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- **Update on cotton production research**
- **Nouvelles recherches cotonnières**
- **Actualidad en la investigación de la producción algodonera**

Contents

Introduction

The spinning industry has been very sensitive to the problem of seed coat fragments in cotton. There are three possible sources of seed coat fragments: unfertilized ovules or aborted fertilized ovules, also called motes; immature or under-developed seeds; and fragments coming out of full grown seeds. All seed coat fragments are created during machine picking and subsequent processing. Seed coat fragments adversely affect the appearance of yarn and fabric and are usually associated with ends down in spinning, lower yarn strength and less uniform yarn. Some varieties are less prone to produce seed coat fragments. Irrigation, growing conditions, and moisture content during ginning also have a significant impact on the origination of seed coat fragments. The rotor spinning process always indicates a lower number of seed coat fragments in the yarn because the yarn structure tends to hide the fragments on the inside of the yarn. Measurement and other issues regarding seed coat fragments are discussed in the first article.

The Food and Agriculture Organization of the United Nations and the International Cotton Advisory Committee undertook a joint study on the current situation and future prospects of transgenic Bt cotton in China (Mainland). Ms. Min Du of the Research Center of Rural Economy of Agriculture, China (Mainland), was hired to undertake the study and write a report. Ms. Du has critically reviewed the need and use of Bt cotton in China (Mainland). She also compared the cost of production between conventional varieties and Bt varieties. Her full report is published in this issue of *THE ICAC RECORDER*.

The boll weevil is the most serious cotton pest in Latin America. The boll weevil invaded Brazil in 1983, Paraguay in 1991 and Argentina in 1994. More recently, the boll weevil has also been detected in Bolivia. In order to tackle the problem and to rescue the cotton industry of the region, the International Cotton Advisory Committee sponsored a project entitled "Integrated Pest Management of the Boll Weevil in Argentina, Brazil and Paraguay." The project was funded by the Common Fund for Commodities and local agencies in the three countries; it became operational in August 1995 and ended in July 2001. The main objectives of the project were to develop and subsequently introduce an integrated pest management system to control the boll weevil and minimize the effect of insecticides on human health and the environment. The project was implemented under the overall responsibility of SENASA-Argentina and various collaborating institutes in Argentina, Brazil and Paraguay. The International Cotton Advisory Committee served as the supervisory body. The third article in this issue summarizes the project's work.

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Transgenic cotton area is increasing. According to the USDA, transgenic cotton was planted on 78% of the total cotton area in the USA during 2001/02. Australia has put a limit on its transgenic cotton area in order to avoid the development of resistance, otherwise, by now, area would be much higher than 30%. In South Africa, Bt varieties were planted on 40% of the total area in 2000/01. In China (Mainland) most of the cotton planted in 2001/02 in the provinces of Hebei, Henan and Shandong was Bt cotton. India is seriously considering allowing commercial production of Bt cotton, and many other countries are evaluating the performance of transgenic Bt cotton. The original goal of transgenic Bt cotton was to achieve an efficient, cost effective and environmentally safe pest control of major lepidopteron insects. But the plant's ability to inhibit the multiplication of lepidopteron insects has many benefits. Bt cotton may or may not give higher yields, affect quality, change farmers choice for varieties, etc., and all this is discussed in the fourth article.

A Dialog search of the Agricola and CAB Databases on contamination in cotton is given at the end of the publication.

The Technical Information Section of the ICAC conducted a Technical Seminar on the topic of integrated crop management at the 60th Plenary Meeting of the ICAC held in Victoria Falls, Zimbabwe in September 2001. Eleven papers from nine countries were presented at the seminar. The seminar proposed how the latest technological developments could be integrated into cotton production systems in various countries. The seminar noted that small farmers are taking equal advantage of Bt cotton, and group farming could further enhance the application and usefulness of new technologies. All the papers have been published together. The report is available from the ICAC Secretariat.

The 61st Plenary Meeting of the ICAC will be held in Cairo, Egypt from October 20-25, 2002 and the Technical Seminar will be held on the topic of "Technology, Management and Processing for Quality Fiber."

The Technical Information Section has updated data on cost of production of raw cotton, and the report can be ordered from the ICAC Secretariat at publications@icac.org. The 112-page report includes data on field operations and individual input costs from 28 cotton-producing countries.

Pre-registration for the World Cotton Research Conference-3 to be held in Cape Town, South Africa from March 9-13, 2003 is open. For more information, visit the ICAC web site at <http://www.icac.org/icac/meetings/meetings.html>.

Seed Coat Fragments

Cotton quality can be reduced by contamination during picking, handling and ginning. Examples of sources of contamination include bark, grass, spindle twist, seed coat fragments, dust, and oil. Seed coat fragments (SCF) are small pieces of cotton seed coats torn off during harvest and ginning. Seed coat fragments adversely affect the appearance of yarn and fabric and are usually associated with ends down in spinning, lower yarn strength and less uniform yarn. Some cotton fibers remain attached to small pieces of the seed coat fragments.

The kind of extraneous matter, and an indication of the amount (light or heavy), is noted by a classer on the classification record. According to the Universal Classification format adopted in the USA, and also followed in many other countries, the amount of extraneous matter in cotton is reported as level 1 (light) or level 2 (heavy).

The cotton program of the USDA has allotted code numbers for identifying the presence and level of seed coat fragments as follows:

Number	Level of Seed Coat Fragments
31	Level 1
32	Level 2

There could be three possible sources of seed coat fragments: unfertilized ovules or aborted fertilized ovules also called motes; immature or underdeveloped seeds; and fragments coming out of full grown seeds. Seed coat fragments in a cotton sample are an indication of just one kind of contamination, or the existence of extraneous matter. It is certain that there are no seed coat neps at the time of harvest.

The Seed Coat

The weathering effects on seed after it has been picked are not pronounced because lint on the seed serves as a shield against most weather. So the seed coat is safe as long as cotton is not ginned. Many internal changes go on even after a full-grown seed has been formed. One change is the concentration of an endogenous constituent abscisic acid, which decreases with the age of the seed until the germination capability is completed. Abscisic acid plays a significant role in the rapidity of germination and quality conditioning. The seed coat does not go through drastic changes during development. However, one change is that the seed coat continues to become harder even after harvest, a factor in the origination of seed coat fragments. The hard and impermeable seed coat, which is the case in many wild species, has several advantages:

- Impermeable seed prevents moisture absorption thus preserving its germination potential for a longer time.
- Impermeable seed does not allow microorganisms to infect the seed, thus reducing the chances of transferring pathogens along with seed.
- Embryo is safe and seed can be stored for a longer period of time.

While impermeability in uncultivated species may be an advantage, it is not preferred in cultivated cottons. A harder seed coat has less chance of breaking during ginning, provided that fibers are not firmly attached to the seed coat. Further, a seed that is too permeable will absorb moisture at a higher rate, which could trigger germination. For microorganisms to grow in the seed and reduce germination potential, a minimum of 12% moisture on a seed wet weight basis is required. If the seed coat is highly permeable, this level can be achieved easily and seed will loose its ability to germinate. Accordingly, the seed coat will also be affected.

The seed coat of cotton is much stronger than many other field crops. A cotton seed coat has six layers, which makes it stronger than other crops like corn, rice, soybean and wheat. Yet, the seed coat is not strong enough to stand the harsh effect of metallic saws. Mechanical damage to the cotton seed coat started with the introduction of saw type ginning; mechanical picking further increased the problem.

Effect of Fiber Moisture on the Seed Coat

Anthony and Griffin Jr., (2001) studied the effect of moisture content on the force with which fibers are attached to the seed coat and concluded that with increasing fiber moisture, the fiber-to-seed attachment force remained constant. They noted some decline in the force as the fiber moisture content increased to between 13-15%. Single fibers being pulled from their seeds at different moisture levels showed an increase in the number of fibers that broke as the moisture contents decreased. The cotton samples were pre-conditioned at various humidity levels and the tests were performed in a constant humidity chamber. The study suggested that seed coat tissues were relaxed when they absorbed some moisture, thus helping the fibers pull from the coat before they break.

In countries where cotton is machine picked, it is common to apply defoliants. Cotton can be defoliated at various stages after bolls start opening, but in most countries it is recommended to defoliate cotton when 60% of bolls have opened. It is assumed that this is a stage that does not result in any losses in yield and quality. Earlier defoliation, such as when only 30% to 40% of bolls have opened, may not cause losses in yield but certainly results in inferior quality lint. The effects of early defoliation on lint quality may be more pronounced, but seed quality is also affected.

For an in-depth analysis of the effects of early defoliation, seedcotton has to be divided into different strata on the plant and ginned separately. While the lower and middle strata may show no effects on seed index and maturity, the upper strata is certain to have a lower seed index and poor maturity. A lower seed index is a strong indication that the seed coat is week and can be broken easily. Seeds having a low seed index may be hosting weaker fibers as well. Weak fibers are loosely attached to the seed coat and can be removed with lesser force thus reducing the chances of damaging the seed coat. But immature seeds with a soft seed coat are broken easily during ginning and otherwise.

Status of Seed Coat Fragments in the World

It is difficult to state what percentage of the world cotton production is contaminated with seed coat fragments and by how much. Seed coat contamination data are not recorded in all countries. The International Textile Manufacturers Federation (ITMF) undertakes a cotton contamination survey every other year that includes a report on contamination with seed coat fragments, although the report is not based on a scientifically designed survey and collection of data. The 7th report was published in June 2001. The report includes information on the status of stickiness and seed coat fragments separately. The sources of contamination surveyed include various types of fabrics, strings, organic matter, inorganic matter and oily substances/chemicals.

According to the ITMF report published in June 2001, almost 40% of all cotton produced in the world tested positive for seed coat fragments as against 38% in 1999 and 32% in 1997. In 1995, almost 39% of world production had some level of seed coat fragment contamination. ITMF does not analyze samples but rather relies on the responses—present or not present—given by the textile industry. According to the report, there are countries that produce cotton free of seed coat fragments, and there are countries where almost two-thirds of production has broken seed coats entangled with the lint.

Sources of Seed Coat Fragments

Most of the blame is ascribed to ginning because that is when the seed looses its protection from lint. Ginning, especially poor ginning, may be a major cause for creation of seed coat fragments in the lint, but there are other factors that contribute to the problem.

Varietal Effects

Many studies are available which prove that seed coat fragments are affected by genotypes. A recent study was published by Hequet et al (1999). Eighteen U.S. varieties were grown at two locations, and two cotton samples were collected from each variety from each location. Cotton was harvested in the same manner at both locations and ginned on the same system to make sure that differences, if repeated at other locations, were attributable to genetic variation among varieties. The main objective of the study was to test a new machine, “Trashcam,” for measuring seed coat fragments in cotton being used in ring-spun and rotor-spun yarn. Trashcam was developed by Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), Montpellier, France, and measurements for seed coat fragments were also taken at the CIRAD lab in France. The number of seed coat fragments obtained on the ring spun yarn for 18 varieties were clearly repetitive across the two locations, showing that the differences are due to genetic variability among varieties. All varieties were also tested for seed coat fragments in rotor spun yarn, and the results were highly repetitive across both locations. Statistical analysis showed a highly significant effect for both varieties and locations but non-significant varieties by locations interaction. The results from CIRAD also proved that differences among varieties could safely be attributed to their genetic make up.

Anthony et al (1988) studied the effect of varieties, harvesting and ginning practices on seed coat fragments. They selected five varieties and planted them for two years, picked them at different intervals and then ginned cotton at various levels of lint cleaning. Normal production practices were followed during growing. Fields were defoliated and seedcotton was spindle-picked as twice-over (first and second harvest) and once-over (delayed picking). The second pick and once-over picking were affected by rain, especially in the second year. Cotton was ginned using zero, one, two and three lint cleaners. Seed coat fragments were counted as well as weighed during both years on samples taken during ginning.

The results clearly showed differences in one year over the other year in counts as well as the weight of seed coat fragments. Differences were evident in four out of five varieties. In one year, the first, second and the delayed picking had almost the same count of seed coat fragments. However, when seed coat fragments were weighed and results pooled for all varieties, the second picking gave a higher weight of seed coat fragments. Varieties could be categorized into two very clear groups, three varieties having 40.5 to 41.9 mg of seed coat fragments in the sample and the second group having 50.7 to 53.7 mg per sample. The effect of lint cleaners was evident by the fact that the higher the number of lint cleaners, the lower the weight of seed coat fragments.

Growing Conditions

Two important conclusions made by Van der Sluijs and Hunter (1999) on the effect of growing conditions and picking are:

- Irrigated conditions on the average resulted in 17% fewer neps than cotton cultivated on dry land, probably due to irrigated cotton being more mature. They did not find any difference in nep size.
- Machine picked cotton requires more cleaning which reflects differences in ginning conditions employed for hand picked cotton versus machine picked cotton. Machine (spindle) picked cotton contained 21% more neps and the nep size was slightly larger than the hand picked cotton.

One of their observations that cultivars only have a slight, if any, effect on nep levels and nep size is not supported by other references in the literature. Most of the work on neps in the literature refers to all kinds of neps and thus specific information on seed coat fragments responsible for neps is not available. But it is sure that if the percentage of neps is high or low, accordingly, neps due to broken seeds will also be high or low. Among growing conditions, if irrigation has an effect on nep creation, certainly other inputs like fertilizer will also have similar effects.

Ginning

The biology of the seed has a lot to do with the origin of seed coat fragments. At the gin, damage occurs when fibers are pulled from the seed coat. If the seed is hit by saw-teeth, seed is broken, thus forming seed coat fragments. Modifications, improvements and repairs to gins result in better ginning, less damage to fiber, lower cost, better lint recovery, and reduced seed coat fragments. Nevertheless, lint cleaning at gins results in increased nep levels and seed coat fragments, irrespective of the gin type.

Gin saws are sharp enough to damage and break any part of a seed, but the chalazal end is most vulnerable and broken most of the time. The amount of seed damaged during ginning depends on two factors: moisture content and ginning speed. Both have linear relationships with seed damage; as seed moisture increases, seed breakage rises, and an increase in the ginning rate (kg lint/saw/hour) also results in increased seed breakage.

Motes

The existence of motes can give rise to smaller and softer seed pieces in lint compared to fully mature seeds. Small motes are defined as ovules that have not been fertilized or underdeveloped seed in which embryos ceased growth shortly after fertilization. Small motes may measure 1 to 2 mm in width and up to 3 mm in length with fibers shorter than 1 mm. Medium size motes measure 1 to 3 mm in width and 3 to 5 mm in length with fibers less than 10 mm long. Non-fertilized motes can be categorized as those in which embryo sac formation was defective and those in which the embryo sac was normal and pollen entered the ovule, but fertilization was not accomplished. Small *G. hirsutum* motes weigh from 1 to 30 mg and have fiber less than half the length of fiber from normal seeds.

Post fertilization termination of embryo growth produces large motes with long fiber. Long-fiber motes weighing 35 to 60 mg have thin fiber cell walls with micronaire values less than 3.0. Short-fiber motes are generally removed during lint cleaning while fiber from long-fiber motes is ginned from the motes and is incorporated into lint.

Effect of Spinning Process on Seed Coat Fragment Counts

The opening and cleaning of lint has little effect on seed coat fragments though fiber neps may increase significantly. Carding may lower the number of seed coat fragments present in lint. Combing significantly reduces most types of impurities including seed coat fragments. Transportation of fiber from one process to another has no effect on seed coat fragments. The ring spinning process exposes the maximum number of seed coat fragments. The rotor spinning process always indicates a smaller number of seed coat fragments in yarn because the structure of open end yarn tends to hide fragments on the inside, as a result of centrifugal force applied during the yarn formation process. Also, the number of seed coat fragments could be reduced in open-end yarn because opening rollers in rotor spinning tend to remove at least some seed coat fragments. Bigger particles have more chances to be removed and to be broken into smaller pieces, and thus the number of bigger particles is reduced.

Testing of Seed Coat Fragments

The high speed spinning process has intensified the need for cleaner cotton free of neps, trash and seed coat fragments. Seed coat fragments affect the operation of machinery and fragments remain in yarn and affect dyeability and ultimately the quality of woven or knitted fabric. Improved blow room machinery and carding can play a significant role in reducing non-lint content of cotton, but it is more difficult to remove seed coat fragments compared to other types of trash particles. Seed coat fragments can be tested visually, by gravimetric mechanical method or by electro-optical means. Visual counting and mechanical analysis are labor intensive and provide only the total weight of trash/seed coat fragments respectively. There is a need for a method that could scan the sample material and analyze it in more detail, including the size of fragments.

The three instruments that are recognized by the industry to measure dust and trash, including seed coat fragments, are the Shirley Trash Separator - MK2; the Micro Dust and Trash Monitor - MDTA 3 (ITV Tester); and AFIS (Nep Model). The microscopic measurement of the number of seed coat fragments is higher in AFIS. Work is ongoing to improve AFIS, video scanning for the HVI Trashmeter, and a private company in Israel is also working to improve the Fiber Contamination Tester for accurate measurement of dust and trash particles. Yarn inspection devices using image analysis technology are capable of classifying different types of contamination in yarn. According to the ITMF International Committee on Cotton testing Methods, one of the important areas of current research is high-speed measurement of dust and trash including seed coat fragments in lint.

Neps and Seed Coat Fragments

Neps and seed coat fragments are interrelated. A nep can be defined as a small knot or a cluster of entangled fibers consisting either of pure fibers or foreign matter along with fibers, including seed coat fragments. Small pieces of foreign matter can also have free fiber tangles, resulting in nep formation. Fiber entanglement or clustering is the primary source of nep formation, followed by seed coat fragments. The number of fibers entangled together to form a nep large enough to be visible in yarn or after finishing has been studied by many researchers. It has been concluded that a minimum of five fibers jumbled together can result in a visible nep in the yarn. However, on average a particular fiber nep contains 16 or more fibers.

Neps in fiber ultimately result in neps in yarn. Yarn unevenness can be due to poor spinning as well, but most of the time uneven places are created due to fiber neps and seed coat fragments. Smaller neps have a higher chance of being hidden in the yarn. But, neps created by seed coat fragments are more prominent, and it is very difficult to hide them in the yarn. Neps formed due to fibers may be more numerous in fine cotton. Coarse fibers are less likely to be bent, entangled and bulked to form a nep. But this is not the case with neps formed from seed coat fragments.

Researchers have studied what percentage of neps in yarn is due to seed coat fragments. According to Hebert et al (1988), 13% of uneven places in yarn are due to seed coat fragments, while other references suggest that up to 28% of imperfections in yarn could be due to seed coat fragments. Work published in India and elsewhere indicates that seed coat fragments could be responsible for 17-19% of yarn unevenness. Fiber neps and seed coat fragments together could be responsible for almost 50% of yarn imperfections. Problems at the card sliver level are much greater than noted in yarn imperfections. In general, fiber micronaire is by far the most related fiber characteristic to the formation of neps, nep level and size.

Variations in the percentage of yarn unevenness related to neps and kinds of neps can largely be related to the origin of cotton, fiber characteristics, mechanical handling including ginning, and also the quality of the yarn made from a particular type of cotton. As the yarn count becomes finer, it becomes increasingly difficult for seed coat fragments to remain invisible. However, in open-end spinning, up to half of yarn imperfections can be related to broken seeds.

Issues for Consideration

Some important areas for study and consideration regarding measurement, elimination, and the origin of seed coat fragments are:

- References in the literature suggest that genotypes are a factor in the origin of seed coat fragments. Currently, this factor is not a consideration among breeders for selecting new genotypes. Breeders are already under strict instruction to adhere to many other agronomic and quality requirements. It is an issue for consideration whether breeders should screen varieties for seed coat fragment formation before release.
- The location by varieties interaction has shown (Hequet et al, 1999) no significant effect on broken seeds and the formation of neps related to seed coat fragments while the effect of location on yield and fiber quality is evident from much of the literature published around the world. There is a need to ascertain under what conditions it is important to test varieties for seed coat-related nep formation and when there is no need to test varieties for such defects.
- Just like stickiness, it is very important to prevent rather than cure seed coat fragments. The role of individual inputs applied under various production practices in forming seed coat fragments needs to be investigated in detail.

- The force with which fibers are attached to the seed coat is an important factor in the formation of seed coat fragments and also affects short fiber content and length uniformity. However, almost no cotton is tested for this character.
- Many times neps and seed coat fragments look alike, particularly in image analysis, and it is almost impossible to isolate seed coat fragments from fiber neps.
- Seed coat fragments may be small or they can be large enough to be visible to the naked eye. While bigger particles are visible on the outer surface of a yarn, small particles can easily hide in the yarn and may not be counted as seed coat fragments. This is one of the reasons that the number of neps per gram in yarn is far below the number measured in sliver. Yarn evenness data may indicate the existence of such particles, but the data cannot differentiate between fiber neps and seed coat fragments. The identification of seed coat neps hidden in yarn is another issue that needs to be investigated.
- The efficient and accurate measurement of seed coat fragments independent of other dust and trash is another issue that requires additional work.

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Transgenic Bt Cotton in China (Mainland): Present Conditions and Prospects

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China (Mainland) is the world's largest cotton producing and consuming country. How to increase cotton yields, improve quality and increase returns on limited land have been important issues at all levels for the government and interested bodies. For many years, especially since the end of the 1980s, pests such as the cotton bollworm *Helicoverpa armigera* lowered cotton yields, increased production costs and enlarged the gap between supply and demand of cotton. Moreover, the excessive and expensive way of controlling pests caused social problems such as pollution and ecological imbalance. When the traditional methods of pest control gradually lost their potency, China (Mainland) began research, on the development and use of Bt cotton (hereafter referred to as "transgenic insect-resistant cotton") in the beginning of the 1990s. It took China (Mainland) about ten years to finish the research, testing, demonstration, extension and commercial production of transgenic insect-resistant cotton varieties. Transgenic insect-resistant cotton is popular with farmers but arouses deep concern from related departments. This report describes the present situation with the development of transgenic insect-resistant cotton in China (Mainland) and analyzes cases surveying producers and consumers. It also attempts to predict its further development in China (Mainland) on the basis of explaining questions of public concern.

The Development of Transgenic Insect-resistant Cotton in China (Mainland): Background

Historical records show that the cotton bollworm has been the main insect jeopardizing Chinese cotton production. In the late1980s and early 1990s, the bollworm struck most of the Chinese cotton growing area violently, bringing disastrous losses to Chinese farmers. Losses caused by the bollworm for an average year were 10% to 15%. The supply and demand figures for China (Mainland) from 1986-1995 (Table 1) show that in these ten years, yield and total production of cotton fluctuated dramatically despite the unchanged demand for cotton. The range of fluctuation in supply these ten years was significant, with as many as five years when the variation exceeded 15%.

Table 1
Supply and Demand of Cotton in China (Mainland): 1986-1995

Year	Area (000 ha)	Yield (Kg/ha)	Production (million tons)	Demand (million tons)	Price (RMB)
1986	4,306	821	3.54	4.37	172*
1987	4,844	878	4.25	4.70	176*
1988	5,535	750	4.15	4.20	196*
1989	5,203	729	3.79	4.00	236
1990	5,588	807	4.51	4.42	300
1991	6,538	869	5.68	4.26	300
1992	6,835	659	4.51	4.46	300
1993	4,985	749	3.74	4.14	330
1994	5,528	785	4.34	4.03	544
1995	5,422	882	4.77	3.57	700

Source: *Report on the Development of Chinese Agriculture 1997*, The Bureau of Cotton and Jute of China (Mainland)'s National Supply & Marketing Cooperative.
* Proportional price

What is particularly noteworthy is the extraordinary fluctuation in cotton supply between 1991 and 1993. The cotton growing area increased by 4.5% over the previous year, but production decreased by about 21% with the result that the gap between supply and demand reached 400,000 tons. The purchase price of cotton remained the same, but the unit yield decreased by 24%. The dramatic decrease in yield was the immediate reason for the decrease in total production, and the large gap between supply and demand. The bollworm infestation was the main reason for the decrease in yield.

The outbreak of the cotton bollworm affected yields, decreased profits and brought serious social problems. To assure cotton yields, farmers had to increase the use of pesticides and labor, thus raising production costs. As recorded in the data of Jiluyu cotton growing area, which was hit most seriously, if the bollworm had been controlled promptly, the average lint yield would have been about 750 kg per ha; otherwise, the yield decreased severely. In 1992 and 1993, some cotton farmers did not control insect pests and as a result, their crops were a total failure. More than twenty sprays were required to control the bollworm and the cost of pesticides per ha. was RMB 1,400 (US$170), an increase of 70% over the 1980s. The health and even the life of cotton farmers were seriously harmed due to the increase in pesticide use. According to the data of the Biotechnology Center of the Chinese Academy of Agricultural Sciences (CAAS), in 1992 alone there were 100,000 poisonings in China (Mainland) due to pesticide spray, with 1,000 deaths. Among those cases, poisonings caused by spraying pesticide on cotton accounted for a large percentage. Besides seriously polluting cotton-growing areas, the overuse of pesticides for a long period induced resistance and the death of pests' natural enemies in large number, thus causing ecological imbalance.

For the above reasons, China (Mainland) followed the United States and formally initiated research and the use of transgenic insect-resistant cotton in the beginning of the 1990s. The transgenic insect-resistant cotton has an insect-resistant toxin from the bacterium *Bacillus thuringiensis* (Bt). As a result, cotton can produce its own insect-inhibiting toxin to resist bollworms.

As seen in Table 2, U.S. companies began to research insect-resistant cotton in the middle and late 1980s. In the late 1980s, a U.S. company, Miorogene, synthesized the Bt insecticidal gene and patented it. Then, Monsanto bought the rights and transferred it into cotton. In 1990, the univalent insect-resistant stem was produced and then the Bt gene was transferred into Deltapine cotton, which bred "Bollgard" cotton and put into commercial production. Thus, the U.S. became the first country to own Bt cotton.

Research and development of transgenic insect-resistant cotton in China (Mainland) went through the following processes:

- 1991 – Funded by the high-tech "863 Project," some scientific research institutions such as the Biotechnology Center and the Cotton Research Institute of the CAAS initiated synthesization of the Bt insecticidal gene.
- 1992 – The univalent insect-resistant gene was synthesized at the Biotechnology Research Center.
- 1994 – The gene was successfully introduced into Chinese cotton strains and China (Mainland) became the second country in the world to own transgenic insect-resistant cotton through independent research.
- 1996 – The bivalent insect-resistant gene was constructed. It not only has a stronger resistance against bollworm but also the ability to resist budworm.

During this period, a line of promising transgenic insect-resistant products was completed.

Experiments and demonstrations were being carried out at the same time as the scientific research. The Chinese Ministry of Agriculture launched regional experiments with insect-resistant cotton in 1995. There was also a special joint project of insect-resistant cotton in the Chinese "863 Project." Much progress has been made in the research, development and spread of insect-resistant cotton. Meanwhile, the related scientific research and administration departments in China (Mainland) have set up projects to research the possible development of resistance to insect-resistant cotton, its permanent use in production, safety of environmental release, segregation of genes and their stability, and the danger of budworms.

Apart from independent research, some provinces and autonomous regions in China (Mainland) introduced American Bollgard cotton. In 1995 and 1996, the Cotton Research Institute of the CAAS cooperated with Delta and Pine Land Company (DPL) in experiments with Bollgard. Since January 1997, some varieties of Bollgard cotton, such as NuCOTN 33 B, DP 99 B, and DP 32 B were approved by the provinces of Hebei and Anhui. At the same time, the Chinese Hebei Provincial Seed Company and DPL developed a joint venture called Ji Dai Cotton Seed Co., Ltd. In 2000, the Chinese Anhui Provincial

Table 2
Comparison Between Transgenic Technology in China (Mainland) and the World

1987	Belgium: Montagu Laboratory	A plant with the insect-resistant gene was developed.	The Biotechnology Research Institute of the CAAS, the Microbiology Institute of the Chinese Academy of Sciences	Transgenic plant was produced, but failed to determine the expression of insecticidal crystal protein.
	U.S.: Miorogene Company	Synthesized Bt insect-resistant gene and patented it.		
1988-1989	U.S.: Monsanto Company	Bought the right of using the Bt gene and began to synthesize insecticidal crystal protein, which was transferred into cotton.	Ibid.	Preparation of Bt transgenic cotton was begun.
1990	U.S.: Monsanto Company	Produced univalent insect-resistant plant. Transferred the Bt gene into Deltapine cotton.	Ibid.	Ibid.
1991	Ibid.	Selected and successfully bred “Bollgard” cotton, which could be commercially produced.	The project on research and development of transgenic insect-resistant cotton under “Project 863” was approved.	Synthesization of the Bt gene insecticidal crystal protein was initiated.
1992	Ibid.	“Bollgard” cotton began to be demonstrated in field and planted experimentally.	Biotechnology Research Institute, CAAS	Bt gene insecticidal crystal protein was synthesized. The univalent insect-resistant genetic plant was produced.
1993—1994	Ibid.	The American “Bollgard” cotton began to be produced commercially.	The Shanxi Cotton Research Institute of the Biotechnology Research Institute, CAAS	Transferred manmade synthesized gene, Bt insect-resistant crystal protein into cotton, obtaining transgenic cotton plant with high insect-resistance. The transgenic cotton was demonstrated and planted experimentally on a small scale.
1995-1996	U.S.: DPL Company	Commercial production of “Bollgard” cotton was approved.	Biotechnology Research Institute, CAAS	The bivalent insect-resistant Bt transgenic cotton plant was produced (bollworm and budworm resistant)

Source: Planting Industry Administration Department of the Chinese Ministry of Agriculture
Agricultural Technology Extension Center of China (Mainland) Biotechnology Research Institute, CAAS
China (Mainland) Transgenic Cotton Information Net

Seed Company and DPL developed another limited seed company called An Dai.

Starting in the 1990s, it took ten years for Chinese transgenic insect-resistant cotton to complete the process of research, testing, demonstration, spread and commercial production through the hard work of scientists and financial support from the “863 Project.”

Present Developments with Transgenic Bt Cotton in China (Mainland)

Research, demonstration and the spread of the transgenic insect-resistant cotton in China (Mainland) arises as the times demand. As soon as it was introduced, it was accepted by farmers and has shown strong vitality. In order to prevent further spread of the bollworm, China (Mainland) planted experimental plots and demonstrated transgenic insect-resistant cotton on a small scale in Hebei, Henan and Shanxi. Encouraged with the preliminary results of research and development, since 1997 the cotton growing area increased in the Yellow River Valley in Shandong, Henan and Shanxi. Later, cotton growing areas in the Yangzi River Valley such as Anhui, Hebei and Jiangsu also planted Bt cotton on an experimental basis. By 2000, the area of transgenic insect-resistant cotton was almost 1 million ha.

Main Varieties and their Market Shares

At present, the varieties of Bt transgenic cotton grown in China (Mainland) include the following three series (Table 3): DPL (Xinmian NuCOTN 33 B, DP 32 B, DP 99 B), Zhongmian (ZM 29, 30, 32, 38) and Guokang (Gk-12, JM- 26, SGK 321, etc). Among them, NuCOTN 33 B, DP 32 B, and DP 99 B were introduced into China (Mainland) through the joint ventures Ji Dai and An Dai, between 1997 and 2000. The CCRI and Guokang series were independently developed by the Cotton Research Centre and the Biotechnology Research Institute of CAAS.

The main facts of the transgenic insect-resistant cotton market from market shares of three varieties in recent years are as follows (Table 3):

- The area of transgenic insect-resistant cotton in China (Mainland) has been growing rapidly. In 1998, the acreage was no more than 100,000 ha, whereas in 2000 it skyrocketed to almost 1 million ha. The proportion of transgenic insect-resistant cotton out of the total cotton area increased from 2.2% in 1998 to 28% in 2000.
- Three major series are dominant in the Chinese transgenic insect-resistant cotton market. From 1998 to 2000, three major lines accounted for more than 80% of the total transgenic insect-resistant cotton market.
- The American Xinmian series expanded rapidly in China (Mainland). NuCOTN 33B and DP 99B accounted for 34% of the market share dominated by the three major varieties in 1999. In 2000, the percentage increased to 43.6%. According to a survey of the cotton growing areas, the share expanded in 2001.

Characteristics of Insect-resistant Cotton Varieties in China (Mainland)

At present, insect-resistant cotton varieties in China (Mainland) have the following characteristics:

- Resistance varies according to time and area. The insecticidal activity of insect-resistant cotton is mainly effective for the bollworm in its 1st and 2nd generations, while for the 3rd and 4th generations, the activity decreases noticeably. In the same period, the insecticidal activity of the cotton bud is lower than the leaf. Therefore, the Bt transgenic cotton performs better in the Huanghuaihai cotton growing area which was seriously hit by the 2nd and 3rd generations of the bollworm, while resistance was weaker in the Yangzi River Valley cotton growing area, which was more seriously hit by the 3rd and 4th generations of the bollworm.
- Resistance is decreasing. Resistance grades of the resistant population decreased from "highly-resistant" to "resistant" and "moderately-resistant."
- The insect-resistant cotton is only effective in killing lepidoptera insects. Thus, pesticides are still needed to control other insects during the growth period of the insect-resistant cotton.

Comparison of Properties and Research and Development of Chinese Transgenic Insect-resistant Cotton Varieties

Properties of transgenic insect-resistant cotton are high yields, insect-resistance, high quality, stable resistance, and simple planting. According to the analysis based on surveys conducted in the Hebei and Shangdong growing areas, the three major lines of varieties grown in China (Mainland) have their own advantages and disadvantages. Some farmers said that NuCOTN 33 B has advantages in resistance, high yields and stability, but also has disadvantages, such as weak growth during the seedling stage, small cotton boll, low ginning outturn and low-quality. 80% of the GK series (such as GK-1, GK-12, JM 26) is insect-resistant and over 15% have high yields, but some problems with stability displayed by the fact that the variety requires special growing conditions: a strain performing well in place A may perform moderately in place B. Some strains such as JM 26 are limited to Shanxi and are difficult to spread to the whole country. Some strains of the Zhongmian series have good comprehensive properties. Hybrid transgenic insect-resistant cotton has the advantages of high yields, good quality and insect-resistance. However, the hybrid cotton is hard to spread because of the complicated seed production method and high costs. Second, in regard to industrialization of cottonseed, Monsanto has a significant advantage over Chinese seed companies. A survey of cotton areas showed that the Xinmian line has a complete system of seed production, promotion and operation. Monsanto also has much better business management and after-sale service than domestic seed enterprises. In contrast, the genetic synthesization, variety selection and breeding, seed production, operation and the spread of domestic insect-resistant varieties are executed in several separate links in Chinese companies. Thus, limited funds are not used wisely and it is difficult to form a joint force. As a result, Chinese companies are slow to complete research and transform research results into production and extension. Furthermore, the management of seed enterprises and market services does not catch up with market developments. Third, the U.S. transgenic insect-resistant cotton research enjoys wide fund channels, large amounts of funding and plentiful achievements. On the contrary, in China (Mainland), much less funding is put in transgenic insect-resistant cotton than in the U.S. and other countries, and channels to raise funds are limited.

Table 3
Main Transgenic Bt Cotton Varieties in China (Mainland) and their Market Share 1998-2000 (000 ha)

Year	Guokang Series	Xinmian Series	Zhongmian Series	Total Bt Transgenic Cotton	Total Cotton Area in China (M)
	Researchers				
	Biology Center of CAAS	Monsanto Company	Cotton Research Institute of CAAS		
1998/99		55		100	4,459
1999/00	230	150*	40	530	4,000
2000/01	350	360*	60	1,000	3,560

Source: Agricultural Machinery Extension Center; Biology Center of CAAS; Monsanto Company.
* Total figure from surveys throughout China (M) (seeds bought by farm households from other provinces and self-saved).

Table 4
Comparison of Length, Strength and Micronaire between Transgenic Bt Cotton and Conventional Cotton

Conventional Cotton				Transgenic Bt Cotton			
Variety	Length (mm)	Strength (g/tex)	Micronaire	Variety	Length (mm)	Strength (g/tex)	Micronaire
CCRI 12	29.9	19.9	4.4	Shiyuan 321	29.0	19.6	4.8
CCRI 23	27.4	21.4	4.6	Xinmian 33B	29.7	21.5	4.3
Jimian 19	28.9	18.3	4.4	CCRI 29	29.4	21.5	4.3
Lumian 6	29.3	19.9	4.0	CCRI 30	29.2	21.5	4.7
Jinmian 10	29.5	20.8	4.1				
Yumian 19	31.0	21.4	4.5				
Junmian 1	29.5	19.7	4.1				
Xinluzao 1	29.0	20.7	3.9				
Xinluzao 8	28.0	19.8	3.4				

Source: Cotton Research Institute of CAAS

Consumer and Producer Concerns About Transgenic Insect-resistant Cotton

As soon as transgenic insect-resistant varieties were developed, there has been concern and controversy. With continued research, concerns have focused on quality assurance, economic profits and safety in use. In this analysis, the term “consumers” refers to textile enterprises and consumers of cottonseed oil, and the term “producers” refers to cotton farmers.

Transgenic Insect-resistant Cotton Quality

Textile mills require a variety of cotton types and qualities. The quality of conventional transgenic varieties (color and length) is comparable. In Table 4, conventional cotton is represented by nine varieties, which represent a significant proportion of Chinese cotton production. Transgenic insect-resistant cotton is represented by NuCOTN 33 B, CCRI 29, CCRI 30 and SY322. From the data, it is clear that the transgenic insect-resistant cotton is not significantly different from conventional varieties in length, strength, and micronaire; it even has advantages over conventional varieties in the parameters measured. The reason is not difficult to find. Transgenic insect-resistant cotton is produced only by introducing insect-resistant genes into cotton and does not change the original properties of the carrier plant. And the carrier, which is transformed with the transgenic Bt gene, is originally a fine variety.

Economic Benefits

The properties of transgenic insect-resistant cotton, such as insect-resistance, high yields and stability reduce the production costs of cotton and enhance profits that benefit cotton farmers. In Hebei, where the largest area of transgenic insect-resistant cotton in China (Mainland) is planted, no pesticide was needed to control bollworms on transgenic insect-resistant cotton in 1998. The cost of pesticides decreased by RMB 1,200 per ha (US$145/ha), with an average yield of 1,050 kg per ha for ginned cotton, an increase of 20% over that of conventional varieties and a decrease of about 150 employees. In total, the income per ha increased by RMB 3,759 per ha (US$455/ha). This result is supported by case studies conducted in Feixiang of Hebei, Huimin of Shandong, and Handan of Hebei and Xiajing of Shangdong for two years.

Table 5 compares input costs and yields between transgenic insect-resistant cotton and conventional varieties in Feixiang of Hebei and Huiming of Shandong. In this case, seed costs for Bt cotton increased by a large degree. Due to different varieties used by cotton farmers at these two places, seed costs increased by 6.6 times and 1.4 times respectively. However, the costs for pesticide decreased drastically. The cost of pesticides for NuCOTN 33 B in Hebei and AM 29 in Shandong decreased by 84% and 82% respectively. Cotton farmers growing NuCOTN 33 B in Hebei and CCRI 29 in Shandong increased their profits by 19.4% and 24.2% (excluding costs for saved labor) and even though input costs did not decrease, yields and profits increased with the change in input costs.

Table 6 shows a case that was studied at Liumingying Village, Yongnian County, Handan City, Hebei Province in March 2001. It compares results from 53.5 ha of transgenic insect-resistant

Table 5
Comparison of Main Costs between Transgenic Bt Cotton and Conventional Cotton in 1998 (RMB/ha*)

Input	Feixiang, Hebei		Huiming, Shandong	
Variety	ZM 33B	Jimian 20	ZM 29	ZM 28
Soil preparation	231	231	75	75
Irrigation	669	669	375	375
Plastic covers	230	230	600	600
Fertilizer	1,860	1,860	1,275	1,275
Pesticides	146	908	225	1,275
Seed	908	120	450	300
Other items	-	-	10	35
Total	4,043	4,018	4,350	4,050
Yield	1,485	1,296	1,620	1,350
Output value	17,820	15,552	19,440	16,200
Income	13,778	11,535	15,090	12,150

Reference: Surveys conducted by the Cotton Research Institute of CAAS
* US$1=8.27 RMB

Table 6
Comparison of Input and Yields of Transgenic Insect-resistant Cotton between Liumingying Village and National Average in China (Mainland) in 1999
Farm households = 61 Area planted = 53.5 ha

	Variety	Input Costs	Labor Input	Daily Labor Cost	Labor Cost	Lint Yields	Selling Price per 50 kg	Output Value	Net Income per ha
Liumingying Village	Zhongmian 33B	3,857	273	9.5	2,594	1,515	380.00	12,954	6,504
Average in China (Mainland)	All varieties	3,507	453	9.5	4,304	1,003	381.37	9,015	1,205

Source: Case study of Liumingying Village, Yongnian County, Handan City, Hebei Province, *Agriculture Year Book of China (Mainland) 2000.*

cotton grown by 61 farm households in Liumingying Village with conventional cotton that year. All 61 households planted the NuCOTN 33 B variety. For comparison, the prices of ginned cotton and by-products are measured by national average prices. The table shows that although input costs of planting cotton are higher than the average costs of local varieties, the return per ha. is higher than the average of the country. There are two main factors responsible for this: first, cotton yields are higher than the average of the country; second, labor input is less than the average of the country, which means cotton growers benefit from high yields and the insect-resistance of transgenic cotton.

Table 7 compares profits of transgenic insect-resistant varieties with conventional varieties grown by nine farm households in four villages of Suliuzhuang Town. The nine farm households surveyed planted a total of 3.36 ha. of cotton, eight of which planted both transgenic and non-transgenic cotton. Seven out of the nine households planted the conventional variety 9418, and the others planted ZHM 19. All nine households planted NuCOTN 33 B. The costs for transgenic insect-resistant cotton increased by RMB 317.2, 64, 25.5 (US$38, 8, 3) for seeds, plastic covers and watering, respectively, over the conventional variety, but a decrease of RMB 4.5, 677.4 and 996.5 (US$0.5, 82, 120) in fertilizers, pesticides, and labor input respectively over the conventional variety. In total, costs per ha. decreased by RMB 1,352.4 (US$164). Plus, transgenic cotton yields were higher than conventional cotton yields. Therefore, there is an average increase of RMB 4103.7 per ha. (US$496/ha).

Table 7
Comparison of Profits of Planting Transgenic Insect-resistant Cotton and Conventional Cotton

Input	Insect Resistant Cotton	Conventional Cotton	Difference
Preparation	214	214	0
Seed	404	167	317
Plastic covers	296	232	64
Fertilizer	1,213	1,217	-4
Pesticides	452	1,129	-677
Irrigation	197	172	25
Man power	8,357	9,354	-997
Total inputs	11,132	12,484	-1,352
Yield	19,669	16,918	2,752
Net income	8,537	4,434	4,104
Area planted	2.6	0.76	

Source: Case studies conducted at Liuxinzhuang Village of Xinshengdian Town, Yujiacang Village of Suliuzhuang Town, Zhumiao Village and Menghan Village of Xiajin Town, Mozhuang Village of Ciangzhaozhuang Town, Xiajin County, Shandong Province.

The case studies conducted in three different provinces, regions and times reflect something in common: insect-resistance, higher yields and lower costs for transgenic insect-resistant cotton compared with conventional varieties. Consequently, farmers' profits are higher. Cotton farmers in Xiajin of Shandong did not intend to plant any conventional cotton in 2001.

Safety of Transgenic Insect-resistant Cotton

There are two common concerns about safety: one is the safety of the transgenic insect-resistant cotton itself, that is, whether cotton fiber and cottonseed oil are harmful to human health or not. The other is safety in using insect-resistant cotton.

First, the reason why transgenic insect-resistant cotton can resist bollworms is that the cotton plant can synthesize Bt insecticidal protein, which changes according to time and position and, accordingly, leads to changes in its insect-resistance property. The Institute of Plant Protection of the CAAS proved that the content of the insecticidal protein changes dramatically according to time and position in the stage of cotton reproduction. At the seedling and budding stages, the content is high. At the flowering stage, the content tends to decrease. The drop is most obvious at the flowering and boll formation stages. In the stages of boll formation and boll opening, there is a slight rise in content. The insecticidal protein also varies with different organs, with the highest in tender leaves. Moreover, planting of the transgenic insect-resistant cotton reduces substantially chemical pesticide use and poisoning of people and animals during cotton production. It also lessens environment pollution of cotton growing areas, protects the ecological balance and natural enemies, and decreases pollution the cotton fiber suffers because of pesticide use. The safety of transgenic insect-resistant cotton is increased instead of decreased because conventional cotton needs a high dosage of pesticides.

Chinese Government Guidelines and Management Measures

The guidelines of the Chinese government for transgenic insect-resistant cotton are active support, observance of a reasonable procedure and healthy development, and stable and strict management.

- Active support

It is agreed in administration documents that transgenic insect-resistant cotton is an effective measure to control bollworm. It can lift farmers' profits and enthusiasm for planting cotton. Thus, the departments responsible for cotton at all levels support it actively, respect cotton farmers' will, protect enthusiasm for planting insect-resistant cotton in areas seriously hit by bollworms, and enhance the healthy development of cotton production.

- Observing procedures

Apart from active support of transgenic insect-resistant cotton, the Chinese government also believes that as a product of high tech, this technology has to be researched deeply and perfected because its application in China (Mainland) is recent. During its development, stipulations and laws about gene release, regional experiments, the examination and approval of varieties, commercialization of its production, and planting arrangements should be strictly observed so as to prevent cotton farmers from suffering losses.

- Healthy development

Several relationships should be well tackled in research on transgenic insect-resistant cotton.

  - The relationship between present and future: although insect-resistant cotton can lessen the harm of lepidoptera at present, pests will become resistant in several years. It has already been found that there is a trend that the harm done by pests such as aphid, spider mite, plant bug, and non-lepidoptera is becoming serious in some areas growing insect-resistant cotton—directly threatening the sustainable development of cotton.

  - The relationship between insect-resistant cotton and non-insect-resistant cotton: the experience of planting insect-resistant cotton in China (Mainland) and in the world suggests that insect-resistant cotton and non-insect-resistant cotton should be planted according to a certain proportion to provide "refuges" for pests so that the development of resistance can be deterred.

  - The relationship between different cotton areas: the model for the development of transgenic insect-resistant cotton should not be a single one because the distribution, situation and duration of pest infestations are different in different cotton areas.

- Strengthening administration

  - Strengthening the administration of genes and varieties: there should be an overall plan for varieties to be developed with insect-resistant genes. The plan should be future-oriented. The varieties developed should be determined differently in the light of different circumstances (in different areas).

  - Strengthening management of seeds: one should establish bases of breeding and processing insect-resistant seeds, supervise seed quality during the whole process, maintain insecticidal activity and purity of the variety, maintain a unified system of seed provision, forbid farmers to save seeds, price seeds reasonably to prevent seeking huge profits, registering homemade insect-resistant cotton brands and produce famous brands.

  - Strengthening planting management: development of insect-resistant cotton needs an overall planning and a rational arrangement. In areas where bollworm infestations are light and where bollworms can be effectively controlled by integrated pest management, planting Bt cotton and other transgenic crops in the same area should be avoided to prolong the life of the transgenic insect-resistant cotton.

  - Strengthening management of resistance property: the U.S. measures are a good example. Transgenic crops should be registered for the convenience of administration.

  - Strengthening the monitoring of insect pests resistance: integrated pest management of transgenic cotton fields should be monitored to ensure its healthy development in China (Mainland).

Conclusions and Outlook

Research, demonstration and the spread of transgenic insect-resistant cotton in China (Mainland) will increase as the times demand. As soon as it was introduced, it was accepted by farmers and showed a strong vitality. China (Mainland) took about ten years to complete the process of research, experimentation, demonstration, extension and commercial production of transgenic pest-resistant cotton. The guidelines of the Chinese government for transgenic insect-resistant cotton is active support, observance of process and healthy development, and stable and strict management measures supporting the work and pushing the work forward. Although the spread of transgenic insect-resistant cotton in China (Mainland) has many imperfections, such as incomplete varieties and an underdeveloped operation and service, which do not keep pace with the market, insect-resistance, high yields and simple use make it economical. Transgenic insect-resistant cotton reduces the use of chemical pesticides, thus reducing pollution, protecting bollworms' natural enemies and maintaining the ecological balance.

It is assumed that the growing area of transgenic insect-resistant cotton in China (Mainland) will increase further. According to some data, in 2001 the growing area of the GK Line alone may approach 800,000 ha. It is believed that the increase of growing area of the transgenic insect-resistant cotton in the following years will be determined by the following factors:

- First, the policy and measures taken by the Chinese government, which will agree on an agriculture and rural policy in the near future. In China (Mainland)'s Tenth Five-Year Plan, the constant increase of farmers' incomes is highlighted on the agenda of economic work, and the industrialization of agriculture is regarded as an important way of promoting the modernization of agricultural operations. It is also pointed out that a high quality and highly effective planting seed industry should be developed with an emphasis on optimizing varieties, improving quality and enhancing profits.

- Second, the supply and demand of cotton at home and abroad in the following years. After China (Mainland) liberalized the cotton market, operation models and prices, in 1998, the supply of cotton was increasingly affected and limited by demand and price. With China entering the WTO, the international cotton market will affect China (Mainland) more and more.
- Third, the inner quality of transgenic insect-resistant cottonseed, the operation of seeds and the consciousness of service. This has been expounded in this report earlier.

There may be a substantial increase in the use of transgenic cotton in the following years. But considering the recent supply and demand situation of cotton, the optimism should be restrained. The inner properties of transgenic insect-resistant cotton, such as insect-resistance, high-yields and stability is the ultimate decisive factor of its survival and development. And, the operation concept of transgenic insect-resistant cotton and consciousness of service are important factors that will decide its market share.

Integrated Pest Management of the Cotton Boll Weevil in Argentina, Brazil and Paraguay

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Overview of Project Activities

The boll weevil invaded Brazil in 1983 and spread to Paraguay in 1991 and Argentina in 1994. Its presence in the southern cone of South America threatened some 4 million ha. of cotton. Since it erupted, Brazil has gone from being a net exporter to a major cotton importer. Therefore, in order to face the problem and to rescue the cotton industry of the region, the Common Fund for Commodities approved a five-year project entitled "Integrated Pest Management of the Boll Weevil in Argentina, Brazil and Paraguay," in September of 1994. The project became operational in August 1995. The main objectives of the project were to develop and subsequently introduce an integrated pest management system to control the boll weevil while minimizing the effect of insecticides on human health and the environment. The project was implemented under the overall responsibility of SENASA-Argentina and various collaborating institutes in Argentina, Brazil and Paraguay. The International Cotton Advisory Committee served as the supervisory body.

The countries that participated in the project, Argentina, Brazil and Paraguay, are the main cotton producers in South America. The boll weevil is mainly controlled in these countries by insecticides, creating ecological risks, development of resistance and high production costs. In order to manage the boll weevil, the project focused on the development and improvement of cultural and biological controls, proper use of insecticides with a gradual but steady shift to less toxic products, monitoring of insecticide resistance and dissemination of knowledge to farmers.

The central objective of the project was to improve cotton productivity and farmers' incomes in Argentina, Brazil and Paraguay through the development and implementation of integrated pest management strategies in cotton. This broad objective was achieved through basic research on the bionomics of the boll weevil, validation of control measures, assessment of new control measures, adoption of acquired technology and technology transfer to farmers.

Participating Institutions

Each participating country assembled a team of experts from different research institutes who were well known for their previous work in one or more relevant areas of IPM. Therefore, specialists in topics like biological control, GIS, biochemical taxonomy, pesticides, plant taxonomy, insect population dynamics and extension were selected in eight institutes in Argentina, three institutes in Brazil and one in Paraguay. Thus, from the three countries, a total of 20 activity leaders and more than 65 associated scientists worked on the project.

Eight working groups were assembled with the participation of scientists from the three countries, who agreed on the objectives and unified criteria on the methodology to be used for each topic. The working groups embraced all the research activities of the project.

Key Management Actions

The Project Executing Agency (PEA) set clear objectives and developed verifiable indicators for evaluating project performance. Indicators were established for each activity, and component objectives were reviewed in view of the concerns and skills of each working group in different countries. The PEA performed its activities within the framework of a number of well-defined programs that were designed to meet the following objectives:

- Maintain and foster research excellence in the framework of the project.
- Assist institutes and researchers to attain the necessary research infrastructure needed for the successful completion of their individual projects.
- Promote, develop and coordinate multidisciplinary and multi-institutional cooperation in research activities.
- Establish, reinforce and exploit international scientific contacts and collaboration.
- Evaluate reports and programs of participants and their outputs
- Optimally utilize all available funds to realize the former objectives mentioned.

Outputs from Different Components of the Project

Molecular Studies on Argentine Populations of *Anthonomus grandis*

The migration routes of the boll weevil *Anthonomus grandis* were determined and gene flow between populations was established using the RAPD technique. The results showed that Misiones (Argentina) populations came not only from cotton growing areas but also from many native hosts. However, insects sampled in Formosa were related to invading populations similar to those from Paraguay and Brazil. Knowledge of migration routes contributed to design control and more efficient eradication strategies, focusing on specific geographic areas.

A. grandis widened its range of host plants within Malvacea during prehistoric times, and this host shift allows natural boll weevil dispersal. For this reason, it is particularly important to determine if boll weevils reproduced in wild hosts are genetically different from boll weevil populations that are better adapted to cotton, and if they can change hosts whenever conditions are favorable.

DNA molecular techniques have become a powerful tool for pest control because they allow characterizing insect populations, determining gene flow and isolation, and solving problems such as the ones mentioned above. RAPD analysis was applied to characterize *A. grandis* populations from Argentina, Brazil and Paraguay with the aim of assessing their gene flow and pathways of dispersal. Populations from seven South American sites were analyzed and compared with samples from Tecomán (México) and Mississippi (USA). Genetic differences between the populations showed that they behave as independent panmictic units. The highest percentage of polimorphic loci was registered in the samples from Tecomán (México) and the Iguazú National Park (Misiones, Argentina), as is typical of central populations.

Results from these studies suggest that boll weevils from Laguna Neick Neck (Formosa-Argentina) come not only from Paraguay, but also from Londrina (Brazil), probably due to commercial activities between Argentina and Brazil. On the other hand, some of the results suggest that populations from Argentina (Puerto Península and Laguna Neick Neck) are intermediate between those from Brazil (Londrina and Carajá) and Paraguay (Caacupé and Ijhoví), except the population from Puerto Iguazú, which is genetically closer to the one from México than to the other South American populations.

Alternative Hosts and Feeding Behavior of the Cotton Boll Weevil

Some plant species from the families Malvaceae, Compositae, Solanaceae, Euphorbiaceae and Leguminosae provide pollen on which adult boll weevils feed in the absence of cotton. The seasonal fluctuation and selectivity with regard to the pollen intake of the boll weevil was found to be independent from the place the sample was taken. Exotic plant species from the family Malvaceae (*Hibiscus tiliaceus*, *Hibiscus schizopetalus*, *Hibiscus sabdariffa, Abelmoschus esculentus, Hibiscus rosasinensis*) are not alternative hosts for *A. grandis* in natural conditions. The data obtained on the blossoming seasonal fluctuation, climate and feeding preferences of the boll weevil can be used to anticipate control measures by predicting which places may be natural reservoirs of the pest.

In subsequent studies, the species *Hibiscus rosasinensis, Hibiscus schizopetalus, Hibiscus tiliaceus, Hibiscus sabdariffa, Malvaviscus arboreus and Abelmoschus esculentus* were assessed as reproductive hosts in natural conditions. The results obtained showed that there was a natural negative response of the boll weevil to those species, indicating that they were not suitable reproductive hosts.

A supply of alternative pollen provided boll weevils with nutrients, increasing survival in the absence of cotton. It should be noted that high rates of winter survival lead to high densities of cotton boll weevils the following cotton season. For this reason, knowledge about the plants that provide a source of food to the cotton boll weevil is very useful for control programs. Hence, the plants acting as a food source for the cotton boll weevil were determined.

In Formosa, pollen grains from boll weevil gut could be assigned to 61 different plant species belonging to the families Malvaceae, Compositae, Solanaceae, Euphorbiaceae and Leguminosae.

Phenology and Dynamics of Adult Cotton Boll Weevil Dispersion

Adult boll weevils survive between cotton growing seasons even in the absence of cotton. Abundant rain and a continuous supply of alternative pollen species permit boll weevil survival. At the beginning of the cropping season, the pest begins to infest crops from the perimeter of plots, and becomes more important when cotton plants are 100 days and older. After harvest, rooting out and burning stubble is one of the most effective methods to avoid or delay re-infestation. By knowing the population dynamics and feeding behavior of the cotton boll weevil, it will be possible to restrict dispersion and infestation of the crop. It has been demonstrated that the use of trap crops, border treatment and stubble destruction are central to managing this pest.

According to the data obtained from different monitoring areas in Paraguay, a higher activity and movement of the boll weevil can be observed in the southern area of the country, followed by the northern and center-west areas. After harvest, boll weevils survive by feeding on pollen from plants remaining between cotton seasons. Food and weather conditions determine the percentage of survival each year.

Use of Insecticides–Insecticide Resistance Monitoring

Susceptibility to Pesticides

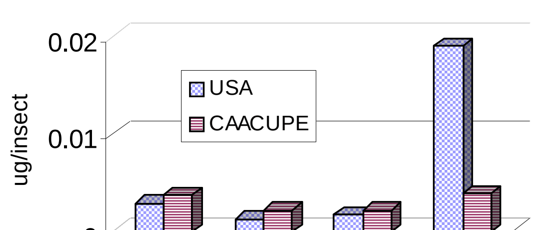
Studies were conduced to quantify relative toxicity of one organophosphate and selected pyrethroids and some of their isomers on *A. grandis* to obtain useful LD_{50} values for monitoring future changes in the susceptibility of these compounds.

On the other hand, by using the same compounds and similar bioassay techniques, two populations were tested for susceptibility: one normal susceptible strain from the USDA's rearing facility in Starkville, MS, maintained on an artificial diet and standard rearing conditions; and a local strain collected from cotton in Caacupé, Paraguay. The results are shown in the figure below.

As seen from the figure:

- The LD_{50} data obtained from bioassays with pyrethroids showed no significant differences with the two strains.
- The LD_{50} obtained with methyl-parathion was higher for the USDA-ARS Mississippi strain than the LD_{50} obtained from the bioassays with the Caacupé strain.

Pesticide susceptibility of two boll weevil strains: USDA-ARS and Caacupé, Paraguay (Cyper = cypermethrin; Delta = deltamethrin; β-cyper = β-cypermethrin; M-para = methyl - parathion)



	Cyper	Delta	ß-cyper	M-para
USA	0.0029	0.0013	0.0018	0.019
CAACUPE	0.0037	0.0022	0.0022	0.0039

- The toxicity data obtained can be used as the baseline information for future pesticide resistance monitoring programs in the framework of cotton IPM.
- The USDA-ARS Mississippi strain showed higher tolerance to the OP pesticide. The reason for this difference could be the previous history of this strain, which is intensive and extensive use of OP pesticides in the US cotton production system.

Use of Insecticides

Due to the fact that it is difficult to control the boll weevil using its natural enemies, chemical control is still the most commonly used method. Field trials were conducted to compare different insecticides, formulations, and recommended doses. The most efficient active substances (Etofemprox, Alfamethrine, Methamidophos, Endosulfan, Deltamethrine and Betacyfluthrin) and formulations (concentrated suspension) to control the boll weevil were determined by field assessment of different commercial products. This knowledge provided benefits to agricultural professionals and farmers, since its implementation would lead to more effective control of the pest and consequently lower pest control costs and environmental impact.

Insecticide Resistance Monitoring

A new technology for insecticide resistance monitoring in the field was developed. This method provided quick and a simple way of diagnosing, in situ, possible insecticide resistance focus in boll weevil populations and, therefore, it allowed implementing management strategies accordingly. This technological development patented in Argentina and Paraguay constitutes a tool to manage resistance by permitting its early detection and alternating pesticide products. This new insecticide resistance diagnostic method represents an improvement in pest control and eradication strategies. At least in the first stage, it is used in situ, so it provides an immediate diagnosis, in consonance with the urgency to apply an insecticide. Consequently, it leads to an increase in management efficiency and to lower environmental impact.

Synthetic insecticides not only pollute the environment but also encourage the surge of resistant populations of insect pests, the destruction of biological control agents leading to pests' re-emergence and the outburst of secondary pests. The constant and intense application of insecticides to control *A. grandis* in the USA caused a rapid development of resistance. In order to identify the causes of insecticide resistance, a study of its biochemical mechanisms and their selectivity is needed. On this basis, operational factors such as the type of insecticide, dose and application method could be selected to create a strategy that delays the development of resistance and increases the useful life of the insecticides used.

Insecticide resistance monitoring detects the appearance of resistance in advance in order to take the necessary measures for correcting management practices. Thus, failure of a control method, and especially the decrease in efficacy of a whole family of pesticides can be avoided.

A method to diagnose resistance in local populations of *A. grandis* was developed. This method, to be used in the field, provided a quick, simple and reliable tool that allowed an *in situ* resistance phenomena pre-assessment in order to choose the right control strategy. Up until now, the usual way to detect the resistance phenomenon was through laboratory bioassays, and insects had to be taken to specialized laboratories where these bioassays were conducted. The process could take days, weeks or even months. The benefits obtained from this new diagnostic method are as follows:

- An increased effectiveness of pest control.
- A reduction in the number of insecticide applications.
- A reduction in environmental pollution.
- A reduction in production costs.
- A lengthened useful life of the insecticides used.

This new method for field resistance diagnosis could be immediately incorporated to the National Program of Prevention and Eradication of the Cotton Boll Weevil, conducted by the SENASA in Argentina. The method is also compatible with integrated pest management practices and suitable to be used in other countries affected by the pest. It is possible to obtain results in 24 hours, and it is possible to diagnose resistance *in situ* and determine which insecticide or control strategy would be the most effective.

Biological Control of the Cotton Boll Weevil

Parasitoids and Predators

Field infestation of the cotton boll weevil populations by parasitoids and predator levels are higher in Paraguay than in other cotton growing regions. High natural control of this pest by parasitoids and predators allows reduction in the number of chemical treatments to a minimum and more intensive crop management actions, leading to high yields and low environmental impact. The knowledge acquired on the parasitoids *B. vulgaris* and *C. grandis* and the predator *E. annulipes* would enable the use of these organisms in biological control practices.

One of the most promising technologies available to control cotton boll weevil populations is biological control, and significant advances were made on this methodology during the 1980s and 1990s. More than 15 insect parasites of this species have been found. Research in the USA demonstrates that cotton boll weevil parasites are very effective population regulators in augmentative releases. The occurrence and frequency of parasitoids were determined in field trials conducted in Paraguay.

Parasites found were identified as *Bracon* spp and *Catolacus grandis*. Parasitism levels found were:

- In cotton stubble

  A high level of larval parasitism was observed during this stage. Adult emergence was observed in only 1.12% of the flower buds studied. 74% of the larvae were affected by parasitism.

- On the crop

  From the total buds showing egg-laying marks, 98% mortality was observed. Parasitism was the main mortality factor, followed by egg mortality. Regarding mortality caused by parasitism, a low level was observed up to 4 days larval age increasing exponentially until 10 days larval age. From that moment onwards parasitism growth became stable at 90% mortality. Parasitism in Paraguay seems to be higher than in any other country affected by the boll weevil, although this pest has been recently introduced to the country. It is one of those rare cases in which a newly introduced species finds its parasites already established.

Cotton pest management should focus on preserving natural enemies (parasites) by applying insecticides cautiously. On the other hand, a program to manage stubble should be developed for increasing parasite reservoirs and maximizing their survival without favoring cotton pests.

Entomopathogen Fungi

A formulated product containing conidia from the entomopathogen fungus, *B. bassiana* was developed. The appropriate application methodology of this product was determined in order to obtain the most effective control of adult boll weevils in laboratory conditions. However, the effectiveness of these formulated products must be assessed in field trials before including them in a cotton IPM program. The results obtained constitute an important advance for the development of adequate formulations using micoinsecticides, which could be used as alternative products to chemical insecticides.

Several laboratory bioassays were conducted with Argentine strains of *B. bassiana* and *Metarhizium flavoviridae*. Preliminary results showed that *Metarhizium flavoviridae* has a very low virulence for *A. grandis*, therefore, 117 Argentine strains of *B. Bassiana* were assessed. The results obtained till present have not allowed the selection of an efficient strain for adult boll weevils. It has been demonstrated in laboratory bioassays and in preliminary field trials that the entomopathogen fungi *Beauveria bassiana* and *Metarhizium anisopliae (Deuteromycetes*) can infect the cotton boll weevil. The effect of the type of formulation and application methodology of *Beauveria bassiana* when used to control the boll weevil was studied in the laboratory. The study conditions were 25±1ºC temperature and 70±10% relative humidity.

Assessment ofTtrap/kill Devices for *A. grandis*

Field trials with bait sticks (TMP) were conducted, and it was determined that this device cannot be used to kill boll weevils in large quantities. However, bait sticks can be used as an indicator/instrument to monitor the presence of the pest in pre-sown and post-harvest periods. Until the present, there are no statistical results available comparing the efficacy of this tool with other tools to control and monitor the pest.

Geographic Information System (GIS)

A geographic information system (GIS) was established in a pilot area and its potential to be used in cotton IPM programs in Argentina, Brazil and Paraguay was verified. A training program was also generated which spread the use of this tool to different working teams in the three countries. The use of a GIS for boll weevil monitoring would enhance the efficiency of ecological management and would allow a more rational assignment of resources. Moreover, the number of insecticide applications both in time and space will be reduced.

A geographic information system (GIS) is a technique for acquisition, storage, analysis and display of geographic data with the aid of a computer. The possibilities offered by GIS to integrate data of diverse origin makes it a unique tool to manage resources. Teledetection systems offer the unique potential of knowing efficiently and continuously the characteristics of agricultural areas, analyzing and relating multiple aspects of the terrain interconnected by specific variables. In the case of pest monitoring and control, they provide a means of defining the evolution of pest populations according to environmental characteristics and cultural practices in agroecosystems. Due to the ecological characteristics of the cotton boll weevil and to the large area that has to be monitored when studying it, the use of GIS is fundamental.

Technology and Information Transfer to Farmers and Extensionists

A great number of agricultural professionals and farmers are now qualified and aware of the benefits of adopting IPM technology on cotton as a result of the activities conducted in this area. Various strategies were used to transfer technology and information, such as courses addressed to farmers and agricultural professionals, validation of weevil-IPM technologies on illustrative plots, and didactic material, among others.

Extension activities and transfer of information and technology took place according to the needs and possibilities of each country. The aim of the training courses addressed to professionals was to raise awareness of the effectiveness of the IPM technology through theoretical knowledge as well as demonstration plots. Twenty-seven qualified technicians worked on transferring technology to farmers, and many others worked as consultants.

Courses were developed to train people on how to recognize insects. These courses were addressed to unskilled laborers, farmers and their families, to train them on how to recognize, register and count the insect pests present on their land, on a weekly basis.

Several complementary activities took place such as farmer meetings, and professionals in charge of giving the courses visited farmers.

As a result of the activities conducted, it was observed that:

- Farmers are putting into practice the knowledge acquired by the transfer and extension activities.
- Farmers are adopting more specific and modern insecticides.
- New technicians will have to be trained since demand for them is increasing.
- Treatment of seeds is now a common practice where extension activities were intense.
- The interest shown by the mass media (radio, TV and newspapers) and farmers indicate that IPM technology is increasingly being adopted.
- Farmers tend to use insecticides in a more rational way, and some of them use damage thresholds to decide when to apply pesticide products.
- Farmers are now attending courses on insect recognition, which shows that they are aware of the benefits of the work done by the people who had previously attended the courses.

Because of the economic and social importance of the cotton crop in Northeastern Brazil, demonstration plots (Demonstration Units) were used as a tool to assess the cotton cropping system recommended by EMBRAPA. The demonstration units proved to be a very useful tool for transfer of IPM technology as they allowed direct communication between researchers. The primary objective of this work was not only to name the technological steps taken at the demonstration units, but also to assess the benefits farmers can attain in the short run by adopting recommended cotton growing technology.

From the data collected, economic indicators of profit, yield equilibrium points and prices were calculated.

- It was verified that irrigated and non-irrigated cropping systems recommended by EMBRAPA-cotton are economically feasible if IPM practices are adopted.
- Farmers are using improved seeds (shown by a 100% increase in the demand of seeds with a certified origin).
- The practice of removing flower buds infested by the boll weevil has been adopted as a control measure.
- The seed distribution system for small farmers is insufficient, which requires farmers to buy seed that is not certified.
- Farmers tend to over or under-dose insecticides, which leads to a lower profit.
- There is a need to develop programs focusing on young people who live in the country. They should be trained to act as rural development agents.

Extension activities have also been conducted through IAPAR-Brazil. The aim was to train extension advisors and make farmers aware of the different technologies available to control the boll weevil. The methodology used was made up of four strategies:

1. Design of technical handbooks
2. Training extension advisors

3. Training farmers
4. Field validation of IPM technologies

Technical handbooks and booklets containing the necessary information to identify the pest and technical guidance on control measures have been prepared. Courses for extension advisors and producers were also given in several parts of Brazil. From April 1998 to April 1999, twenty training events took place. Courses were addressed to people involved in Brazil's cotton-growing industry.

Due to the current situation in Paraguay and the economic limitations of its organizations, it is impossible to adopt individual technical assistance for farmers. This can only be accomplished by grouping farmers and orient them towards self- action.

Training workshops and technical meetings were conducted in the framework of the activity. The methodology was based on the assimilation of practical examples apart from theoretical classes; it also allowed the validation of new technologies in farmers' fields. As a result of this activity, extension advisors and producers are now aware of the benefits of the use of IPM technology.

Impact of Transgenic Cotton

The original goal of transgenic Bt cotton was to achieve efficient, cost effective and environmentally safe pest control of major lepidopterous insects. The plant's ability to inhibit the multiplication of lepidopteron pests provides multiple benefits, like reduced use of insecticides; lower levels of air pollution; less waste production; improved safety of farm workers, particularly in countries where insecticides are sprayed manually; enhanced use of beneficial insects as biological control agents; lower cost of production and, ultimately, higher yield. Other benefits include the ability to control bollworms (lepidopteron) that have already developed resistance to insecticides and the ability to produce cotton in areas that have been abandoned due to uneconomical bollworm control costs. Some of these issues are discussed here in detail.

Growers' Selection of Varieties

In most countries, growers can select varieties of their own choice for planting every year. There are premiums and discounts based on the quality of cotton to be produced from each variety. The trend in various countries shows that premiums and discounts are not enough to change farmers' decisions regarding variety selection. Farmers' decisions are primarily based on yield. Farmers are always excited to grow new varieties because new varieties are supposed to yield higher over existing varieties. Since the introduction of transgenic cotton, farmers' preference for varieties has changed. It is less based on the search for new and high yielding varieties and more on the availability of in-built resistance to insects and herbicides. The herbicide issue is particularly true for the USA but in other countries, like South Africa, smallholder farmers with low yields have shown great interest in cotton varieties that are genetically resistant to lepidopterous insects. In South Africa, transgenic insect resistant varieties were planted on 40% of the total cotton area in 2000/01. In China (Mainland), the *Helicoverpa armigera* resistant provinces in the Yellow River Valley have embraced Bt varieties without any hesitation and area has increased to million hectares in just a few years. Although Bt cotton guarantees protection against lepidopteron caterpillars only, and growers still have to spray against other pests, the primary focus in selecting varieties has changed at the farmers' level from yield to assured resistance to insects. The rate of adoption of Bt cotton indicates the level of confidence in the in-plant toxin to control bollworms.

Yield Increase

A great deal of information is available in the literature on yield increases due to Bt cotton. But there is a lot of variation in the extent of the increase, which is quite justified due to reasons discussed below. While there is no increase, there is also no decrease expected, because no negative correlation between the non-cotton gene with the cotton genome in the currently available transgenics has been detected so far. The range of increase will depend on many factors and will vary from year to year-to some extent from variety to variety, location to location-that authentic and reliable yield data are not available for head to head comparisons. One set of data on fiber quality was presented at the 2000 Beltwide Cotton Conferences by Kerby et al (2000). More recently, Kerby (2001) reported on yield performance of transgenic and straight varieties. He has presented comparisons made on seven transgenic varieties versus their recurrent parents, grown together side by side under similar conditions in the same field. This provided a direct comparison across management and environments of a conventional parent to its corresponding transgenic genotype. The following data are the average of Deltapine varieties planted in small replicated trials.

The data is an indication of the performance of Bt gene varieties against their recurrent parents and is in no way a guarantee

Yield Comparison of Transgenic Versus Recurrent Parents

Characteristic	Conventional (Kg/ha)	Transgenic (Kg/ha)	% Change Recurrent on Parents
Bollgard (Bt)	1,121	1,216	+9
Roundup Ready	1,177	1,157	-2.0
Stacked	1,209	1,259	+4

that such an increase or decrease in yield will be realized. The toxin expression varies from one location to another, from variety to variety, from time to time, and from one part to another plant part; accordingly, pest control will be affected and thus, yield.

Why Yield May or May Not Increase Due to Bt Gene

The observation that Bt gene varieties will always out-yield their recurrent parents may be true for certain conditions but not for others. Even if it is proved year after year that transgenic varieties, particularly Bt varieties, produce higher yields, it should not be assumed that the addition of the Bt gene in the cotton plant will boost the plant's ability to produce a higher yield. The yielding ability of the cotton plant remains the same with or without the Bt gene. However, the ability of transgenic Bt plants to avoid bollworm losses due to host plant resistance enables them to grow more productive bolls compared to plants affected by bollworms. In conventional production, it is recommended to spray the crop with insecticides when the pest population has reached a particular economic injury level. This is a level when it is assumed that the economic benefit in yield is higher than the cost of insecticide and its application. But this is a stage when some loss in yield has already occurred due to bollworms. In contrast, Bt cotton can escape from such a loss and give higher yields because the toxin is always present in the plant.

The increase in yield from the use of Bt varieties depends on the number of times the economic threshold would be reached to spray against bollworms. If an economic threshold is never reached, but bollworms persist for a significant time during the boll formation stage, there may be some increase in yield. However, the increase would not be equivalent to the situation when an economic threshold is reached frequently during the season. The increase in yield in Bt varieties could serve as an indicator of how best a farmer has been controlling bollworms. If bollworms are among major pests, no increase or a minimum increase is a good indication that they are being controlled well. According to Joubert et al (2001), the fact that Bt cotton has become more popular among small farmers in South Africa, compared to large farmers, is testimony that bollworm control was not good under conventional practices.

The currently available Bt varieties have a single bacterial gene that is not able to control all bollworms. The cry1Ac gene in Bollgard® varieties in the USA and elsewhere, and Ingard varieties in Australia (all Bt varieties) have the ability to control mainly the tobacco budworm, the cotton bollworm and the pink bollworm. If these bollworm species do not exist or they never reach the levels close to the threshold, no increase in yield due to the Bt gene may be expected. The introduction of the Bollgard® II gene (cry2Ab) will enhance the ability of transgenic cottons to control more insects. The development of a multiple toxin system in transgenic plants, with toxin pyramiding that recognizes different binding sites, has not only reduced the chances of resistance development but also enhanced the plant's defense against more species of insects. Accordingly, expectations that stacked gene Bt varieties will give higher yields have also increased. A comparison of the effectiveness of two Bt genes against various pests follows:

Bollgard® (cry1Ac)	**Bollgard®** II (cry2Ab)
Heliothis virescens (Tobacco budworm)	*Spodoptera frugiperda* (Fall armyworm)
Helicoverpa armigera (Cotton bollworm)	*Spodoptera exigua* (Beet armyworm)
Pectinophora gossypiella (Pink bollworm)	*Trichoplusia ni* (Cabbage looper)
	Pseudoplusia includens (Soybean looper)

Natural Enemies

There are some concerns from countries, organizations and even individuals that do not encourage the production of transgenic varieties. However, these concerns are more related to food crops. As far as cotton is concerned, six years of commercial production of Bt varieties in the world has demonstrated that the Bt gene technology provides effective control of target insects. Herbicide resistant transgenic varieties are just now expanding to countries outside the USA, but the situation within the USA has confirmed its success. Although the long-term impact of some of the benefits, including the enhanced use of beneficial insects, has yet to be seen, the short-term indications are that Bollgard® cotton preserves more natural enemies compared to conventional spraying. Last year, Head et al (2001) started large-scale long-term studies to assess the relative impact of the Bt gene and conventional varieties treated with insecticides on the populations of beneficials in the field. They selected a number of fields in three states in the USA. Only comparable fields with fewer than four hectares were selected for monitoring. The arthropod population was monitored on a weekly basis in Bt and non-Bt fields throughout the cotton growing season. The population of natural enemies varied among locations, but in all cases the Bt varieties preserved more natural enemies and the population of predatory bugs, spiders and ants significantly decreased in fields where conventional insecticides were used as usual. The data are for one year and it remains to be seen what will happen in five years or more.

Higher Cost of the Planting Seed

Transgenic seed is sold at a higher price because seed companies have to take extra care in ginning, delinting and seed treatment processes. Moreover, farmers have to pay a "technology fee," which is said to be the cost of savings on insecticide use. The company that owns the gene charges the fee, which currently is not the same in all countries. In Australia, it has changed from year to year, and in the USA it has been the same since 1996. The technology fee in the USA is US$80/ha for the Bt gene, lower than in Australia, but extremely high for many other countries. There is no set formula to calculate the technology fee, but it can roughly be related to the cost of insecticides used to control the affected bollworms. It seems that farmers in many countries will need financial help in the form of loans or advances to pay for the technology fee up front.

Fiber Quality

The popularity of transgenic cotton varieties is due to improvements in insect pest management and additional options in weed control. The literature tells of no impact on fiber quality that could be related to a harmful effect of the Bt gene. If there are any minor changes in the reading for various characteristics, they could be due to a change in the location of bolls on the plant. Bt varieties provide bollworm control from the very beginning and protection from shedding due to early bollworm attack. Even if there is no increase in the number of bolls on the plant, their position/distribution will change, which could have an effect on fiber quality. The number of first-position bolls could change and the crop maturity could be affected, depending on the high rate of boll formation in the beginning.

Economic Impact

The following conclusions can be drawn regarding the economic impact of transgenic cottons, particularly the Bt varieties.

- It is not economical to grow Bt varieties everywhere in all countries.
- The economic impact will depend on what kind of bollworms attack cotton and the level of pest pressure during flowering and boll formation stage.
- There is always a seasonal variation in pest pressure and, accordingly, the extent of economic benefits will vary year to year.
- The technology fee is an important factor in determining the economic benefits. If the technology fee is higher than the cost of insecticides used to control bollworms, Bt cotton may not become popular.
- The actual cost of pesticides is a crucial factor in deciding to use Bt cotton. If governments subsidize pesticides and there is no financial help for technology fees, growers may be reluctant to switch to Bt cotton.

Who will benefit most from the use of transgenic technology often depends on either the seed companies or the owners of the technology. The quick adoption of the technology in China (Mainland), the USA and other countries is a clear indication that growers are sharing the economic benefits of this technology. The situation in Mexico shows that growers are taking a good share of the economic advantage of Bt cotton. Bt cotton has been adopted in Mexico more easily than in other countries. Deltapine varieties were imported and used on a commercial scale. According to a report presented at the Fifth International Conference on the Economics of Biotechnology that took place in Ravello, Italy in June 2001—organized by the International Consortium on Agricultural Biotechnology (ICABR) in cooperation with the University of Rome "Tor Vergata," the Economic Growth Center of the University of Yale, New Haven, and the Center of Sustainable Resource Development of the University of California at Berkeley—under the Mexican situation, 85% of the total profit due to Bt varieties accrued to farmers, while 15% went to the seed companies.

Need for Institutional Capacity in Biotechnology

Biotechnology is a comparatively new science, particularly with respect to its application in agriculture, and the introduction of transgenic cotton has changed the focus within the research systems in most countries. There are a number of limitations, which not only hinder the spread of this technology to other countries but also limit awareness of the technology within a country. The current motivation is inclined to promote products and not the science or principles under which such products are developed. Many countries are in the process of developing their own systems but they are faced with problems due to a lack of knowledge and experience, which in most cases lie with the private sector. Unlike many other disciplines of cotton production research, genetic engineering research is expensive, and developing countries-where most cotton is grown-cannot afford to set up basic research facilities. Buying the technology in the form of products ready for use, like Bt cotton, also carries a big price tag. Even if a country is ready to buy the technology in a finished form, it has to have biosafety regulations in place, without which a product unfit for local conditions could be spread.

The biotechnology system carries various stages of which the four most important are

- Research institutions/companies carrying research on genetic engineering of cotton
- Permission to conduct field trials
- Permission for limited commercial planting
- Approval for full commercial use

The process can be further extended to more committees and approvals, as is the case in Egypt. In the June 2001 issue of *THE ICAC RECORDER*, a detailed article was published on biosafety regulations in Egypt along with responsibilities of various agencies to introduce or research a biotechnology product. The process can also be narrowed to only three stages as in India, where the Review Committee of Genetic Manipulation, the Genetic Engineering Approval Committee and the Indian Council of Agricultural Research deal with reviews and approval of GE products for research and small scale trials, approve field tests for large scale projects and importation of GE crops for commercialization, and facilitate research and technology transfer. It is the responsibility of governments to develop such systems and to educate the public in their countries in the safe use of this technology.

All the transgenic cotton currently used was developed by the

Regulatory Approval of Transgenic Cotton

Characteristic	Argentina	Australia	China (M)	Indonesia	Mexico	South Africa	USA
Bromoxynil (BXN)	-	-	-	-	-	-	1994
Roundup Ready (RR)	1999	2000	-	-	-	-	1995
Bollgard/Ingard (Bt)	1998	1996	1997	1999 (?)	1997	1997	1995
Insect Resistant Bt + Herbicide Resistant (RR)	-	-	-	-	-	-	1997

Note: Bt cotton is also called Ingard in Australia.

Agrobacterium tumefaciens mediated plant transformation method. The year of regulatory approval may be different from the year of commercial production.

Reason for Bt Cotton in China (M)

In China (Mainland), two types of transgenic bollworm resistant cottons are grown: one is the same Bt cotton grown in other countries and the other has been developed locally. The adoption of Bt cotton in China (Mainland) was due to different reasons than those of other countries. China (Mainland) planted cotton on 6.5 million hectares in 1991/92 when the average yield was 867 kg/ha. The next year area increased to 6.8 million hectares and the average yield dropped to 660 kg/ha. Such a significant drop in yield is attributed to bollworm resistance to insecticides. The cotton bollworm developed resistance to most insecticides and it became difficult to control, particularly in the Yellow River Valley where yields dropped to less that 500 kg/ha in 1992/93. The number of sprays increased significantly and many farmers in the provinces most affected-Hebei, Henan and Shandong-could not afford to continue producing cotton. Consequently, the most affected area was taken out of cotton production. Cotton production expanded in the northwest region, which was traditionally a high yielding area.

Replacement of low yielding area with the high yielding area coupled with integrated pest management programs did show some positive impact on yields, but the average yield remained below one ton of lint until 1997/98. Since 1997, when Bt cotton was approved and started commercial production on a large scale, the average yield in China (Mainland) has been more than one ton of lint per hectare. At the national level, Bt cotton was planted on only 2% of the total area in 1998/99, increased to 14% in 1999/00, and almost to 25% in 2000/01. However, it is estimated that most of the area in the above-mentioned provinces is being planted with Bt varieties. The Bt cotton would not have been adopted at such a fast rate in China (Mainland), had they not suffered heavy losses due to the insecticide resistance problem.

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Short Notes

- **Genetically Engineered Viruses**

  Insects can be controlled by various means. Among the recognized methods, the use of viruses as a method of pest control was known even before synthetic insecticides were discovered. The nucleopolyhedrovirus insecticides are benign to non-target species, leave no environmental residue, can initiate action from a single cell, and are sometimes cheaper to produce. However, they are not a good insecticide replacement due to their slow rate of effect, conditions for their ingestion by the target host, rapid inactivation by ultraviolet light, long-term storage disadvantages and sometimes higher cost of production. Some of the early products like “Elcar” had additional disadvantages, mainly, a slow rate of kill during which the larvae continued causing damage to the crop, weak effect on medium to large size larvae, and half-life of the virus under field conditions.

Researchers have been trying to overcome the deficiencies in the nucleopolyhedroviruses (NPV) to use them as biopesticides for commercial use. One of the approaches has been to transform NPVs. As early as August 1991, the Division of Entomology of the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia demonstrated that a faster acting virus could be produced by introducing foreign genes into the available NPV. Results showed that larvae exposed to GE NPV ceased to feed and were paralyzed long before larvae exposed to the normal NPV. Lately, there has been more progress in the development of GE NPV in Australia. The GE NPV contains an insect-specific protein—effective against *Helicoverpa armigera*—and can kill the bollworm larvae in less than half the time of the un-engineered virus, in addition to potent anti-feeding action.

The GE NPV-affected larvae move to the top of the plant (toward light) and firmly attach to the leaf before death. The larval cuticle eventually ruptures and virus progeny is released as a liquid on the leaves. However, quick action and early fall of the larvae to the ground are creating other concerns, i.e., fewer virus progenies and longer time taken for inactivation due to non exposure to sunlight. Both issues are critical for commercial use of any GE NPV and Australian researchers are currently undertaking trials to establish that the GE NPV will not pose risks if released for commercial use.

(*The Australian cottongrower*, Volume 22, No. 2, 2001).

• Cotton Varieties Planted in the USA

According to the latest ICAC estimates, cotton was planted on 5.7 million hectares in the USA during 2001/02. The cotton program under the Agricultural Marketing Service of the U.S. Department of Agriculture estimates the area planted to varieties and a report is usually published in August every year. Varieties planted are categorized by company brands in addition to the area under each variety. According to the 2001 report, the Paymaster brand of upland varieties was the most popular during the 2001/02 season. Paymaster varieties were planted on 37% of the total cotton area compared to 31% under Deltapine varieties and 12% under Stoneville, and almost 8% under Sure-Grow varieties. Aventis brand varieties were planted on 4.5% of the total cotton area in the USA.

Paymaster varieties were most popular in the Southwestern region and were planted on 65% of the total area in the region. In the Southeastern region, Deltapine brands covered the maximum area by occupying about 60% of the total cotton area. In the West region Deltapine and CPCSD brands were planted on 37% and 35% of the total area respectively. In the South Central region Paymaster, Deltapine and Stoneville brands were planted on an area ranging 26-31%. On an overall basis, the seven most popular varieties and area under each variety are shown on the table.

The area under all transgenic varieties resistant to bollworms and herbicides increased to 78% of upland cotton planted area in the USA in 2001/02, compared with 72% last year. Straight Bt varieties formed only 2% of the total transgenic varieties. Herbicide resistant varieties formed almost 37% of the transgenic varieties while stacked gene varieties, herbicide plus bollworm resistant, were planted on over 39% of the total U.S. cotton area in 2001/02.

Most Popular Cotton Varieties in the USA - 2001/02

Variety	Area in %
PM 2326 RR	11.4
PM 1218 BG/RR	10.7
DP 451 B/RR	6.4
ST 4892 BR	5.8
PM 2200 RR	5.6
DP 458 B/RR	5.4
ST 47 BXN	3.3

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World Cotton Research Conference–3

Cotton Production for the New Millennium

Cape Town, South Africa

9-13 March 2003

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After the great success of the World Cotton Research Conference–1, held in Brisbane, Australia in 1994, and the World Cotton Research Conference–2, held in Athens Greece in 1998, the World Cotton Research Conference–3 (WCRC–3) will be held in Cape Town, South Africa, from 9-13 March 2003 under the auspices of Cotton SA and the Agricultural Research Council of South Africa.

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Please, return the preregistration form to:

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This form is also available on the Internet at the ICAC web page at <http://www.icac.org/icac/meetings/meetings.html>. Additional information will be available in the next brochure that will be published in early 2002. To enable us to draw up a program for the WCRC–3, please complete and return the preregistration form.

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Additional information on the Conference can also be obtained from the Organizing Committee at the following address:

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