessment, potentially can have a profound effect on the second, Opportunities for Small-Scale Cotton Growers. This statement is true because regulations promulgated in the name of "biosafety" can, in effect, be barriers to implementation of otherwise beneficial biotechnical advances. This can happen when only the socioeconomic perspective is considered in the assessment process. In 1991 I wrote (Stewart, 1991) that, "Issues of concern to a society tend to be based…on perception…" rather than upon reality. Today, 16 years later, this is still true. As Michael Kane stated (Kane, 2001), "…perception is reality." In 1991, it was not anticipated that genetic engineering would be negatively perceived by some once it was understood how the process works from a scientific perspective. At the time of that review (five years before the first commercial use of biotech cotton) a process of risk assessment was in place in the USA that emphasized a scientific approach. This led to approval and the rapid adoption of biotech cotton by producers beginning in 1996. In the ensuing years, various groups, some being extremely vocal and adept at influencing public opinion, have raised objections to production of biotech foods and possible negative effects of biotechnology in general. As an example, my wife told me that she was not going to eat "rat genes" in her lettuce. When I queried her, she said that she had "heard" that rat genes were being put into lettuce but was unable to tell me the source. When I tried to explain to her that, even if it were true, a gene is only a sequence of DNA common to all living organisms. In other words, I used scientific reasoning to establish an argument against an emotional reaction. As you might expect, my "scientific reasoning" fell on deaf ears. Perception is reality.

Biotech cotton receives less scrutiny than food crops that have been genetically engineered because traditionally the fiber is made into textiles that are not eaten. Perhaps it is through lack of knowledge that extensive use of biotech cotton as a feed for dairy and beef cattle does not receive extensive notice. Also, one does not hear extensive complaint about the use of cottonseed oil from biotech cotton, perhaps for the same reason (although the amount of protein in cottonseed oil is extremely low).

One of the early complaints about biotech cotton concerned the perception that it would benefit only the large scale farmers who could afford the increased cost of seed. The argument followed that this would increase the difference in the relative well being of poor vs. rich producers. By extension, this was also applied to developing countries vs. developed countries. In 1991 it seemed to me (Stewart, 1991) that the technology would be of more benefit to the small scale farmer than the big producer. History has since shown that extensive benefits from biotechnology have accrued to the small scale producer. Many cotton producers in India and South Africa already enjoy these benefits (James, 2006). Perhaps because of the success enjoyed by these producers, today you do not hear this argument very often. In reality, the greatest disparity seems to be between those countries that have adopted biotechnology and those that have not.

Thus far, I have dwelt on the past and present situation with regard to biotechnology. My charge is to look into the future and try to offer prognostications concerning the role of biotechnology in the future. Because of the obvious benefits to cotton producers who have already adapted biotech cotton, one can predict that the application of biotechnogy will continue to expand into those areas and countries where it is not now grown. However, concerns about the safety of GMO's have slowed adoption and potentially could limit its spread into the areas where it is most needed. Hopefully, this Consultation will help provide partial, and perhaps full, answers to lingering questions concerning any environmental and socioeconomic risks associated with biotech cotton.

One of the issues that remains today, and probably will remain in the future, concerns the question of risk of environmental harm related to the release of biotech cotton into the environment. Of course, the question most at hand relates to the effect of biotech cotton expressing a Bt toxin or an enzyme that confers resistance to a particular herbicide, since these are the only biotech products that are currently commercially available. The history of the last 10 years tells us that the first generation of biotech products have not had a negative effect on the environment and will be widely grown in areas where they are currently not grown. The reasons why they are not currently grown are probably related to lack of a coherent set of approval mechanisms (country choice) or the lack of a viable method for protecting intellectual property rights (provider choice). As these various countries institute regulatory mechanisms and intellectual property rights, the technology will be made available through international trade. Part of the equation for protection of intellectual property is the establishment of a viable planting seed industry for reliable delivery of the seed to the producer.

For those countries with the capacity to develop their own biotech cotton varieties through public or private funds, the two elements of regulatory oversight and IP protection are still necessary. Pakistan is an example of this. Although it has the capacity to produce biotech cotton, only recently has the regulatory and IP systems been put into place. India, on the other hand, established its system more than 5 years ago, so that biotech cotton is now widely grown in that country.

One might ask, "Why is a regulatory system necessary if biotech cotton is not harmful to the environment?" To answer this question, one has to realize that regulation of biotechnology applies to all transgenic plants – not just to cotton. In addition, the regulatory rules must consider future genes that may be genetically engineered into cotton. As an extreme example, assume someone were to genetically engineer the botulinum toxin gene into cotton. As you know, the botulinum protein is a very powerful neutrotoxin. While cotton genetically engineered to express the gene might be grown as a specialty crop for isolation of the protein, because of the potential harm of the protein to humans, its production would have to be in isolation to prevent gene flow to other cotton. A viable regulatory system would require that the biotech cotton be grown and handled in such a way as to prevent any possible gene escape or any harm to humans.

To be commercially viable the cost of biotech cotton seeds must be priced lower than the cost of insect control practiced in that region. In this way both the developer of the biotech cotton and the producer will receive benefits. However, the late entry of some countries into the use of biotechnology in their agricultural enterprises, and especially cotton, places those counties at somewhat of a disadvantage in a global market. The cost of cotton production without the aid of biotechnology is relatively high because of losses to (or, control of) insects. In the interim, as more countries adapt to the reality of biotech cotton, yields increase, leading to higher production of cotton. Because of the increase in the world cotton supply available to the textile industry, the price received by producers could remain relatively low. Thus, the producer of non-biotech cotton will be at a distinct disadvantage.

Traditionally farmers are encouraged to produce cotton because it is a "cash crop" that provides foreign currency to the exporting country. However, in the absence of a domestic market for a cotton producer is subject to the global economy. This is very evident in the countries that historically have been dominant in cotton production and utilization. Because of the increased yield of biotech cotton, India will probably surpass the USA in total cotton production to become the number two cotton producer behind China, by virtue of the number of acres produced with increased yield. Because of the viable textile industries in both China and India, consumption of cotton will also increase as the economic status of those two countries increases. Hopefully, this will relieve some of the pressure on world cotton supplies.

Opportunities For Small-Scale Cotton Growers

The first commercially viable products in biotech cotton have been those that decreased the inputs required to manage the crop. The cheapest method to manage any insect or disease organism is through genetic resistance. By genetically engineering the *Bt* gene into cotton to resist lepidopterian insects, the cost of controlling these insects by chemicals is decreased dramatically. The developing companies recoup their investment by transferring part of the chemical management cost into the cost of the seed. In the case of genetically engineered herbicide resistance, in developed countries where labor is expensive or unavailable, the "technology fee" for the seed is less than for seed conferring insect resistance because part of the cost of development is recouped in sales of herbicide. In areas where hand labor for weeding is inexpensive and readily available, as in developing countries, it is not likely that herbicide tolerant biotech cotton will be successful.

As a result of biotechnology, farming systems have evolved. At the beginning of the green revolution, the mind-set of producers had to change in order that the technology be incorporated into their farming methods. This involved planting of genetically advanced seeds, planting at different plant densities than is traditionally done, chemical control of pests, changes in the application of fertilizers, etc. The implementation of biotechnology as an innovative method to improve production also requires a change in the mind-set of all stakeholders including the developers, producers and, perhaps for the first time, the consumer. Crop management must be accompanied by changes in cultural practices for success to be insured. Implementation of the new technology will depend upon 1) adequate education and training of producers to ensure that there is comprehension of the new technology. For example, engineered pest resistance does not mean that the crop can be planted and ignored until harvest. If anything, scouting for pests must be intensified. 2) For the technology to be useful, all of the genetic material must be adapted to the local conditions. That is, the engineered trait must be in a locally adapted variety. 3) Due attention must be given to the possibility that pests will develop resistance to the engineered resistance. Every effort must be made to delay the development of resistance so that the usefulness of the technology is not lost. 4) Ultimately the technology must provide benefits not only to the producers and developers, but it must also provide a benefit for the consumers of the raw product that can be passed to the ultimate consumers.

Both herbicide tolerant and Bt cotton are considered to be first generation products and are directed toward reducing the cost of inputs to manage the crop. Because reduction of input costs is of great benefit to producers in terms of cost of production, biotech developments have been rapidly incorporated into farming schemes. On the other hand, much of the potential benefit has been transferred to the companies developing the products at the expense of the chemical industry. While farmers have benefited from the biotech developments through increased yield and reduction in cost of managing the crops, consumers have benefited only to a lesser degree (through lower costs for textiles) because the raw product (cotton fiber) constitutes only a small part of the cost of producing and distributing a garment. A major criticism of those opposed to the biotech revolution is that producers receive only a faction of the potential benefits and the consumer receives very little.

To address this issue, the second generation of genes that will be available to the producer will probably be directed toward out-put traits, such as fiber quality and quantity and abiotic stress resistance. These are generally low value traits which, while extremely useful to producers, will not allow the biotech companies to charge high "technology fees" for seeds. In these cases, the strategy of the seed companies will be to maintain or gain "market share" for their seeds. Other low-input traits (e.g., fungal resistance; viral resistance), that may have extreme importance in a relatively small area, fall into this same category. These will have to be developed locally or regionally (depending upon biotechnological capacity). While "technology fees" at first appear to be high, as competition increases these can be expected to decrease, so that all the technology is within the perceived means of all producers. ("Cash flow" possibly could deter some producers, although by adopting the technology they would ultimately earn more from the crop.)

A new area that is receiving attention is the use of plants to produce pharmaceuticals. Plants can be genetically engineered to produce some drugs cheaper than they can be obtained from traditional sources. Although the cost of meeting regulatory requirements may be high, the high market value of the drugs could make the effort worthwhile. Part of the regulatory process will be to have absolute assurance that the trait will not be transferred to other plants not possessing the engineered gene. Of course, there are many factors that determine what the crop of choice would be for production of a specific drug, and cotton will be only one of many choices. Because of the use of cotton fiber as a wound dressing, it seems logical that it would be the plant of choice for production of antimicrobial compounds in the fiber.

The cost of meeting regulatory requirements has been, and will continue to be, a barrier to new biotech developments by academic scientists. Because of this, there has been a shift away from genetic engineering with a concomitant increase in the use of molecular markers to identify useful traits in crop germplasm. Cotton is fortunate in possessing a relatively large genetic pool from which to draw new genes (Stewart, 1995). Extensive effort is being devoted to mapping of the cotton genome and close relatives. Plants resistant to various pests and stresses that are derived from these efforts will avoid the high costs of meeting regulatory requirements since they will be developed through "natural" hybridization. A pertinent example of this would be the development of resistance to the leaf curl virus in *G. hirsutum* (4X) by introgression of resistance from *G. arboreum* (2X) While resistance probably can be developed through genetic engineering of cotton with appropriate genes that confer resistance to CLCV, in fact, it may be faster and certainly less expensive to introgress the resistance from the diploid species (*G. arboreum*), especially if a molecular marker can be associated with the area of the chromosome conferring resistance. As the molecular map of cotton evolves, selection of markers associated with particular traits will become easier, as will transfer of useful traits from exotic germplasm to elite cultivars.

In the future, biotechnology should be able to shift existing production systems to more environmentally friendly systems, especially in developing countries. Biotic resistance is just one of many traits needed to provide cotton crops that will yield more on less land. Some of the traits that are currently receiving attention are 1) increased light harvesting efficiency, 2) drought tolerance, 3) high and 4) low temperature tolerance, 5) salt tolerance and 6) fiber quality.

1) Any feature that improves the capture of light for photosynthesis would be useful in genetic engineering as a way to improve cotton yields. One way to do this would be to delay senescence of the leaves so that each leaf remains functional for a longer period of time. This seems to be a relatively straightforward method for improving light interception. Photosynthetic efficiency is a subject that has received much interest but little progress. Rubisco has affinity for both CO_2,which results in carbon fixation, and for O_2,which leads to carbon loss through photorespiration. A slight increase in affinity for CO_2 relative to O_2 would have a significant impact on carbon fixation.

2) Drought tolerance is a complex environmental parameter, that is often confounded by heat stress, or also (in the case of cotton) chilling stress. Much work has been done on model plants relative to gene expression in response to this abiotic stress. A number of genes have been increased that appear to be related to increased tolerance to water-deficit stress but they have not been reverse engineered yet, to verify a functional role in tolerance. Genes found in other plants (such as Arabidopsis) to be regulated by water-deficit, and other abiotic stresses, have also been found to be similarly regulated in cotton (e.g., DREB) (Lui, 2002). Some of these genes in model plants are claimed to increase tolerance to water-deficit and other abotic stresses (such as salt-stress). Because tolerance to biotic stress is a complex phenomenon, a single gene used to transform another plant is not expected to provide much increase in tolerance.

3) Heat stress potentially can be a limiting factor in cotton production in many parts of the world [Pakistan (Multan) is but one example where the average maximum temperature exceeds 42^0 C during June]. Wise *et al.* (2004) reported that electron transport reaches its limit in Pima cotton grown under field conditions in the USA southwestern desert. Deridder and Salvucci (2007) found that high temperature initially made Rubisco activase unstable but that it stabilized with time. This suggests that chaperon-type proteins probably stabilize the rubisco activase and that these proteins could provide a level of protection to the vital biochemical functioning of heat-stressed cells. Possibly genes coding for chaparon-type proteins could be genetically engineered for constitutive expression into cotton to increase tolerance to heat. Since these proteins play a role in enzyme protection and even in refolding of denatured protein, they would be expected to give a level of increased tolerance to most abiotic stresses.

4) Work on chilling-stress in cotton goes back many years (my graduate research), but as yet there has been no breakthrough in a viable approach to increase resistance to chilling-stress. Work at Texas Tech University suggests that maintaining a highly reductive biochemical environment improves tolerance to chilling-stress (Payton *et al.*, 2001). Transformation of cotton with superoxide dismutase increased its tolerance to chilling temperatures. Primarily, the antioxidants aid in removing damaging free radicals generated because of poor membrane function, especial in the combination of chilling temperatures and high light intensity. The cumulative information indicates that temperature membrane transition from a gel to a sol at around 12^0 C in cotton is related to its sensitivity to chilling temperatures. Genetically engineering cotton to have more flexible membranes (more unsaturated lipids) should increase its tolerance to chilling. On the other hand, this would probably also result in increased sensitivity to heat stress.

5) Salt tolerance. Many of the resistances to abiotic stress engage in "cross-talk", that is, the resistance mechanisms draw upon a sub-set of genes that function to improve resistance to an environmental stress. For example, because of their protein-protective nature, the chaparonins function in any abiotic stress where proteins potentially can be inactivated. Cotton is considered to be relatively tolerant of salt, and its cultivation might be extended into areas when other crops cannot grow because of high salinity. Many plants are considered to be halophytes (plants that will grow under high salt concentrations.) Several genes have been identified from these plants that seem to function in salt tolerance and have great potential in genetic engineering. A Na+/H+ anti-port enzyme, which excludes Na from the plant cell, may have potential for improving the salt tolerance of cotton.

6) Fiber quality is an area that everyone recognizes as a component of production, but few workers have sufficient knowledge of the molecular biology of fiber to speculate what genes might contribute to fiber quality. Although the process has been slow, the biology of fiber is going to unravel. Of particular note are the claims that single

genes have dramatic effects on fiber yield and quality. Dr. Haigler *et al*., (2000a) transformed cotton with a sucrose phosphate synthase, while Thea Wilkins (USA) transformed extensin into cotton. In each case the claim was that the plants expressing the gene had longer and stronger fiber and increased yield (Haigler *et al*., 2000b; Wilkins, personal communication). It seems unusual that single genes would have a dramatic effect on a range of quantitative traits.

Each of these are steps toward producing more and better cotton in a sustainable way. Also, one could hope that the output traits derived from biotechnology will be viewed favorably by the general public since they will not imply the plant is producing a "toxin," as now is the case.

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