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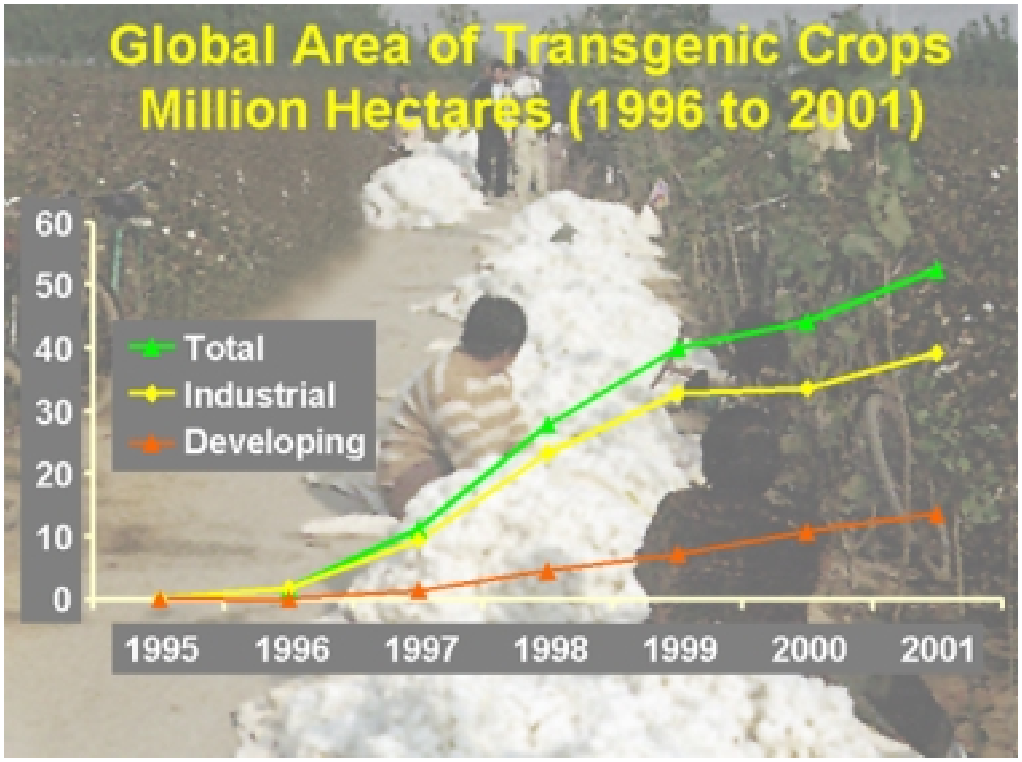
Global Review of Commercialized Transgenic Crops: 2001
Feature: Bt Cotton

by

Clive James
Chair, ISAAA Board of Directors



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Published by: The International Service for the Acquisition of Agri-biotech Applications (ISAAA).

Citation: James, C. 2002. Global Review of Commercialized Transgenic Crops: 2001 Feature: Bt Cotton. *ISAAA Briefs* No. 26. ISAAA: Ithaca, NY.

ISBN: 1-892456-30-3

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EXECUTIVE SUMMARY

Global GM Crop Area

- In 2001 global area of transgenic or GM crops was 52.6 million hectares or 130 million acres, grown in thirteen countries by about 5 million farmers, over 75% of whom were small resource-poor farmers in developing countries. The US was the largest grower of GM crops (68%), with one quarter of the GM crop area grown in the developing countries, principally in Argentina and China.

- The principal GM crops were soybean, corn, cotton and canola. On a global basis, 46% of the 72 million hectares of soybean was GM, 20% of the 34 million hectares of cotton, 11 % of the 140 million hectares of maize, and 11% of the 25 million hectares of canola.

- In the first six years of GM crop commercialization, 1996 to 2001, a cumulative total of over 175 million hectares of GM crops were planted globally which met the expectations of millions of small and large farmers in both industrial and developing countries.

- Global GM crop area is expected to continue to grow in 2002.

Value of the Global Transgenic Seed Market in 2001

- The value of the global transgenic seed market is based on the sale price of transgenic seed plus any technology fees that apply. The value in 2001 was $3.8 billion up from $3.0 billion in 2000.

Global R& D Expenditures in Crop Biotechnology in 2001

- Current global R&D expenditure in the private and public sectors is $4.4 billion with over 95% of the total in the industrial countries, led by the US. China is the leading investor in R&D crop biotechnology in the developing countries, followed by India.

Overview of the Commercial Seed Industry

- An overview of the $30 billion plus commercial seed industry is presented. Expressed as a proportion of the global commercial seed market, transgenic seed represented approximately 13% of the estimated $30 billion plus global commercial seed market in 2001.

Overview of Developments in the Crop Biotechnology Industry

- The major developments in crop biotechnology in the private sector in 2001 are summarized. Specific developments are discussed in each of four areas: acquisitions, mergers and spin-offs; genomics and product discovery; patents and licensing; and re-registration, approvals and commercialization.

Economic Benefits of GM Crops

- In the 2000 ISAAA Global Review of Transgenic Crops, an assessment was published of the global benefits associated with the principal GM crops - soybean, corn, cotton and canola. In the interim, several studies and surveys have been conducted and these are summarized to provide the reader with the current information on benefits from GM crops; these include an overview of the current and potential economic benefits of GM crops in the US, RR soybeans in Argentina, Bt maize in the Philippines and Spain and a review of the investments of China in crop biotechnology.

Feature for the 2001 Review: Bt Cotton

The content of this chapter is structured chronologically to provide the reader with a global overview of the cotton crop, present available data for assessing the performance of Bt cotton to-date and project its global potential for the future. The focus on developing countries is consistent with ISAAA's mission to assist developing countries in assessing the potential of new technologies. The principal aim is to present a consolidated set of data that will facilitate a knowledge-based discussion of the potential benefits that Bt cotton offers global society.

- A total of 33.5 million hectares of cotton were grown globally in 2001, worth approximately $20 billion. Developing countries planted over 70% of the global area, and industrial countries grew 20%, mainly the USA (5.6 million hectares), as well as Australia, Greece and Spain. The remaining 10% was grown in Uzbekistan and other Central and West Asian countries. Asia has about 60% of world cotton, with India, China, and Pakistan dominating with 50% of global hectarage. Latin America grows <5% where Brazil is the only major grower. Africa has almost 15% of global cotton with 22 countries growing small (30,000 hectares) to modest (500,000 hectares) areas of cotton. There are approximately 20 million cotton farmers globally, 97% of whom farm in developing countries, 2% in Central and West Asian countries and <1% in the industrial countries. Most cotton growers in developing countries are small resource-poor farmers growing 2 hectares or less of cotton.

- Insect pests represent a major constraint to increased productivity in most cotton growing countries. The yield losses and the cost of controlling insect pests with insecticides costs cotton farmers an estimated $5 billion annually. The most important insect pests globally are the caterpillar moths – the lepidopteran pests - amongst which the 'bollworms' are the most damaging with losses and insecticide control costs totaling about $3 billion per year. Approximately 88% of the global cotton area suffer from medium to high infestation of lepidopteran pests. On a global basis, cotton farmers used $1.7 billion worth of insecticides in 2001 in their attempt to control cotton insect pests - more insecticides are applied to cotton than any other crop. Cotton consumes 20% of all insecticides applied to all crops globally.

- A novel method of controlling lepidopteran pests is the use of Bt genes from a soil bacterium, *Bacillus thuringiensis* (Bt). Bt genes have been incorporated in cotton through genetic engineering and were first introduced commercially in 1996 in the US and Australia in Bollgard® varieties. Bt cotton has been developed by private sector companies and deployed globally in nine countries. In China, the public sector has also released Bt cotton varieties, which compete with Bt cotton from the private sector. Since 1996 a total of nine countries, seven developing and two industrial countries have successfully grown 13 million hectares of Bt cotton. These include USA, Mexico, Argentina, and Colombia (pre-commercial) in the Americas, China, India, Indonesia and Australia in Asia and South Africa on the African continent.

- The potential development of resistance poses the biggest challenge to Bt cotton and the development and implementation of Insect Resistance Management (IRM) strategies is essential. Countries that have adopted Bt cotton have successfully implemented different IRM strategies and no resistance to Bt cotton has been detected to-date despite the fact that 13 million hectares of Bt cotton have been grown worldwide since 1996; several claims from critics proved to be unfounded. The recent approval in Australia of Bollgard II will considerably fortify IRM strategies because it has two independent Bt genes that confer resistance; other Bt and novel genes for cotton insect resistance are expected to be available by 2004. From a global viewpoint, any international initiative to substantially extend the adoption of Bt cotton must also anticipate and consider the implications of a significant expansion in the global area of Bt cotton. These considerations at the international level are similar to those at the national level and include necessary global strategies for responsibly managing and optimizing the durability of resistance, and the spatial and temporal deployment of different varieties carrying different sources of resistance. An effective international mechanism to formulate, coordinate and oversee a global strategy for deploying Bt cotton responsibly and effectively could play a seminal role if it could be operated without onerous bureaucracy.

- Eight country case studies are presented which provide detailed and current information on all aspects of the cultivation, adoption and performance of Bt cotton, including an assessment of the agronomic, economic, environmental, health and social impact of the technology. Country studies are presented for the USA, Australia, China, India, Mexico, Argentina, South Africa and Indonesia which collectively have six years' experience with Bt cotton and grew almost 20 million hectares of cotton in 2001, equivalent to 60 % of the global hectarage of cotton.

- All countries that have introduced Bt cotton have derived significant and multiple benefits. These include increases in yield, decreased production costs, a reduction of at least 50% in insecticide applications, resulting in substantial environmental and health benefits to small producers, and significant economic and social benefits. In the US in 2001, the economic benefit from Bt cotton was estimated at $103 million or $50 per hectare. In China in 2001, Bt cotton increased yield on 1.5 million hectares and reduced insecticide use by 78,000 tons (formulated product) resulting in significantly fewer farmer insecticide poisonings. In 2001, Bt cotton in China increased annual farmer income by $500/hectare, equivalent to a national benefit of $750 million. Small resource-poor cotton farmers in the Makhathini Flats in South Africa, 50% of whom are women, derived similar benefits including significant social benefits devoting less time to carrying water and spraying insecticide and more time caring for children, attending to the sick, and family duties. To put a human face on the benefits of Bt cotton, for the average cotton holding of 1.7 hectares in the Makhathini Flats in South Africa, in a typical season, a woman farmer is relieved of 12 days of arduous spraying, saves over 1,000 liters of water (over 250 US gallons), walks 100 km less, suffers less insecticide poisoning and increases her income significantly by approximately $85 per season, through using Bt cotton, rather than conventional cotton.

- Up to 5 million farmers benefited from Bt cotton in 2001, most of them small resource-poor farmers in developing countries, mainly in China and also in South Africa where Bt cotton contributed to the alleviation of poverty by increasing incomes of small farmers substantially. On a global basis, the benefits from the deployment of Bt cotton between 1998 and 2001 were estimated to be $1.7 billion.

- In terms of environmental impact, Bt cotton has resulted in a significant decrease in the volume of insecticides applied to cotton, which in turn reduced insecticide runoff into watersheds and aquifers. In the US alone for the three year period 1998, 1999 and 2001 the volume of insecticides applied to cotton was reduced by 2,979 MT (active ingredient). In China for the three period 1999 to 2001, insecticide tonnage on cotton was reduced by a substantial 123,000 MT of formulated product. Consequently, insecticide poisonings of cotton farmers, applying insecticides by hand with knapsacks, decreased by up to 75%. Similar evidence on insecticide poisonings has been reported for South Africa.

- Cotton is in many ways an ideal candidate for introduction to cotton-growing countries as the pilot and model GM crop. Its principal use as a fiber crop, rather than a food/feed-crop, facilitates its regulation and acceptance by the public at large. From a biosafety viewpoint it is a self pollinating tetraploid that will not outcross with native diploid cottons and the movement of the large pollen, which is not dispersed by wind, is limited to a few meters. Cotton is not found as a weed in the global production areas and Bt is unlikely to confer an advantage that would result in Bt cotton establishing as a weed. Thus, the potential biosafety consequences are negligible due to the limited movement of pollen, natural genetic barriers that preclude outcrossing with native cotton, with no known compatibility with any wild relatives. The safety of the Cry1Ac protein is well documented and the Cry1Ac gene is very unlikely to confer any competitive advantage. With the adoption of any technology, there is always a risk that unintended or unforeseen effects could present new challenges. However, with the significant and substantial proven benefits that Bt cotton offers developing countries, the greatest risk is not to explore the technology, and thus be certain to suffer the consequences of inferior technology that will disadvantage farmers in developing countries who have to compete in international markets.

- To-date, only nine countries have adopted Bt cotton, which begs the question of what is the global potential for Bt cotton in the 50 key countries that grow cotton throughout the world. In the absence of field data to assess the performance of Bt cotton in the 50 countries, the projected saving in insecticide that would be associated with the use of Bt cotton can be used as an indicator of the potential of Bt cotton globally. The annual projected insecticide saving for the countries with medium to high infestations of lepidopteran pests is 33,000 MT valued at $690 million and equivalent to 37% of the 81,200 MT of cotton insecticides used globally in 2001. The gain of $690 million excludes the significant additional benefits that would accrue from reducing labor needs for insecticide sprays by half, plus the substantial additional income from the higher yields of Bt cotton. Potential annual global water savings, from optimizing the deployment of Bt cotton globally would reduce insecticide use by half, saving an estimated 6.3 billion liters of water (of which 1.7 billion liters have already been saved) or approximately 1.8 billion US gallons. To put this saving into context, 6.3 billion liters would supply a city of 1.5 million people in Africa, with their per capita consumption of 47 liters per day of water, for approximately 3 months

The six countries that have the potential for significant benefits from Bt cotton have either already adopted the technology, (China, India, USA and Australia) or are exploring its development (Pakistan and Brazil). The challenge is to provide the same opportunity for the potential beneficiary countries, with small to modest areas of cotton, in the developing world where several factors preclude access to Bt cotton. It is important that these smaller cotton-growing countries with resource-poor cotton farmers are offered the option of commercial access to Bt cotton so that they are not disadvantaged by being denied the significant benefits that accrue to adopters of the technology. There are 30 such developing countries, 21 in Africa, five in Asia and four in Latin America that grow small to modest areas of cotton that are potential beneficiaries of commercial Bt cotton but because of various constraints do not have the option to explore the potential benefits that Bt cotton offers in their own countries. The constraints range from absence of a regulatory framework that would allow field-testing of Bt cotton to determine its performance, lack of trained personnel, material and financial resources or the transaction cost may be too high for commercializing a relatively small area of cotton. Experience to-date in several developing countries has clearly demonstrated that Bt cotton can deliver significant economic, environmental, health and social benefits to small resource poor farmers that are assigned high priority by the donor community. Developing countries interested in evaluating Bt cotton and gaining commercial access to the technology in their own countries need assistance from the international public and private sector development community which pledged its support at Johannesburg, for a more sustainable agriculture, a better quality of life and alleviation of poverty for the poorest of the poor, which include millions of resource-poor cotton farmers. The compelling case for providing more developing countries the option of sharing in the substantial environmental, health, economic and social benefits delivered by Bt cotton to millions of resource-poor cotton farmers in developing countries on millions of hectares over the last six years, represents a challenge for both the donor community and the developing countries which are the potential beneficiaries. Bt cotton presents a unique opportunity to utilize technology to contribute to the alleviation of poverty as proposed in the 2001 UNDP Human Development Report.

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APPENDIX

1. INTRODUCTION

The unprecedented rapid adoption of transgenic crops during the initial five-year period, 1996 to 2000, when GM crops were first adopted, reflects the significant multiple benefits realized by large and small farmers in industrial and developing countries that have grown transgenic crops commercially. Between 1996 and 2000, a total of fifteen countries, 10 industrial and 5 developing, contributed to more than a twenty-five fold increase in the global area of transgenic crops from 1.7 million hectares in 1996 to 44.2 million hectares in 2000. The accumulated area of transgenic crops planted in the five-year period 1996 to 2000 total 125 million hectares, equivalent to more than 300 million acres.

Adoption rates for transgenic crops are unprecedented and are the highest for any new technologies by agricultural industry standards. High adoption rates reflect grower satisfaction with the products that offer significant benefits ranging from more convenient and flexible crop management, higher productivity and/or net returns per hectare, health and social benefits, and a safer environment through decreased use of conventional pesticides, which collectively contribute to a more sustainable agriculture. There is a growing body of evidence that clearly demonstrates the improved weed and insect pest control attainable with transgenic herbicide tolerant and insect resistant Bt crops, that also benefit from lower input and production costs; genetically modified (GM) crops offer significant economic advantages to farmers compared with corresponding conventional crops. The severity of weed and insect pests varies from year to year and hence this will directly impact on pest control costs and economic advantage.

Despite the on-going debate on GM crops, particularly in countries of the European Union, millions of large and small farmers in both industrial and developing countries continue to increase their plantings of GM crops year after year because of the substantial and multiple benefits they offer. This high adoption rate is a strong vote of confidence in GM crops, reflecting grower satisfaction. Many recent studies have confirmed that farmers planting herbicide tolerant and insect resistant Bt crops are more efficient in managing their weed and insect pests. An estimated 3.5 million farmers grew transgenic crops in 2000 and derived multiple benefits that included significant agronomic, environmental, health, social and economic advantages. In 2001, the number of farmers planting GM crops is expected to grow substantially and the global area of GM crops is expected to continue to grow. Global population exceeded 6 billion in 2000 and is expected to reach approximately 9 billion by 2050, when approximately 90% of the global population will reside in Asia, Africa and Latin America. Today, 815 million people in the developing countries suffer from malnutrition and 1.3 billion are afflicted by poverty. Transgenic crops, often referred to as genetically modified crops (GM), represent promising technologies that can make a vital contribution to global food, feed and fiber security.

The activities of ISAAA, the International Service for the Acquisition of Agri-biotech Applications in crop biotechnology transfer and the dissemination of information and knowledge is described by James (2001c). Global reviews of transgenic crops have been published by the author as ISAAA *Briefs* annually since 1996. This publication is the fifth by the author in the annual review series, to characterize and monitor the global status of commercialized transgenic crops. The first reviewed transgenic crops planted globally in 1996 (James and Krattiger 1996), the second for 1997 (James 1997a), the third for 1998 (James 1998); the fourth for 1999 comprised an early Preview (James 1999) followed by the annual Review for 1999 crops (James 2000a). The fifth for 2000 included a Preview (James 2000b) followed by the full annual Review for 2000 crops (James 2001a). The current publication presents the full annual global review of transgenic crops for 2001; a Preview (James 2001b) of this publication was published previously. This publication provides the latest information on the global status of commercialized transgenic crops for 2001. A detailed global data set on the adoption of commercialized transgenic crops is presented for the year 2001 and the changes that have occurred between 2000 and 2001 are highlighted. The global adoption trends during the last five years from 1996 to 2001 are also illustrated. The recent issues in relation to public acceptance of GM food as food aid in Africa has intensified the debate on transgenic crops.

The principal aim of this publication is to:

- provide an overview of the global adoption of transgenic crops in the period 1996 to 2001;
- document detailed information on the global status and distribution of commercial transgenic crops in 2001, by region, country, crop, and trait;
- rank the dominant transgenic crop/trait combinations in 2001;
- summarize and highlight the significant changes between 2000 and 2001;
- review the value of the transgenic seed market from 1995 to 2001 in the context of the global crop protection and seed market;
- provide current estimates of the global R & D expenditures in crop biotechnology;
- summarize the current status of the global commercial seed market;
- review crop biotechnology developments in the private sector, particularly the continuing alliances, acquisitions, and collaborations;
- review selected highlights for transgenic crops; and

- provide a comprehensive global overview of the experience with Bt cotton over the last six years since its introduction in 1996; the agronomic, environmental, economic and social benefits that it has delivered to date and its global potential in the future.

Note that the words maize and corn, rapeseed and canola, as well as transgenic and GM crops, are used synonymously in the text, reflecting the usage of these words in different regions of the world. Global figures and hectares planted commercially with transgenic crops have been rounded off to the nearest 100,000 hectares and in some cases this leads to insignificant approximations, and there may be slight variances in some figures, totals, and percentage estimates. It is also important to note that countries in the Southern Hemisphere plant their crops in the last quarter of the calendar year. The transgenic crop areas reported in this publication are planted, not harvested, hectarage in the year stated. Thus, the 2001 information for Argentina, Australia, South Africa and Uruguay is hectares planted in the last quarter of 2001 and harvested in the first quarter of 2002.

2. OVERVIEW OF GLOBAL STATUS AND DISTRIBUTION OF COMMERCIAL TRANSGENIC CROPS, 1996 TO 2001

Information on the adoption of commercial transgenic crops was provided by many independent sources from both the public and private sectors. Multiple sources of data, as well as additional and independent commercial marketing information, allowed several cross-checks to be conducted, which facilitated a rigorous verification of the estimates. For convenience and ease of interpretation, the data for the global status and distribution of commercial transgenic crops are presented in two complementary formats. Figures are used to best illustrate the changes in global transgenic area between 1996 and 2001. Companion tables provide more detailed corresponding information for 2001 and to illustrate the changes that have occurred between 2000 and 2001.

The estimated global area of transgenic crops for 2001 is 52.6 million hectares or 130.0 million acres (Table 1). It is noteworthy that 2001 is the first year when the global area of transgenic crops has exceeded the important historical milestone of 50 million hectares equivalent to approximately 125 million acres. To put this global area of transgenic crops into context, 52.6 million hectares is equivalent to more than 5% of the total land area of China (956 million hectares) or the US (981 million hectares) and more than twice the land area of the United Kingdom (24.4 million hectares). The increase in area of transgenic crops between 2000 and 2001 is 19%, equivalent to 8.4 million hectares or 20.8 million acres. This increase of 8.4 million hectares between 2000 and 2001 is almost twice the corresponding increase of 4.3 million hectares between 1999 and 2000 which was equivalent to an 11% growth.

Table 1. Global Area of Transgenic Crops, 1996 to 2001

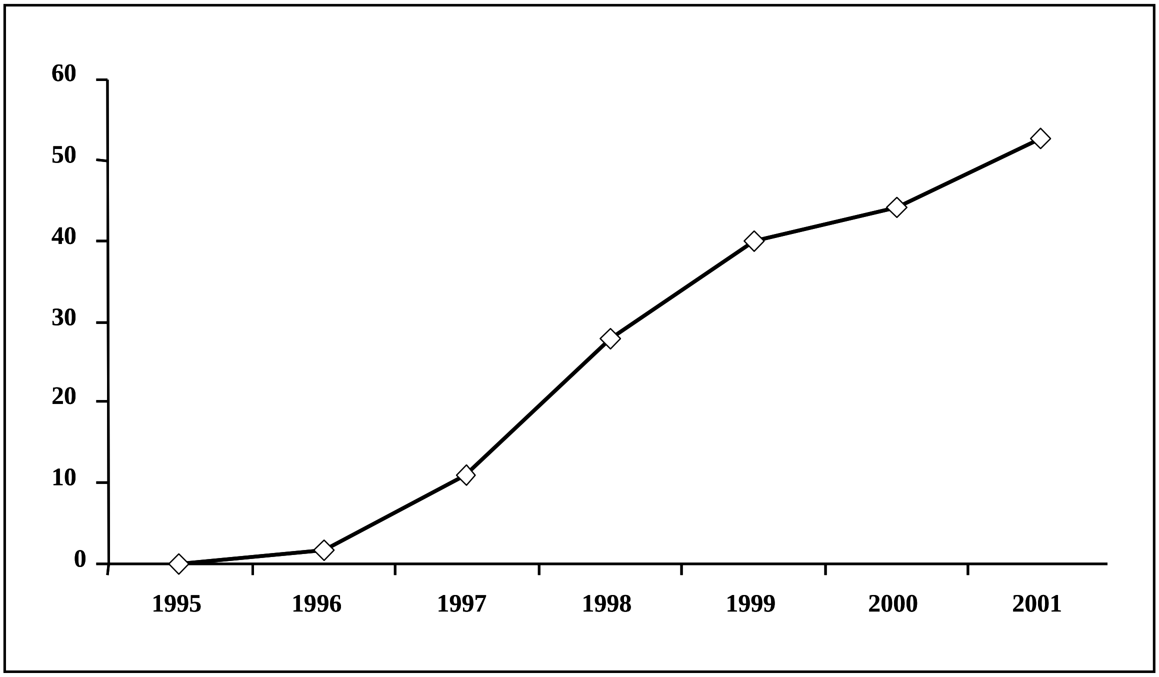
	Hectares (million)	**Acres** (million)
1996	1.7	4.3
1997	11.0	27.5
1998	27.8	69.5
1999	39.9	98.6
2000	44.2	109.2
2001	52.6	130.0

Increase of 19%, 8.4 million hectares or 20.8 million acres between 2000 and 2001.

Source: Clive James, 2002.

During the six-year period 1996 to 2001, the global area of transgenic crops increased by more than 30-fold, from 1.7 million hectares in 1996 to 52.6 million hectares in 2001 (Figure 1). This high rate of adoption reflects the growing acceptance of transgenic crops by farmers using the technology in both industrial and developing countries. During the six-year period 1996

Figure 1. Global Area of Transgenic Crops, 1996 to 2001 (Million Hectares).



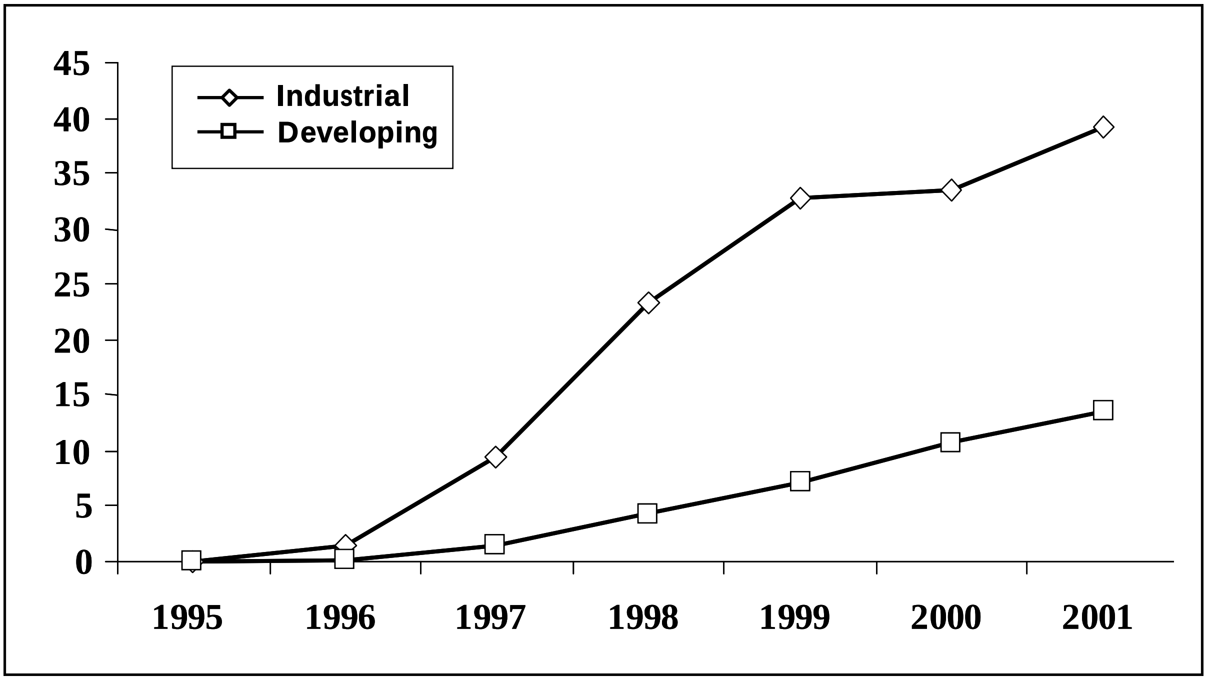
Source: Clive James, 2002.

– 2001, the number of countries growing transgenic crops more than doubled, increasing from 6 in 1996 to 9 in 1998, to 12 countries in 1999 and 13 in 2000 and 2001.

2.1 Distribution of Transgenic Crops in Industrial and Developing Countries

Figure 2 shows the relative hectarage of transgenic crops in industrial and developing countries during the period 1996 to 2001. It clearly illustrates that whereas the substantial share of GM crops have been grown in industrial countries, the proportion of transgenic crops grown in developing countries has increased consistently from 14% in 1997, to 16% in 1998, to 18% in 1999, 24% in 2000 and 26% in 2001. Thus, in 2001 more than one quarter (Table 2) of the global transgenic crop area of 52.6 million hectares, equivalent to 13.5 million hectares, was grown in developing countries where growth continued to be strong between 2000 and 2001. Whereas the absolute growth in GM crop area between 2000 and 2001 was twice as high in industrial countries (5.6 million hectares)

Figure 2. Global Area of Transgenic Crops, 1996 to 2001: Industrial and Developing Countries (Million Hectares).



Source: Clive James, 2002.

Table 2. Global Area of Transgenic Crops in 2000 and 2001: Industrial and Developing Countries (Million Hectares)

	2000	%	2001	%	+/-	%
Industrial Countries	33.5	76	39.1	74	+ 5.6	+ 17
Developing Countries	10.7	24	13.5	26	+ 2.8	+ 26
Total	**44.2**	**100**	**52.6**	**100**	**+ 8.4**	**+ 19**

Source: Clive James, 2002.

compared with developing countries (2.8 million hectares), the percentage growth was higher in the developing countries of the South (26%) than in the industrial countries of the North (17%).

2.2 Distribution of Transgenic Crops, by Country

In 2001, four countries grew 99% of the global transgenic crop area (Table 3), and all four countries reported growth of GM crops between 2000 and 2001 (Figure 3). It is noteworthy that the top four countries include two industrial countries, USA and Canada, and two developing countries, Argentina and China. Consistent with the pattern since 1996, the USA grew the largest transgenic crop hectarage (68%) in 2001. The USA grew 35.7 million hectares, followed by Argentina with 11.8 million hectares (22%), Canada 3.2 million hectares (6%) and China 1.5 million hectares (3%). China displayed the highest percentage year-on-year growth by tripling its GM crop area of Bt cotton between 2000 and 2001. Year-on-year growth was the same (18%) for the USA and Argentina and lower for Canada (6%). In 2001, transgenic crop hectarage also increased in South Africa and Australia where the growth rates were 33% and 37% respectively.

The 13 countries that grew transgenic crops in 2001 are listed in descending order of their transgenic crop areas (Table 3). There are 7 industrial countries and 6 developing countries. In 2001, transgenic crops were grown commercially in all six continents of the world – North America, Latin America, Asia, Oceania, Europe (Eastern and Western), and Africa. Of the top four countries that grew 99% of the global transgenic crop area, the USA grew 68%, Argentina 22%, Canada 6% and China 3%. The other 1% was grown in the remaining 9 countries, with South Africa and Australia being the only countries in that group growing more than 100,000 hectares or a quarter million acres of transgenic crops.

In the USA there was an estimated net gain of 5.4 million hectares of transgenic crops in 2001; this came about as a result of significant increases in the area of transgenic soybean and cotton, a modest increase in canola, and a small decrease in the area of transgenic corn. In Argentina, a gain of 1.8 million hectares was reported for 2001 because of significant growth in transgenic soybean and a modest increase in corn.

For Canada, a net gain of 0.2 million hectares was estimated with gains in both GM corn and soybean with a slight decrease in GM canola associated with the general decrease of 856,000 hectares in the national area planted to canola in 2001 compared with 2000. For China, the area planted to Bt cotton increased by a significant 1.0 million hectares from 0.5 million hectares in 2000 to 1.5 million hectares in 2001.

A significant increase of Bt corn was reported for South Africa, where the combined area of transgenic corn and cotton and soybean is expected to be approximately 225,000

Table 3. Global Area of Transgenic Crops in 2000 and 2001: by Country (Millions of Hectares)

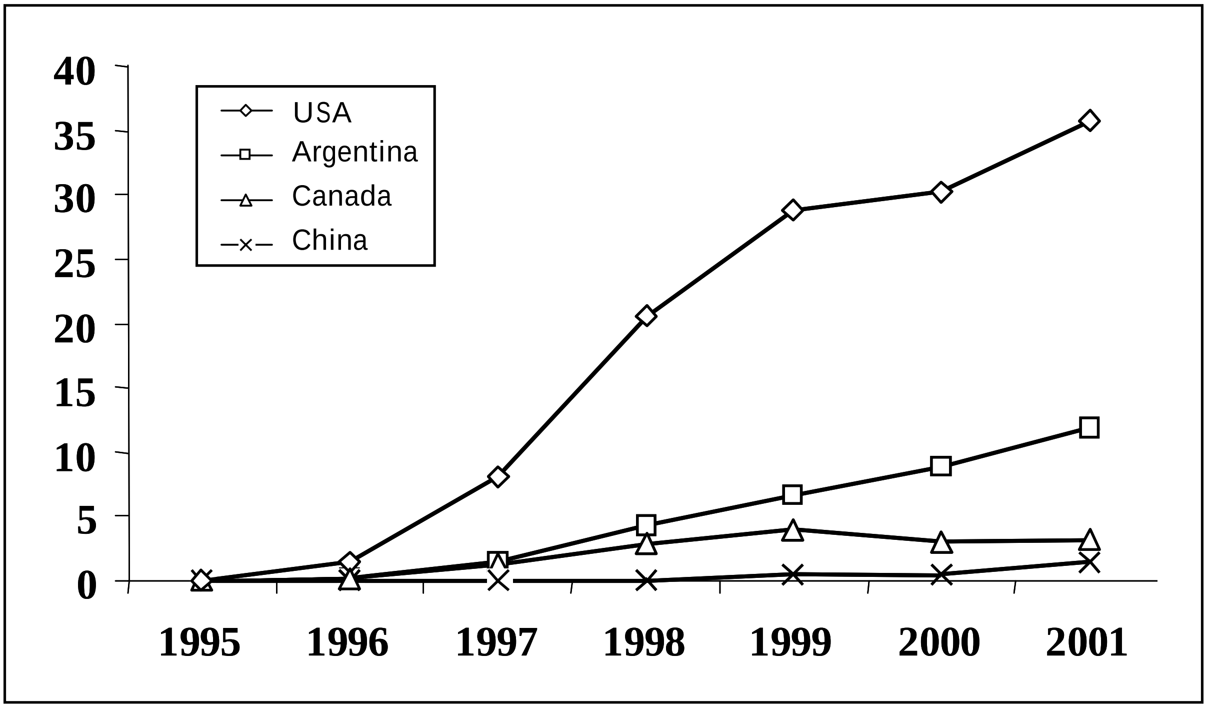
Country	2000	%	2001	%	+/-	%
USA	30.3	68	35.7	68	+ 5.4	+ 18
Argentina	10.0	23	11.8	22	+ 1.8	+ 18
Canada	3.0	7	3.2	6	+ 0.2	+ 6
China	0.5	1	1.5	3	+ 1.0	+ 200
South Africa	0.2	<1	0.2	<1	< 0.1	+ 33
Australia	0.2	<1	0.2	<1	< 0.1	+ 37
Mexico	<0.1	<1	<0.1	<1	< 0.1	- -
Bulgaria	<0.1	<1	<0.1	<1	< 0.1	- -
Uruguay	<0.1	<1	<0.1	<1	< 0.1	- -
Romania	<0.1	<1	<0.1	<1	< 0.1	- -
Spain	<0.1	<1	<0.1	<1	< 0.1	- -
Indonesia	- -	- -	<0.1	<1	< 0.1	- -
Germany	<0.1	<1	<0.1	<1	< 0.1	- -
France	<0.1	<1	- -	- -	- -	- -
Total	**44.2**	**100**	**52.6**	**100**	**+ 8.4**	**+ 19%**

Source: Clive James, 2002.

hectares. In Australia, over 200,000 hectares of transgenic cotton was planted in 2001 compared with 150,000 hectares in 2000, with Mexico reporting a modest area of transgenic cotton and soybean. The countries growing transgenic crops in 2001 include two Eastern European countries, Romania growing soybean, and Bulgaria growing herbicide tolerant corn. The two European Union countries – Spain and Germany – which grew small areas of Bt corn in 2000, continued to grow Bt corn in 2001 – Spain grew about 12,000 hectares and Germany less than a hundred hectares in 2001. France, which grew a token area of Bt corn in 2000, did not report any Bt corn for 2001. One new GM country, Indonesia, reported the commercialization of transgenic crops for the first time in 2001, growing a small area, 4,000 hectares, of Bt cotton.

The country portfolios of deployed GM crops continued to diversify in 2001 with several crop/trait introductions reported for the first time. These included: herbicide tolerant corn in Argentina; herbicide tolerant cotton as well as the stacked Bt/herbicide tolerant cotton in Australia; herbicide tolerant soybean, Bt white corn and herbicide tolerant cotton in South Africa and Bt cotton in Indonesia.

Figure 3. Global Area of Transgenic Crops, 1996 to 2001: by Country (Million Hectares).



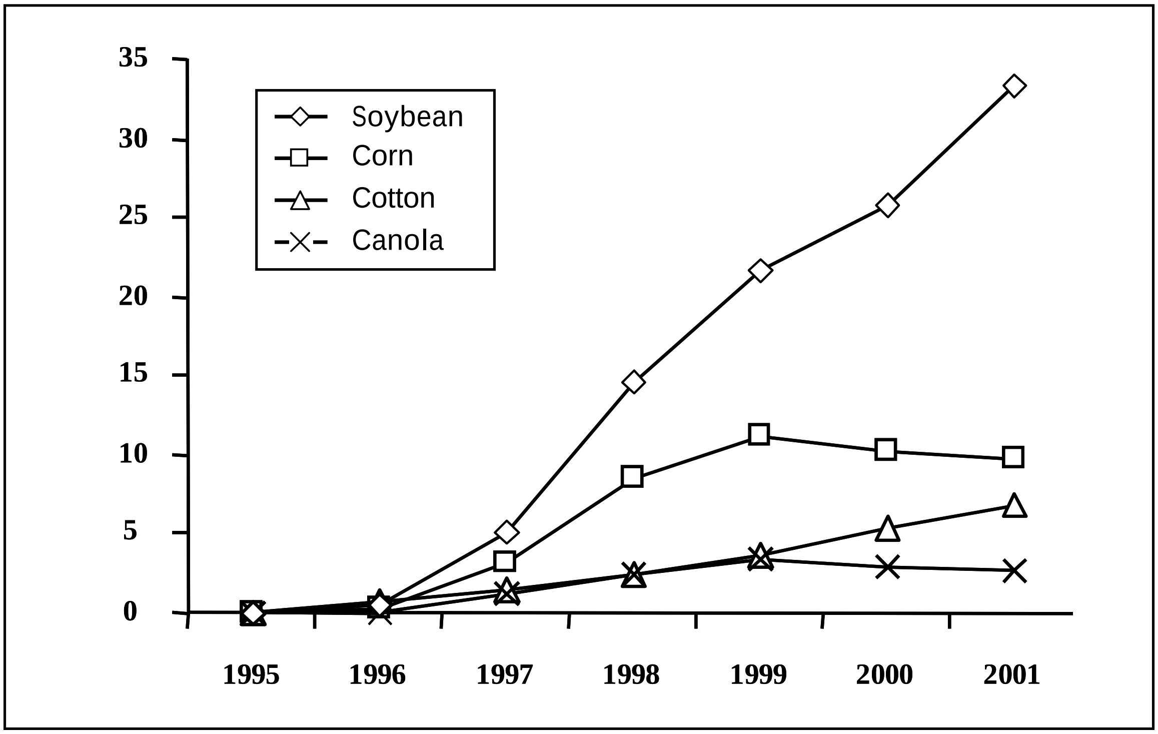
Source: Clive James, 2002.

2.3 Distribution of Transgenic Crops, by Crop

The distribution of the global transgenic crop area for the four major crops is illustrated in Figure 4 for the period 1996 to 2001. It clearly shows the dominance of transgenic soybean occupying 63% of the global area of transgenic crops in 2001; the entire transgenic soybean is herbicide tolerant. Transgenic soybean retained its position in 2001 as the transgenic crop occupying the largest area. Globally, transgenic soybean occupied 33.3 million hectares in 2001, with transgenic corn in second place at 9.8 million hectares, transgenic cotton in third place at 6.8 million hectares, and canola at 2.7 million hectares (Table 4).

In 2001, the global hectarage of herbicide tolerant soybean is estimated to have increased by 7.5 million hectares, equivalent to a 29% increase. Gains of approximately 5.7 million hectares of transgenic soybean were reported for the USA in 2001 with 71% of the national soybean area of 30.1 million hectares planted to GM crops. Argentina reported a gain of 1.8 million hectares of GM soybean with adoption rates estimated at 98% of the 11.2 million hectares of soybeans grown in 2001.

Figure 4. Global Area of Transgenic Crops, 1996 to 2001: by Crop (Million Hectares).



Source: Clive James, 2002.

Transgenic corn area in 2001 is estimated to have decreased globally by about 500,000 hectares (Table 4) with all the reduction in the USA. Some observers have attributed the reason for the decrease in transgenic corn in the USA in 2001 to some farmers concluding that the historically low infestations of European Corn Borer in 1999 and 2000 did not merit the use of Bt corn in 2001 on the basis that infestation may continue to be low; however ECB levels in 2001 proved to be much higher than expected and this may result in increased plantings of Bt corn in 2002. Others have suggested that some farmer uncertainty about markets for transgenic corn as well as low prices may have contributed to decreased plantings of Bt corn in 2001 by a small proportion of farmers. Decreases in transgenic corn in the USA were offset by significant increases in transgenic corn in Canada, Argentina and South Africa where adoption rates increased.

The small decrease of 100,000 hectares in area planted globally with transgenic canola in 2001 all occurred in Canada and was associated with the general decrease of 856,000 hectares in the national area planted to canola in Canada in 2001 compared with 2000. However, the percentage of the canola

Table 4. Global Area of Transgenic Crops in 2000 and 2001: by Crop (Millions of Hectares)

Crop	2000	%	2001	%	+/-	%
Soybean	25.8	58	33.3	63	+7.5	+29
Maize	10.3	23	9.8	19	-0.5	-5
Cotton	5.3	12	6.8	13	+1.5	+28
Canola	2.8	7	2.7	5	-0.1	-4
Potato	<0.1	<1	<0.1	<1	<0.1	- -
Squash	<0.1	<1	<0.1	<1	(- -)	- -
Papaya	<0.1	<1	<0.1	<1	(- -)	- -
Total	**44.2**	**100**	**52.6**	**100**	**+ 8.4**	**+ 19**

Source: Clive James, 2002.

crop in Canada planted to transgenics increased from 55% in 2000 to 61% in 2001. The decrease in Canada in 2001 was offset by a modest increase in transgenic canola in the USA which increased by more than 10% in 2001.

The global area of transgenic cotton in 2001 is estimated to have increased by 1.5 million hectares, from 5.3 million hectares in 2000 to an estimated 6.8 million hectares in 2001 – this is equivalent to a year-over-year increase of 28% in the global area of transgenic cotton. The most significant increase was reported for China which tripled its Bt cotton area from 0.5 million hectares in 2000 to 1.5 million hectares in 2001. In the USA the percentage of transgenic cotton increased from 72% in 2000 to 77% in 2001. Australia also increased its transgenic cotton area by 33% from 150,000 to 200,000 hectares with plantings at approximately the same levels in Mexico, Argentina, and South Africa.

2.4 Distribution of Transgenic Crops, by Trait

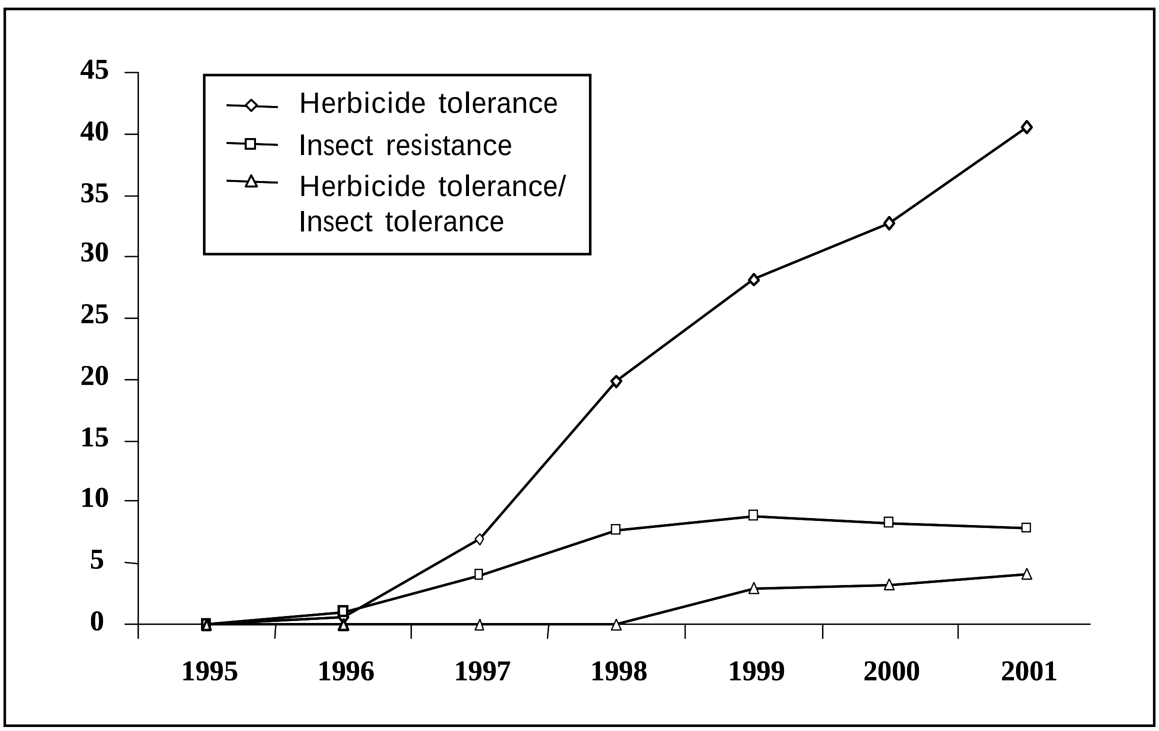
During the six-year period 1996 to 2001, herbicide tolerance has consistently been the dominant trait with insect resistance being second (Figure 5). In 2001, herbicide tolerance, deployed in soybean, corn and cotton, occupied 77% of the 52.6 million hectares (Table 5), with 7.8 million hectares planted to Bt crops equivalent to 15%, and stacked genes for herbicide tolerance and insect resistance deployed in both cotton and

Table 5. Global Area of Transgenic Crops in 2000 and 2001: by Trait (Millions of Hectares).

Trait	2000	%	2001	%	+/-	%
Herbicide tolerance	32.7	74	40.6	77	+ 7.9	+ 24
Insect resistance (Bt)	8.3	19	7.8	15	- 0.5	- 6
Bt/Herbicide tolerance	3.2	7	4.2	8	+ 1.0	+ 31
Virus resistance/Other	<0.1	<1	<0.1	<1	< 0.1	- -
Global Totals	**44.2**	**100**	**52.6**	**100**	**+8.4**	**19**

Source: Clive James, 2002.

Figure 5. Global Area of Transgenic Cops, 1996 to 2001: by Trait (Million Hectares).



Source: Clive James, 2002.

corn occupying 8% of the global transgenic area in 2001. It is noteworthy that the area of herbicide tolerant crops has increased significantly by 24% or 7.9 million hectares between 2000 and 2001 (32.7 million hectares to 40.6 million hectares). Crops with stacked genes for herbicide tolerance and Bt also increased from 3.2 million hectares in 2000 to 4.2 million hectares in 2001, whereas the global area of insect resistant crops has decreased from 8.3 million hectares in 2000 to 7.8 million hectares in 2001 (Table 5 and Figure 5). The trend for stacked genes to gain an increasing share of the global transgenic crop market is expected to continue.

2.5 Dominant Transgenic Crops in 2001

Herbicide tolerant soybean was the most dominant transgenic crop grown commercially in seven countries in 2001 – USA, Argentina, Canada, Mexico, Romania, Uruguay and South Africa (Table 6). Globally, herbicide tolerant soybean occupied 33.3 million hectares, representing 63% of the global transgenic crop area of 52.6 million hectares for all crops. The second most dominant crop was Bt maize, which occupied 5.9 million hectares, equivalent to 11% of global transgenic area and planted in six

Table 6. Dominant Transgenic Crops 2001

Crop	Million Hectares	% Transgenic
Herbicide tolerant Soybean	33.3	63
Bt Maize	5.9	11
Herbicide tolerant Canola	2.7	5
Herbicide tolerant Cotton	2.5	5
Bt/Herbicide tolerant Cotton	2.4	5
Herbicide tolerant Maize	2.1	4
Bt Cotton	1.9	4
Bt/Herbicide tolerant Maize	1.8	3
Total	**52.6**	**100**

Source: Clive James, 2002.

countries – USA, Canada, Argentina, South Africa, Spain, and Germany. The other six crops listed in Table 6 all occupy 5% or less of global transgenic crop area and include, in descending order of area: herbicide tolerant canola, occupying 2.7 million hectares (5%); herbicide tolerant cotton on 2.5 million hectares (5%); Bt/herbicide tolerant cotton on 2.4 million hectares (5%); herbicide tolerant maize on 2.1 million hectares (4%); Bt cotton on 1.9 million hectares (4%); and Bt/herbicide tolerant maize on 1.8 million hectares (3%).

2.6 Global Adoption of Transgenic Soybean, Corn, Cotton and Canola

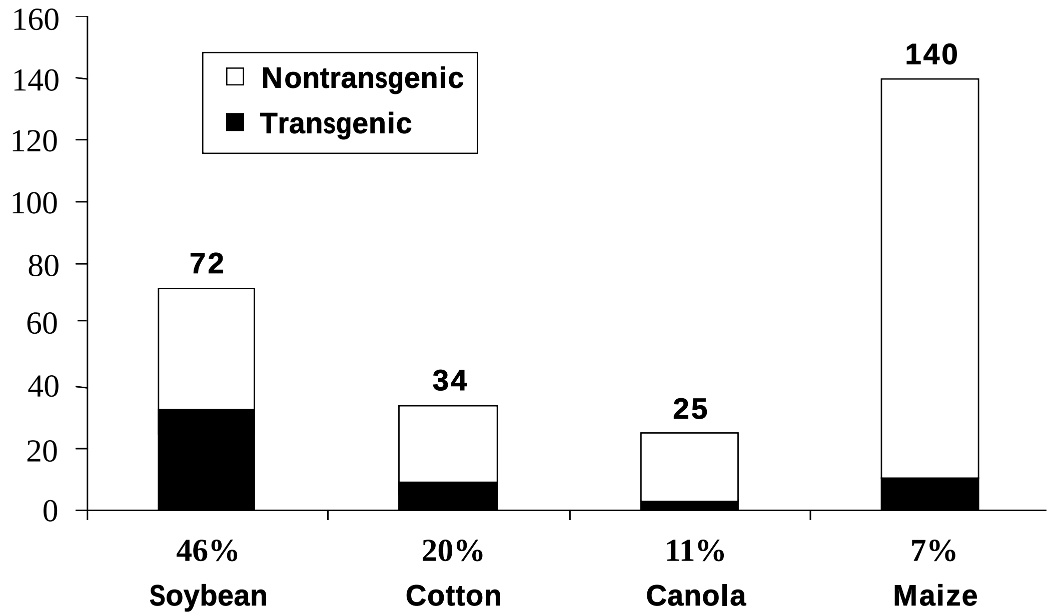
One useful way to portray a global perspective of the status of transgenic crops is to characterize the global adoption rates of the four principal crops – soybean, cotton, canola and corn – in which transgenic technology is utilized (Table 7 and Figure 6). The data indicates that in 2001, 46% of the 72 million hectares of soybean planted globally were transgenic - up from 36 % in 2000. Similarly, 20% of the 34 million hectares of cotton up from 16 % in 2000 were planted to transgenic cotton. The areas planted to transgenic canola and maize, expressed on percentage basis, were unchanged at 11% of the 25 million hectares of canola, and 7% of the 140 million hectares of maize respectively. If the global areas (conventional and transgenic) of these four crops are aggregated, the total area is 271 million hectares, of which 19%, up from 16% in 2000, is genetically modified. It is noteworthy that two-thirds of these 271 million hectares are in the developing countries where yields are lower, constraints are greater, and the need for improved production of food, feed, and fiber crops is the greatest.

Table 7. Transgenic Crop Area as % of Global Area of Principal Crops, 2001 (Million Hectares)

Crop	Global Area	Transgenic Crop Area	Transgenic Area as % of Global Area
Soybean	72	33.3	46
Cotton	34	6.8	20
Canola	25	2.7	11
Maize	140	9.8	7
Others	-	-	-
Total	**271**	**52.6**	**19**

Source: Clive James, 2002.

Figure 6. Global Adoption Rates (%) for Principal Transgenic Crops, 2001 (Million Hectares)



Source: Clive James, 2002.

2.7 Summary of Significant Changes between 1999 and 2001

The major changes in area and global share of transgenic crops for the respective countries, crops, and traits, between 2000 and 2001 were related to the following factors:

- In 2001, the global area of transgenic crops increased by 19%, or 8.4 million hectares, to 52.6 million hectares, from 44.2 million hectares in 2000. Eight transgenic crops were grown commercially in 13 countries in 2001, one of which, Indonesia grew a transgenic crop, Bt cotton, for the first time. France, which grew a small area of Bt maize in 2000 did not report transgenic crops in 2001.

- The four principal countries that grew the majority of transgenic crops in 2001 were USA 35.7 million hectares (68% of the global area); Argentina, 11.8 million hectares (22%), Canada 3.2 million hectares (6%); China 1.5 million hectares (3%). The balance was grown in South Africa, Australia, Mexico, Bulgaria, Uruguay, Romania, Spain, Indonesia and Germany. The highest growth in transgenic crop area between 2000 and 2001 was reported for the USA (5.4 million hectares), followed by Argentina (1.8 million hectares), China (1.0 million hectares) and Canada with 0.2 million hectares.

- In the developing countries growth in area of transgenic crops between 2000 and 2001 was 26% compared with 17 % in industrial countries, whereas absolute growth in area was twice as high in industrial countries (5.6 million hectares) compared with 2.8 million hectares in developing countries.

- In terms of crops, soybean contributed the most to global growth of transgenic crops, equivalent to 5.7 million hectares between 2000 and 2001, followed by cotton with an increase of 1.5 million hectares. Corn and canola decreased by 0.5 and 0.1 million hectares respectively because of decreases in USA and Canada, which were partly offset by increases in transgenic corn in developing countries.

- There were three noteworthy developments in terms of traits; herbicide tolerance contributed the most (7.9 million hectares) to global growth between 2000 and 2001; the stacked genes of insect resistance and herbicide tolerance in both corn and cotton contributed 1.0 million hectares, with insect resistance decreasing by 0.5 million hectares.

- Of the 4 major transgenic crops grown in 13 countries in 2001, the two principal crops of soybean and corn represented 63% and 19% respectively for a total of 82% of the global transgenic area, with the remaining 18% shared between cotton (13%) and canola (5%).

- In 2001, herbicide tolerant soybean was the most dominant transgenic crop (63% of global transgenic area, compared with 59% in 2000), followed by insect resistant maize (11% compared with 15% in 2000), herbicide tolerant canola and cotton and Bt/herbicide tolerant cotton all at 5%, herbicide tolerant maize and Bt cotton at 4% and Bt/herbicide tolerant maize at 3%.

The combined effect of the above seven factors resulted in a global area of transgenic crops in 2001 that was 8.4 million hectares greater and 19% more than 2000. This is a significant year-on-year increase considering the high percentage of the principal crops already planted to transgenics in 2000.

3. VALUE OF THE GLOBAL TRANSGENIC SEED MARKET, 1995 TO 2001

The value of the transgenic crop market is based on the sale price of transgenic seed plus any technology fees that apply. The estimates published here are the most recently revised estimates from Wood Mackenzie Agrochemical Services (Wood Mackenzie 2002) which exclude non-genetically modified herbicide tolerant seed. Global sales of transgenic seed have grown rapidly from 1995 onwards (Table 8). Initial global sales of transgenic seed were estimated at $ 1 million in 1995. Sales increased in value to $ 148 million in 1996, and increased by approximately $ 711 million in 1997 to reach $ 859 million. Sales increased by another $1,111 million between 1997 and 1998 to reach $ 1.97 billion in 1998. Sales continued to increase substantially in 1999 by an additional $ 977 million to reach $2.95 billion in 1999 and in 2000 plateaued at $ 3,044 million. In 2001 there was a renewed significant increase of $795 million to $3.8 billion.

Table 8. Estimated Value of Global Transgenic Seed Market, 1995-2001 ($ Millions)

Year	Market Value $
1995	1
1996	148
1997	859
1998	1,970
1999	2,947
2000	3,044
2001	**3,839**

Source: Wood Mackenzie, 2002 (Personal Communication)

4. VALUE OF TRANSGENIC CROPS IN THE CONTEXT OF THE GLOBAL CROP PROTECTION MARKET

All the traits introduced to-date are crop protection traits, and thus it is useful and appropriate to discuss the value of total sales of transgenic crops as a percentage of the global crop protection market. Wood Mackenzie (2002) estimated that transgenic seed in 1998 accounted for 6.3% of the $31.25 billion global crop protection market at the ex-distributor market value. Between 1998 and 2001 the value of the transgenic seed market has increased steadily from 6.3% in 1998 to 9.5% in 2000, and to 12.4 % in 2001 (Table 9) equivalent to $ 3.839 billion out of a total crop protection market of $30.943 billion. It is noteworthy that the transgenic crops category is the only one of the five categories to show an increase in value between 2000 and 2001 (Table 9); transgenic crops increased by a significant 26.1%, whilst herbicides decreased by 6.9%, insecticides by -6.1% and fungicides by -6.9%.

The distribution of the sale of transgenic seed, based on value, is shown by region and product in Table 10. It is clear that the major market is in North America with its share valued at $ 2.865 billion equivalent to 60% of the global market; the second largest market is in Latin America with $766 million equivalent to 20% of the global market, followed by the Far East (developing countries of Asia) at $195 million or 5% of global market share. In terms of product, soybean has the major market share at $2.194 billion or 57% of the global market followed by maize at $ 783 million (20%), cotton at $ 636 million (17%) and canola $226 million (6%).

Table 9. Global Crop Protection Market in 2001: by Product (Value in $ Millions)

Group	$ Millions	% Change from 2000
Herbicides	12,885	- 6.9%
Insecticides	7,559	- 6.1%
Fungicides	5,306	- 6.9%
Plant Growth Regulators and Others	1,354	- 3.3%
Transgenic Crops	3,839	+ 26.1%
Total	**30,943**	**- 5.7%**

Source: Wood Mackenzie Agrochemical Services, 2002 (Personal Communication).

Table 10. Value of Global Transgenic Crops in 2001: by Crop and Region ($ Millions)

Crop	$ Millions
Soybean	2,194
Maize	783
Cotton	636
Canola	226
Total	**3,839**
Region	
North America	2,865
Latin America	766
West Europe	<2
East Europe	<3
Far East	195
Rest of the World	10
Total	**3,839**

Source: Wood Mackenzie, 2002 (Personal Communication).

The data in Table 11 is a matrix of crop protection products, including GM biotech traits deployed in industrial and developing countries. It shows the relative distribution between industrial and developing countries in relation to the different types of pesticides. It is noteworthy that the value of the transgenic crop market in USA and Canada ($2.865 billion, Table 10) is already worth 9% of the global crop protection market of $31 billion and continues to grow annually – this compares with 2% for Latin America ($766 million), and <1% for the developing countries of the Far East. It is evident from the data in Table 11 that the value of the transgenic crop market is higher in the industrial countries, $2.869 billion equivalent to 59% of the global market, compared with $970 million, equivalent to 25%, in the developing countries, over 78% of which is in Latin America and with most of the balance in the Far East.

Of the total crop protection market of $19.656 billion in the industrial countries, $2.869 billion equivalent to 15% is transgenic crops. The corresponding figure for the developing countries is a total crop protection market of $11.287 billion of which transgenic crops are valued at $970 million equivalent to 9%, up from 5% in 2000. Whereas, the value of the herbicide market in the industrial countries ($ 8.6 billion) is twice that in the developing countries ($4.3 billion), the countries of the South spend more on insecticides ($3.9 billion) than the countries in the North ($3.6 billion). However, the significant difference in herbicide usage between industrial and developing countries is likely to become less marked in the future. Agronomic practices such as zero or low–tillage, availability and cost of labor in developing countries will offer new opportunities for farmers to use more herbicide tolerant varieties, that allow improved conservation of moisture and nutrients that collectively contribute to a more sustainable agriculture. Efficient use of water in both rainfed and irrigated agriculture will become increasingly important and herbicide

Table 11. Global Crop Protection Market, 2001: by Industrial/Developing Country and Product ($ Millions)

	Herbicides	Insecticides	Fungicides	Others	Biotech	Total
Industrial Countries	8,624	3,616	3,556	991	2,869	**19,656**
Developing Countries	4,261	3,943	1,750	363	970	**11,287**
Total	**12,885**	**7,559**	**5,306**	**1,354**	**3,839**	**30,943**

Source: Wood Mackenzie, 2002 (Personal Communication).

tolerance technology will be seen by farmers to be compatible with changing and emerging new needs.

Of the total global crop protection market of $31 billion, about two-thirds is in the industrial countries ($19.656 billion) with the other one-third ($11.287 billion) in the developing countries (Table 11). The data in Table 12 indicate the global market share of the 12 principal countries in crop protection; the balance is assigned to the remaining "Others" category. Of the top 12 countries, eight are industrial countries (USA, Japan, France, Canada, Germany, South Korea, Australia and Italy) and four are developing countries (Brazil, China, Argentina and India). Expressed as a percentage of the global market, there are five countries with 5% or more of global market share.

The US is by far the biggest crop protection market (32% of the global $31 billion market), followed by Japan (9%), Brazil (8%), China (6%), and France (5%). The remaining seven countries listed in Table 12 have global market shares of between 2% and 5%. It is not surprising that the top four countries that grew 99% of the transgenic crops in 2001 (USA, Argentina, Canada, and China) are also in the top ten in the global crop protection market. Collectively the top four countries that grew transgenics in 2001 consumed 45% of the global pesticide market and are already benefiting from reduced and/or more efficient pesticide usage. Similarly, the four major transgenic crops, soybean, maize, cotton and canola include three out of the top five crops that consume pesticides globally (Table 13). Collectively, the four crops consume 38% of global pesticides and are already benefiting from reduced and/or more efficient pesticide usage, particularly in crops such as Bt cotton where major reductions are being realized in terms of insecticides and fewer health hazards to farmers in countries such as China and South Africa. Further reductions and increase in efficiencies in pesticide usage can be realized as more insect resistant crops and herbicide tolerant varieties are deployed. Coincidentally, these technologies will provide major benefits in terms of more flexible and improved

Table 12. Global Crop Protection Market, in 2001: by Country Expressed as Percentage of Total Market

Country	% Global Market
USA	32
Japan	9
Brazil	8
China	6
France	5
Argentina	4
Canada	3
Germany	3
South Korea	3
Australia	2
India	2
Italy	2
Others	21
Total	**100**

Source: Wood Mackenzie, 2002 (Personal Communication).

Table 13. Global Crop Protection Market, in 2001: by Crop Expressed as Percentage of Total Market

Total Crop Protection Market by Crop	%
Fruit and Vegetables	24
Soybeans	15
Cereals	13
Maize	11
Cotton	10
Rice	9
Oilseed Rape/Canola	2
Sugar Beet	2
Other Crops	14
Total	**100**

Source: Wood Mackenzie, 2002 (Personal Communication).

conservation and management practices that farmers value highly and which collectively contribute to more sustainable farming systems.

It is noteworthy that the increase in the developing country GM crop market from $671 million in 2000 to $970 million is a 44% increase and significantly greater than the corresponding 20% increase in industrial countries from $2.373 billion to $ 2.869 billion. The significant increase in developing countries reflected a 41% increase in the value of the transgenic market in Latin America, and a 79% increase in Asia.

5. GLOBAL R&D EXPENDITURES IN CROP BIOTECHNOLOGY AND FUTURE GM CROP MARKETS

The advent of biotechnology in the early 1980s resulted in a significant change in the relative R&D investments of the public and private sectors in agriculture. Estimates of R&D investments in agricultural biotechnology in 1985 (Persley 1990) indicated that the total annual investments were $900 million with $550 million (61%) invested by the private sector and $350 million (39%) by the public sector. The life sciences concept embraced by the private sector in the early 1990s, which resulted in a spate of expensive acquisitions and mergers significantly increased the investment of industry in agricultural biotechnology. In 1995, R&D investment in agricultural biotechnology was $2 billion for the USA alone (James 1997b) and globally at $2.75 billion. Public sector investments in crop biotechnology continue to be substantial in the USA in 2001 and remain dominant in the global context. Australia is also committed to its public sector investments in crop biotechnology and three EU countries, UK, Germany and France, continue to support crop biotechnology. In Asia, Japan and South Korea have modest public sector investments in crop biotechnology (Kalaitzandonakes 2000).

In 1995 the private sector viewed crop biotechnology, prior to the commercialization of the first GM crops in 1996, as an important new opportunity for markets that would contribute to lowering crop production costs, increasing productivity, provide a safer environment and a more sustainable system for ensuring global food, feed and fiber security. Later in the 1990s the private sector judged the life science concept to be an inappropriate strategy for the future. There followed a series of spin-offs and mergers culminating in consolidation that resulted in six transnational North American and European based crop protection/ biotechnology entities. By the late 90s, the rate of investments in R&D by the private sector in GM crops was slowing despite the fact that the technology had a great deal to offer society. The disincentive for industry was mainly the reluctance and strong opposition of the countries of the European Union to the commercialization of GM crops in the EU, with knock-on negative effects in developing countries and also the campaigns waged by some NGOs opposed to GM technology.

The slower rate of investments by industry in mainstream GM crops has to some extent been offset by new investments in areas such as genomics and increased investments and interest by some key developing countries who view GM crops as important elements in their future strategy for food, feed and fiber security. Notable amongst the developing countries is China which made its initial investments in crop biotechnology in the mid 1980s. By 1999, there were 35 institutes in China conducting research on crop biotechnology with a staff of 1,200 plus another 800 staff at other institutions for a total of 2,000. The annual R&D budget in China for crop biotechnology in 1999 was $112 million (Huang et al 2002) with a commitment to increase it by 400% by 2005. China invests more than half of the R&D crop biotech budget of the developing countries estimated at $180 million. Other independent estimates by consultants suggest that crop biotechnology investments in China could be as high as $300 million (Kalaitzandonakes 2000). China, which conducts biotechnology research on 50 plant species and 120 functional genes, has approved 45 GM crop applications for field trials, 65 for environmental release and 31 for commercialization. These crops include the three major food staples: rice for insect resistance (Bt and CpTi) and disease resistance (Xa 21), and herbicide and salt tolerance; wheat for BYDV virus disease resistance and quality improvement; and maize for insect resistance and quality improvement. As much as 90% of GM crop applications are focused on insect and disease resistance. About 9.2% of government R&D support for crop research is devoted to biotechnology (Huang et al 2002). The positive Chinese experience with Bt cotton provides home-grown evidence that some of the perceptions of antibiotech critics are not substantiated in practice and that the technology can deliver significant agronomic, economic, environmental health and social benefits to small resource-poor farmers and contribute to the alleviation of poverty.

India is also increasing its investment in crop biotechnology in both the public and private sectors. Following approval by the Government of India to commercialize Bt cotton in 2002, it was noteworthy that the Genetic Engineering Advisory Committee (GEAC) approved field trials of GM mustard and indicated its intent to consider applications for GM soybean and maize. The Indian Council of Agricultural Research (ICAR) is committed to biotechnology and is already developing its own Bt cotton and the indigenous private sector in India is increasing its investments in GM technology. It is estimated that India is investing $15 million per year in public sector research with an additional $10 million by the private sector for a total of $25 million.

In Latin America, Brazil is investing up to $3 million per year through its national agricultural research system, EMBRAPA, and The Sao Paulo Research Foundation is investing up to $10 million, plus private sector investment of $2 million for a total of $15 million per year.

Other developing countries that are investing in crop biotechnology include Pakistan and Malaysia, Thailand, Indonesia, Philippines and Vietnam in South East Asia. In Latin America, Brazil, Mexico, Cuba, Argentina and Chile have agricultural biotech activities. In Africa, the major investments are in South Africa, Egypt, Zimbabwe, and Kenya, with the President of Nigeria having committed $263 million per year in 2001, for three years for biotechnology in agriculture and medicine.

Reviewing investments by both the private and public sectors in crop biotechnology in 2001(Table 14), the total R&D expenditure in crop biotechnology was estimated to be

Table 14. 2001 Estimates of Global R&D Expenditures on Crop Biotechnology

	$ millions	
Industrial		**4,220**
Private	3,100	
Public	1,120	
Developing Countries**		**180**
China	115*	
India	25	
Brazil	15	
Others	25	
Total		**4,400**

Source: Compiled by Clive James, based on industry and public sector estimates. Global estimate for crop biotechnology of $4.4 billion courtesy of Freedonia Group Inc., 2002 Personal Communication. Breakdown of $4.4 billion from various other sources: * 1999 estimate (Huang et al 2002); public sector investments in China could be as high as $300 million (Kalaitzandonakes 2000): global investments in crop biotechnology (Huang et al 2002, James 1997); ** Includes public (80%) and private sector (20%) expenditures.

Table 15. Global Value of Transgenic Crop Market 1996-2010

Year	Millions of $
1996	148
1997	859
1998	1,970
1999	2,947
2000	3,044
2001	3,839
2005	5,000
2010	10,000 to 15,000

Source: Wood Mackenzie estimates for 1996 to 2001, Projections by Clive James for 2005 and 2010 approximately $4.4 billion (Freedonia 2002). The industrial country investments (author estimates) comprised >95% of the total global investments at $4.22 billion, with the balance of $180 million invested by the developing countries, mainly by the public sector, with China investing the majority of the R&D resources. The success and return on investment that China has achieved with Bt cotton, which delivered total benefits of $750 million at a national level in 2001, of which at least half is attributable to the CAAS Bt cotton varieties, is an important experience that can catalyze and reinforce China's intent to quadruple its R&D investments to $450 million in crop biotechnology by 2005. Similar progress by India with Bt cotton could provide the incentive for India to accelerate and increase its investments in crop biotechnology. China and India, the two most populous countries in the world, with a combined population of 2.3 billion and 250,000,000 hectares of crop land could provide the role models and stimulus for other developing countries in Asia, Latin America, and Africa to make their own investments in crop biotechnology. The incentive for countries like China and India, two countries with a strong tradition in trading, is not only to develop GM products to meet their own food, feed and fiber needs, but also to develop new markets for their GM crops in other developing countries of the South, where the majority of the 1.5 billion hectares of crop land is cultivated, and where the need for food, feed and fiber is greatest.

Given the above status of R&D expenditures in crop biotechnology and the indications that global area of 52.6 million hectares of GM crops in 2001 will continue to grow in 2002 and beyond, the global deployment of GM crops is expected to increase to $5 billion by 2005 and up to $10 to $15 billion by 2010, (Table 15) with both agronomic and quality traits contributing to increased value. These estimates do not include the area of GM crops reported to be grown in countries such as Brazil, where official approval is still pending despite the fact that farmers have planted substantial areas of GM crops for several years.

6. OVERVIEW OF THE COMMERCIAL SEED INDUSTRY

The author estimates that, expressed as a proportion of the global commercial seed market, transgenic seed represents approximately 13% of the estimated $ 30 billion plus global commercial seed market in 2000 (FIS 2001).

Given that seed is the vehicle for incorporating and deploying transgenic traits, it is instructive to characterize the global commercial seed market to gain a sense of the scope, scale and size of the relative sub-segments of the global market classified by country, or seed, or exports. The latest estimate for the global commercial seed market is approximately $30 billion (FIS 2001), with almost 30% of the market in the developing countries. Six of the top ten country markets (Table 16) are in the industrial countries: USA ($ 5.7 billion), Japan ($ 2.5 billion), Commonwealth of Independent States ($ 2 billion), France ($ 1.4 billion), Germany ($ 1.0 billion) and Italy ($ 650 million). The four developing countries in the top ten are China ($ 3 billion), Brazil ($ 1.2 billion), Argentina ($ 930 million) and India ($900 million). Of the 13 countries that grew transgenic crops in 2000, nine are in the top twenty countries in terms of seed sales; the four exceptions are South Africa, Romania, Bulgaria and Uruguay.

Table 16. Latest Estimated Values (US $ Millions) of the Commercial Markets for Seed and Planting Material for the Top 20 Countries

Country	Internal Commercial Market
USA	5,700
China	3,000
Japan	2,500
CIS	2,000
France	1,370
Brazil	1,200
Germany	1,000
Argentina	930
India	900
Italy	650
United Kingdom	570
Canada	550
Poland	400
Mexico	350
Spain	300
Netherlands	300
Australia	280
Hungary	200
Denmark	200
Sweden	200
Total	**22,600***

* This total represents the sum of the commercial seed markets of the 20 listed countries. The commercial world seed market is assessed at US$ 30 billion.

Source: FIS, 2001.

Considering seed exports worldwide, the global market is valued at approximately $3.5 billion, equivalent to about 10% of the global market valued at $ 30 billion (Appendix Table 1A). Maize is the most important seed export market, valued at $ 530 million annually. The top five crops that have export sales of more than $ 75 million annually are maize ($ 530 million), herbage crops ($ 427 million), potato ($ 400 million), beet ($ 308 million) and wheat ($ 75 million). Breaking down the seed export market by country, out of the top ten countries the top nine are industrial countries with annual exports of seeds valued from $ 799 million to $ 105 million. Given the ongoing debate in Europe re transgenic crops, it is noteworthy that approximately half of the global seed export sales are from European countries. Out of a total global market of $3.5 billion, the USA is ranked # 1 with $ 799 million (Appendix Table 2A), followed by the Netherlands ($ 620 million), France ($ 498 million), Denmark ($190 million), Germany ($ 185 million), Chile ($144 million) Canada ($122 million), Belgium ($ 111 million), Italy ($ 111 million) and Japan ($ 105 million) for a total of $ 2.9 billion. Only one of the top ten countries exporting seeds is a developing country - Chile with annual sales of $ 144 million.

7. OVERVIEW OF DEVELOPMENTS IN THE CROP BIOTECHNOLOGY INDUSTRY

The major developments in crop biotechnology in the private sector in 2001 are summarized in Table 17. The narratives below, discuss the specific developments in each of four areas, acquisitions, mergers and spin-offs, genomics and product discovery, patents and licensing, and re-registration, approvals and commercialization.

7.1 Acquisitions, Mergers and Spin-offs

Acquisitions, alliances, mergers and spin-offs continued to impact the industry in 2001 albeit at a significantly slower pace than earlier years. Nonetheless, two significant acquisitions were completed in 2001. In February, Dow AgroSciences acquired Rohm & Haas for approximately US$ 1 billion. The agreement included Rohm & Haas' biotechnology portfolio. Rohm & Haas, with sales of approximately $ 500 million in 2000, concentrated on high value specialized markets such as fruit and vegetables rather than the major agricultural crops. Rohm and Haas enjoyed significant growth in revenues during the last decade when many of the major agrochemical companies faced a more challenging situation. Reconfigured agrochemical revenue for Dow AgroSciences and Rohm & Haas in 2000 was $ 2.6 billion, making Dow AgroSciences the fifth largest agchemical company on a global basis with 9 % of the sales.

A more significant acquisition took place in September 2001 when Bayer confirmed the acquisition of Aventis Crop Science for $6.6 billion, approximately 1.8 times 2000 sales. With the acquisition of Aventis, Bayer becomes the second largest agrochemical company to Syngenta with reconfigured sales of $ 5.8 billion for 2000. The new entity, Bayer Crop Science, will be headquartered in Monheim, Germany. The acquisition does not include Starlink.

Monsanto acquired Limagrain Canada Seeds in Saskatchewan with activities in R&D, production and marketing. Monsanto acquired a minority share in 1997 with an option to increase its share at a future date. Pharmacia announced that it would spin off Monsanto in the second half of 2002. The spin off of Pharmacia's 85.3 % share in Monsanto will allow the two businesses to operate separately. Acquisition of Monsanto by one of the leading agbiochemical companies is not thought to be likely because of antitrust considerations. Syngenta acquired the remaining 44 % of its shares in the joint venture with the French cereal breeding company CC Benoist, which specializes in developing wheat and barley using new technologies. Syngenta also acquired Tomono Agrica in Japan which has $ 105 million annual sales in crop protection.The Japanese companies Tomen Corporation and Nichimen Corporation merged their respective life sciences divisions into a new company.

7.2 Genomics and Product Discovery

The Torrey Mesa Research Institute (Syngenta's Genomic facility) and Myriad Genetics, in conjunction with Clemson University completed (99.5%) sequencing of the rice genome. The genome comprises 430 million DNA bases equivalent to 50,000 genes. Rice is the first crop of economic importance to be decoded after *Arabidopsis* was completed during the latter part of 2000. Syngenta will make the genomic information available to academia through collaborative arrangements and provide the information and the technology with no royalties for uses in products used by subsistence farmers. An analysis of the gene expression and rice proteins is now underway. The complete sequencing of the rice genome by Syngenta/ Myriad/Clemson follows release of a working draft by Monsanto in April 2000. The complete sequencing of the rice genome is an important step because it is the first major crop to be sequenced and has implications for other major crops.

Maxygen, the US genomics company delivered two candidate products to Syngenta, under the terms of an agreement between Maxygen and Zeneca initiated in 1999. The products represent a portfolio of improved traits for pest and disease control as well as those that confer quality, nutritional and productivity improvements. Syngenta and Egea Biosciences agreed to develop pest resistant plants that rely on naturally occurring molecules. Egea will create and synthesize long DNA chains of 30,000 bases or more, which encode for Syngenta-discovered genes from natural sources.

The US biotechnology company, Exelixis reported that its joint venture company with Bayer, Genoptera had developed several novel insecticide targets for assessment by Bayer, which has exclusive rights on the products. Bayer extended another contract with the US genomics company Paradigm Genetics for another 5 years at a cost of $ 30 million to discover new herbicides. Paradigm Genetics, developed a DNA micro array for the fungal causal agent of the economically important disease rice blast. The micro array allows analysis of the fungal pathogen's gene expression. Paradigm Genetics reported progress in its collaboration with Monsanto in the use of its Gene Function Factory technology to discover the function of genes. The agreement has been extended for a six year period and the scope of work broadened. In May 2000 the Monsanto/Paradigm Genetics collaboration was extended to include Renessen, the joint venture between Monsanto and Cargill focusing on quality traits in processed grains and oil seeds. Paradigm Genetics was granted a US patent for a gene that can be used as a herbicide target.

Dow Chemical, Epicyte Pharmaceuticals and Centocor agreed to collaborate to evaluate human monoclonal antibody production in plants. Dow will utilize its gene expression expertise and maize production and processing expertise in conjunction with Epicyte's Plantibody technology to produce the Centecor antibody. Dow claims that the technique is more cost effective than current technologies and can be used for high volume production.

Dow AgroSciences terminated its collaboration between its subsidiary, Mycogen, and Demegen. The work was initiated in 1997 to develop disease resistant and nutritionally enhanced crops. Dow AgroSciences and Exelixis announced that the latter has delivered four crop protection targets related to weed and disease control. DuPont and the US company Discovery Partners International agreed to collaborate in the discovery and development of products for DuPont's Crop Protection Division. Monsanto and the US genomic company Mendel agreed to a five year $ 20 million R&D contract, which extends their first collaboration initiated in 1997. The project focuses on the identification by Mendel of genes for improved yield, drought and disease resistance.

7.3 Patents and Licensing

Delta and Pine Land (D & PL) obtained exclusive rights from USDA (ARS) for the commercialization of a pollen transformation system in a broad range of crops. D & PL plans to sublicense the technology which is less complicated and costly than current transformation technology in that it does not require regeneration of plants from transformed cells. The technique involves only transfer of pollen which is then used directly to pollinate the target plant. D & PL hope that the technology will facilitate and accelerate the development of transgenic crops in cereals, legumes, forages, citrus, fruits and vegetables.

The European Patent Office reconfirmed the legality of Aventis' patent (EP 275957) for GM plants tolerant to Glufosinate (Liberty) which had been challenged by Greenpeace. The patent was granted to Aventis on the basis that the gene, isolated from a bacterium had been modified prior to patenting and was not the natural gene found in wild populations, as claimed by Greenpeace. The gene is deployed by Aventis in both maize and canola. MPB Cologne from Germany licensed its "gene switch" technology to Aventis Crop Science. The technology allows activation or deactivation of a specific gene and is used to excise DNA sequences from transgenic crops.

Neogen Corporation and Envirologix Inc signed non-exclusive licenses with Monsanto to acquire proprietary technology for the detection of the glyphosate trait in soybean, cotton, canola and corn and specific Bt traits in corn and cotton. Renessen (the joint venture between Cargill and Monsanto) agreed to a world wide licensing agreement with Sangamo Sciences, USA, to utilize gene regulation technology for improving selected crops for animal feed and processing. Dow AgroSciences licensed Third Wave Agbio's technology to detect single nucleotide polymorphics (SNP) and DNA sequences in genetically engineered plants before commercialization; it can be used for elimination of antibiotic markers. SemiBioSys, a Canadian biotech company, was granted a US patent on plant-based somatropin production. SemiBioSys uses GM technology to express proteins in safflower seed which facilitates the extraction of oil. SemiBioSys has a collaborative agreement with Syngenta to develop technology featuring transgenic expression of proteins in oil seeds.

7.4 Reregistration, Approvals and Commercialization

EPA renewed Monsanto's Bollgard® cotton for another 5 years in the US, noting that there is no evidence of the development of insects resistant to Bt. Over a six year period Monsanto data indicated an average yield increase of 7 % for Bt compared with unprotected cotton and an annual saving of 2 million pounds (0.9 million kg) of insecticide in the US since the introduction of its Bt cotton. In the US, EPA re-registered Bt maize for 7 years, terminating on 16 October 2008. EPA noted that the scientific data indicated that Bt maize does not pose a risk to human health and the environment, decreases use of pesticides and does not impact on Monarch butterflies. Companies with Bt maize registration include Monsanto, Syngenta, Pioneer/DuPont and Mycogen/Dow AgroSciences.

South Africa introduced its fourth GM crop, Monsanto's RR soybean, which compliments the other 3 GM crops already commercialized - Bt yellow maize for feed, Bt cotton and RR cotton.

Pioneer and Dow AgroSciences announced that a new Bt maize, Herculex 1 had been approved for food and feed use in the US. Herculex 1 contains the Cry F1 gene that provides broader resistance to pests including European corn borer, Southwestern corn borer, black cutworm, fall armyworm, and intermediate resistance to corn earworm. Dow AgroSciences will develop its Nexera canolas for BASF's Clearfield Production System. The improved varieties will be tolerant to imidazolinone herbicides and contain the Natreon quality oils which have higher oxidative stability and reduced trans-fat content.

Monsanto obtained commercial approval for RR cotton in Argentina. The approval was granted by the Ministry of Agriculture following review of the submission by CONABIA and SENASA. A modest launch of RR cotton was planned for 2001. Monsanto plans to discontinue sale of New Leaf Potato after the 2001 season. In 1999 Naturemark deployed New Leaf varieties with stacked traits; New Leaf Y resistant to Colorado beetle and virus Y and New Leaf Plus (resistant to Colorado beetle and leaf roll virus). In both cases the Bt gene Cry 3Aa was used to effectively confer resistance to Colorado beetle which is a major insect pest in North America. The major issue contributing to the decision was the refusal of potato processors to accept GM crops despite the fact that New Leaf potatoes required significantly less insecticides, which ironically is assigned high priority by the public at large. Monsanto plans to reintroduce New Leaf potatoes in appropriate markets in the future. Monsanto recalled Quest RR canola (Event GT 73) in Canada because some seed lots had trace amounts of another event, GT 200. Whereas both events have been approved in Canada, GT 200 has not yet been approved in some Canadian export markets. Monsanto's offer was made in line with its quality assurance program for RR canola. Monsanto inaugurated a cotton molecular breeding facility in Mississippi and an upgraded maize seed facility in Nebraska. Monsanto announced that a simplified pricing system would be used for GM soybean and maize from 2002 onwards. The current technology fee, payable by farmers directly to Monsanto, is being replaced by a royalty fee payable by the seed companies to Monsanto. Thus, farmers will only make a single payment for the seed which will include the royalty fee. The new pricing system will not apply to Monsanto's GM cotton and canola.

BASF Plant Science established a subsidiary in the US to develop maize inbred lines. The new company will work with established US seed companies with well-adapted germplasm which is recognized to be a significant advantage. BASF's US based plant biotech company ExSeed Genetics, inaugurated an R&D facility in Iowa, USA, to conduct strategic research on traits that confer nutritionally enhanced maize.

Syngenta and the Australian National Wheat Exports Board (AWB) announced an alliance to develop improved wheat varieties. The alliance is intended to be the first step in establishing a joint venture to commercialize new wheat varieties in Australia. Syngenta will reduce the number of its global technology centers from 12 to 6; the closures, along with the closing of 10 manufacturing plants will result in $ 150 million savings by 2004. A New Technology Segment in the Syngenta reporting structure will monitor R&D costs for product development including genomics. The 6 new portfolio groups are: marker assisted breeding, input traits, agronomic effects, animal feed, functional foods and consumer health. With the restructuring, Syngenta's R&D investments are $ 161 million in New Technology, $ 111 million in seeds development, and $ 473 million in agrochemicals. Syngenta, which spent 10.4% of its 2000 revenue of $ 7.17 billion on R&D, plans to reduce its R&D expenditures below 10% of revenues. Syngenta closed its Mogen R&D facility in the Netherlands. The discontinuation of Mogen activities was due to a duplication of effort which came about following the formation of Syngenta in November 2000. Aventis Crop Science and AVEBE in Germany agreed to form a joint venture company called Solavista to conduct R&D on potato starch. Potatoes with improved starch will be developed for industrial use in paper production, textiles, glues and processed foods.

For the convenience and information of readers, the highlights in the crop biotechnology industry in 2001 are chronicled by month in Table 17.

Table 17. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
January	**Renessen** (the joint venture between **Cargill** and **Monsanto**) agreed to a world wide licensing agreement with **Sangamo Sciences**, USA, to utilize gene regulation technology for improving selected crops for animal feed and processing.
January	The Japanese companies **Tomen Corporation** and **Nichimen Corporation** agreed to merge their respective life sciences divisions into a new company.
January	The **Torrey Mesa Research Institute** (**Syngenta**'s Genomic facility) and **Myriad Genetics**, in conjunction with **Clemson University** announced the completion (99.5 %) of the sequencing of the rice genome.
February	**Dow AgroSciences** agrees to acquire **Rohm & Haas** for approximately US$ 1 billion. The agreement includes Rohm & Haas biotechnology portfolio.
February	**Delta and Pine Land (D & PL)** obtains exclusive rights from **USDA** (ARS) for the commercialization of a pollen transformation system in a broad range of crops.
February	European Patent Office reconfirms the legality of **Aventis**' patent (EP 275957) for GM plants tolerant to Glufosinate (Liberty) which had been challenged by **Greenpeace**.
March	**Monsanto** plans to discontinue sale of New Leaf Potato after the 2001 season. In 1999 **Naturemark** deployed New Leaf varieties with stacked traits; New Leaf Y resistant to Colorado beetle and virus Y and New Leaf Plus (resistant to Colorado beetle and leaf roll virus).
March	**Monsanto** and **Aventis** settle two outstanding law suits on GM cotton. Monsanto authorized Aventis to commercialize RR & Bollgard® (Bt) in Aventis' FiberMax cotton varieties (developed by CSIRO Australia) in the US. Aventis authorized Monsanto to use specific Bt genes in stacked genes for multiple insect resistance.
March	A US court ruled that **Pioneer Hi-Bred International**'s license to sell **Monsanto** RR soybeans and canola was terminated when Pioneer merged with **DuPont** in October 1999. However, the same court also ruled that Monsanto was not entitled to damages. Pioneer plans to appeal the decision and to continue marketing the products in the meantime.

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Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
March	The US biotechnology company, **Exelixis** reported that its joint venture company with **Bayer**, **Genoptera** had developed several novel insecticide targets for assessment by Bayer, which has exclusive rights on the products.
April	**Neogen Corporation** and **Envirologix Inc** sign non-exclusive licenses with Monsanto to acquire proprietary technology for the detection of glyphosate trait in soybean, cotton, canola and corn and specific Bt traits in corn and cotton.
April	**Monsanto** recalls Quest RR canola (Event GT 73) in Canada because some seed lots had trace amounts of another event, GT 200. Whereas both events have been approved in Canada, GT 200 has not yet been approved in some Canadian export markets. Monsanto's offer was made in line with its quality assurance program for RR canola.
May	**Monsanto** obtains commercial approval for RR cotton in Argentina. The approval was granted by the Ministry of Agriculture following review of the submission by CONABIA and SENASA. A modest launch of RR cotton is planned for 2001.
June	**Bayer** is emerging as the most likely candidate to acquire **Aventis**' crop protection business. Bayer is the fifth largest agchemical company globally with revenue of $2.3 billion in 2000. Bayer and Aventis combined revenue in 2000 would have been $ 5.8 billion, second only to Syngenta at $ 6.2 billion. Bayer, which is currently not active in crop biotechnology would acquire a GM crop portfolio of herbicide tolerant and insect resistant crops if it acquires Aventis.
June	**Monsanto** acquires **Limagrain Canada Seeds** in Saskatchewan with activities in R&D, production and marketing. Monsanto acquired a minority share in 1997 with an option to increase its share at a future date.
June	**Dow AgroSciences** completes acquisition of **Rohm & Haas**. In addition to business in North America, the deal includes businesses in Brazil, Colombia, China, France and Italy.
June	The **Global Crop Protection Federation** changes its name to **Croplife International**, whose members represent 90 % of the global market for crop protection.

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Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
June	**Monsanto** announces that a simplified pricing system will be used for GM soybean and maize from 2002 onwards. The current technology fee, payable by farmers directly to Monsanto, will be replaced by a royalty fee payable by the seed companies to Monsanto. Thus, farmers will only make a single payment for the seed which will include the royalty fee. The new pricing system will not apply to Monsanto's GM cotton and canola.
June	**Bayer** extends contract with **Paradigm Genetics (US)** for another 5 years at a cost of $ 30 million to discover new herbicides.
June	**Pioneer** and **Dow AgroSciences** announce that a new Bt maize, Herculex 1 has been approved for food and feed use in the US. Herculex 1 contains the Cry F1a gene that provides broader resistance to the pests European corn borer, Southwestern corn borer, black cutworm, fall armyworm, and intermediate resistance to corn earworm.
July	**Syngenta** acquires **Tomono Agrica** in Japan which has $ 105 million annual sales in crop protection.
July	**BASF Plant Science** establishes a subsidiary in the US to develop maize inbred lines. The new company will work with established US seed companies with well-adapted germplasm which is recognized to be a significant advantage.
July	**Syngenta** and the **Australian National Wheat Exports Board (AWB)** announces an alliance to develop improved wheat varieties. The alliance is intended to be the first step in establishing a joint venture to commercialize new wheat varieties in Australia.
July	EPA in the US did not accede to the **Aventis** request to establish a 20 parts per billion tolerance for the Cry 9c protein in Starlink maize. However EPA also stressed that the risk of exposure that would induce an allergic response is low.
August	**Syngenta** will reduce the number of its global technology centers from 12 to 6; the closures, along with the closing of 10 manufacturing plants will result in $ 150 million savings by 2004. A New Technology Segment in the Syngenta reporting structure will monitor R&D costs for product development including genomics. The 6 new portfolio

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Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
	structure will monitor R&D costs for product development including genomics. The 6 new portfolio groups are: marker assisted breeding, input traits, agronomic effects, animal feed, functional foods and consumer health. With the restructuring, Syngenta's R&D investments are $ 161 million in New Technology, $ 111 million in seeds development, and $ 473 million in agrochemicals.
August	**Pioneer** inaugurates a new $ 10 million soybean production facility in Illinois. Pioneer's market share for soybean in North America is estimated at approximately 24 %.
August	**BASF**'s US based plant biotech company **ExSeed Genetics**, inaugurates R&D facility in Iowa, USA, to conduct strategic research on traits that confer nutritionally enhanced maize.
August	**Dow AgroSciences** licenses **Third Wave Agbio**'s technology to detect single nucleotide polymorphics (SNP) and DNA sequences in genetically engineered plants.
August	**MPB Cologne** from Germany licenses its "gene switch" technology to **Aventis Crop Science**. The technology allows activation or deactivation of a specific gene. The technology excises DNA sequences from transgenic crops before commercialization, and is used for elimination of antibiotic markers.
August	**Monsanto** inaugurates a cotton molecular breeding facility in Mississippi and an upgraded maize seed facility in Nebraska.
August	The US genomic company, **Paradigm**, develops a DNA micro array for the fungus which causes rice blast. The micro array allows the analysis of the fungal pathogen's gene expression.
September	**Aventis** and **CropScience Shinogi**, Tokyo, establish a joint venture headquartered in Japan.
September	On 20 September **Bayer** confirms the acquisition of **Aventis Crop Science** for $ 6.6 billion, approximately 1.8 times 2000 sales. With the acquisition of Aventis, Bayer became the second largest agrochemical company to Syngenta ($6.2 billion) with reconfigured sales of $ 5.8 billion in 2000. The new entity Bayer Crop Science will be headquartered in Monheim, Germany. The acquisition does not include Starlink.

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Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
September	**Dow Chemical**, **Epicyte Pharmaceuticals** and **Centocor** agree to collaborate to evaluate human monoclonal antibody production in plants. Dow will utilize its gene expression expertise and maize production and processing in conjunction with Epicyte's Plantibody technology to produce the Centecor antibody. Dow claims that the technique is more cost effective than current technologies and can be used for high volume production.
September	EPA renews **Monsanto**'s Bollgard® cotton for another 5 years in the US, noting that there is no evidence of the development of insects resistant to Bt. Over a six year period Monsanto data indicated an average yield increase of 7 % for Bt compared with unprotected cotton and an annual saving of 2 million pounds (0.9 million kg) of insecticide in the US since the introduction of its Bt cotton in 1996.
September	The US biotechnology company **Paradigm Genetics** reports progress in its collaboration with **Monsanto** in the use of its Gene Function Factory technology to discover the function of genes. The agreement has been extended for a six year period and the scope of work broadened. In May 2000 the collaboration was extended to include **Renessen**, the joint venture between **Monsanto** and **Cargill** focusing on quality traits in processed grains and oil seeds.
September	**Dow Chemical** was awarded a $ 5 million grant by the US Department of Energy to research production of plastics and chemicals from renewable plant oils such as castor oil. The aim of the project is to assess the feasibility of substituting non-renewable petrochemical materials; the project is part of a $ 30 million US Dept. of Energy initiative to develop bioenergy products.
October	**Monsanto** and **DuPont** resolve issues related to the use of the MON 810 Bt event in maize marketed as Yield Gard. **Monsanto** and **Dow Agro Sciences** also resolved issues related to the use of Bt maize technology by Dow AgroSciences acquired from **Mycogen**, and with implications for the new Bt maize Herculex 1.
October	**Syngenta** acquires the remaining 44 % of its shares with the joint venture with the French cereal breeding company **CC Benoist**, which specializes in developing wheat and barley using new technologies.

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Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
October	In the US, EPA re-registers Bt maize for 7 years, terminating on 16 October 2008. EPA noted the scientific data indicated that Bt maize does not pose a risk to human health and the environment, decreases use of pesticides and does not impact on Monarch butterflies. Companies with Bt maize registration include **Monsanto**, **Syngenta**, **Pioneer**/**DuPont** and **Mycogen**/**Dow AgroSciences**.
October	The US biotechnology company **Paradigm Genetics** is granted a US patent for a gene that can be used a herbicide target.
October	**SemiBioSys**, a Canadian biotech company, is granted a US patent on plant-based somatropin production. SemiBioSys uses GM technology to express proteins in safflower seed which facilitates the extraction of oil. SemiBioSys has a collaborative agreement with **Syngenta** to develop technology featuring transgenic expression of proteins in oil seeds.
November	**Pharmacia** announces that it will spin off **Monsanto** in the second half of 2002. The spin off of its 85.3 % share in Monsanto will allow the two businesses to operate separately. Acquisition of Monsanto by one of the leading agbiochemical companies is not thought to be likely because of antitrust considerations.
November	**Monsanto** and the US genomic company **Mendel** agree to a five year $ 20 million R&D contract, which extends the first collaboration initiated in 1997. The project focuses on the identification by Mendel of genes for improved yield , drought and disease resistance.
November	**Aventis Crop Science** and **AVEBE** in Germany agree to form a joint venture company called **Solavista** to conduct R&D on potato starch. Potatoes with improved starch will be developed for use in industrial use in paper production, textiles, glues and processed foods.
November	**Maxygen**, the US genomics company delivers two candidate products to **Syngenta**, under the terms of an agreement between Maxygen and Zeneca initiated in 1999. The products represent a portfolio of improved traits for pest and disease control as well as those that confer quality, nutritional and productivity improvements.

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Table 17. Cont'd. Selected Highlights of Crop Biotechnology Developments in Industry, 2001

Month	Corporations Involved and Nature of Development
November	**Syngenta** and **Egea Biosciences** agree to develop pest resistant plants that rely on naturally occurring molecules. Egea will create and synthesize long DNA chains of 30,000 bases or more, which encode for Syngenta-discovered genes from natural sources.
November	**Dow AgroSciences** terminates collaboration between **Mycogen**, its subsidiary, and **Demegen**. The work was initiated in 1997 to develop disease resistant and nutritionally enhanced crops.
November	**DuPont** and the US company **Discovery Partners International** agree to collaborate in the discovery and development of products for DuPont's Crop Protection Division.
November	**Dow AgroSciences** and **Exelixis** announce that the latter has delivered four crop protection targets related to weed and disease control.
December	**Dow AgroSciences** will develop its Nexera canolas for **BASF**'s Clearfield Production System. The improved varieties will be tolerant to imidazolinone herbicides and contain the Natreon quality oils which have higher oxidative stability and reduced trans-fat content.
December	South Africa introduces its fourth GM crop, **Monsanto**'s RR soybean which compliments the other 3 GM crops already commercialized - BT yellow maize for feed, Bt cotton and RR cotton.
December	**Syngenta** closes the Mogen R&D facility in the Netherlands. The discontinuation of Mogen activities is associated with a duplication of effort following the formation of Syngenta in November 2000.
December	**Syngenta**, which spent 10.4 % of its 2000 revenue of $ 7.17 billion on R&D, plans to reduce its R&D expenditures below 10 %.

Source: Compiled by Clive James (2002) from various sources, including Wood MacKenzie.

8. ECONOMIC BENEFITS OF GM CROPS

In the 2000 ISAAA Global Review of Transgenic Crops (James 2001a), an assessment was published of the global benefits associated with the principal GM crops, soybean, corn, cotton and canola. In the interim, several studies and surveys have been conducted and these are summarized here to provide the reader with the current information on benefits from GM crops.

8.1. Economic Benefits of GM Crops in the USA

The economic benefits in the US have recently been assessed and updated (Gianessi et al 2002) and are summarized here. The work reported by Gianessi et al is particularly useful because improved and uniform methodology has been used to assess all the principal GM crops in the US, making comparisons between crops more meaningful. The study examined current benefits for 2001 as well as potential future benefits. Forty case studies for GM crops are usefully and critically compared with previous assessments by the same authors as well as comparisons with estimates published by other authors. The study (Gianessi et al 2002) reports results for a typical year for the three categories of crops, detailed below:

8.1.1 Benefits from the 8 GM crop varieties planted commercially in the US in 2001

The total economic benefit to US farmers who planted GM crops on a total area of

Table 18. Impact of GM Crops Planted in USA in 2001

GM Crop/Trait	Ha 000s	Production Millions		Pesticide Use Millions		Net Economic Gain	
		Lbs.	(Kgs.)	Lbs.	(Kgs.)	National $ Millions	Farm level $/Ha
1. Soybean HT	20,241	-		-28.7	(-13.0)	1,011	50
2. Cotton HT	3,764	-		-6.2	(-2.8)	133	35
3. Corn IR	6,041	+3,541	(+1,606)	-2.6	(-1.2)	125	21
4. Cotton IR	2,082	+185	(+84)	-1.9	(-0.9)	103	50
5. Corn HT	2,350	-		-5.8	(-2.6)	58	25
6. Canola HT	352	-		-0.5	(-0.2)	11	31
7. Papaya VR	<1	+53	(+24)	-		17	2,625
8. Squash VR	<2	+6	(+3)	-		1	803
Total	**34,831**	**+3,875**	**(+1,717)**	**-45.7**	**(-20.7)**	**1,459**	**Avg 42**

Source: Gianessi et al., 2002. HT - Herbicide Tolerant, IR - Insect Resistant, VR - Virus Resistant approximately 35 million hectares in 2001 was estimated at $ 1.5 billion (Table 18). This is equivalent to an overall national economic gain for farmers of $ 42 per hectare compared with corresponding conventional varieties. The economic benefits were due to various factors including higher yields, lower costs of production, decreased use and/or lower cost of pesticides, less need for cultivation and pesticide spraying.

Of the 8 commercial GM crops planted in the US in 2001, 4 delivered benefits to farmers in excess of $ 100 million. Approximately two-thirds, equivalent to $ 1 billion, of the total benefits were associated with one crop, RR soybean, planted on over 20 million hectares; the economic gain per hectare for RR soybean was $ 50, compared with a corresponding conventional variety. The second largest benefit of $ 133 million, equivalent to $ 35 per hectare was for herbicide tolerant cotton, planted on 3.7 million hectares. The third ranking at $ 125 million and equivalent to $21 per hectare, was for Bt corn grown on 6 million hectares, and the fourth crop was Bt cotton, planted on 2 million hectares, which delivered a national benefit of $ 103 million, equivalent to $ 50 per hectare – the same return as RR soybean. Four other GM crops also benefited farmers with significant economic benefits at below $ 100 million per crop at a national level. The four crops were herbicide tolerant corn, grown on 2.4 million hectares which delivered benefits of $ 58 million to US farmers in 2001, equivalent to $ 25 per hectare; herbicide tolerant canola grown on 352,000 hectares resulted in an economic gain to farmers of $ 11 million nationally, and equivalent to $ 31 per hectare; virus resistant papaya grown on less than 1,000 hectares resulted in a benefit to farmers in Hawaii of $17 million, equivalent to $ 2,625 per hectare; and virus resistant squash grown on less than 2,000 hectares delivered a benefit of $ 1 million, equivalent to approximately $ 800 per hectare.

One of the factors that resulted in significant economic savings was the lower cost of crop protection due to a decreased need for pesticides. In the US in 2001, savings of 45.7 million pounds or 20.7 million kg (20,700 metric tons) of pesticide (active ingredient or a.i.) were realized due to the adoption of 6 herbicide tolerant and insect resistant crops requiring less pesticides. Most savings were made on RR soybean, which required 28.7 million pounds or 13.0 million kg less herbicide (active ingredient). Similarly, herbicide tolerant cotton required 6.2 million pounds/2.8 million kg less herbicide (a.i.); herbicide resistant corn required 5.8 million pounds/2.6 million kg less insecticide (a.i.); insect resistant corn required 2.6 million pounds/1.2 million kg less insecticide (a.i.); insect resistant cotton consumed 1.9 million pounds/0.9 million kg less insecticide (a.i.); and finally herbicide tolerant canola consumed 0.5 million pounds/0.2 million kg less herbicide (a.i.).

In addition to pesticide savings, yield increases in 2001 resulted from the deployment of some GM crops in the US. The largest increase was for insect resistant corn, which produced 3.5

billion pounds/1.6 billion kg for Bt corn farmers in the US in 2001.The deployment of Bt cotton resulted in an increase in production of 185 million pounds/84 million kg, virus resistant papaya in an increased production of 53 million pounds/24million kg, and virus resistant squash resulted in a production gain of 6 million pounds or almost 3 million kg.

8.1.2 Potential impact of GM crops approved but not deployed in US in 2001

The study by Gianessi et al (2002) includes four case studies of GM crops where the GM product is approved but pending deployment; potential benefits were calculated using the same methodology. In a typical year the expected overall economic gain for US farmers when they deploy all four crops, HT sugar beet, IR/VR potato, IR sweet corn and HT sweet corn is projected at $158 million, with an associated 1 billion pound increase in production and a savings of 583,000 pounds of insecticides and herbicides; see details in Table 19. Of the total national economic gain of $158 million, $93 million equivalent to $153 gain per hectare) was attributed to herbicide tolerant sugar beet grown on 600,000 hectares with an addition of 963,000 pounds/437,000 kg of herbicide (a.i.). An economic gain of $59 million (equivalent to $233 gain per hectare) is projected for insect/virus resistant potatoes grown on 250,000 hectares with a savings of 1.45 million pounds/657,000 kg of insecticide (a.i). Potential gains from Bt and herbicide tolerant sweet corn grown only on 25,000 hectares are, as expected, modest at $5 million and $ 1million respectively.

Table 19. Potential Impact of GM Crops Approved but not Adopted in USA in 2001

Crop/Trait	000s acres (has.)	Economic Benefit Total $ millions	Gain $/ha	Pesticide Use lbs 000s	(kg)
Sugar beet HT	1,500 (607)	93	153	+963	(+437)
Potato IR/VR	621 (251)	59	233	-1,450	(-657)
Sweet corn IR	32 (13)	5	433	-112	(-51)
Sweet corn HT	30 (12)	1	83	+16	(+7)
Total	**2,183 (882)**	**158**		**-583**	**(-264)**

Source: Gianessi et al., 2002. HT - Herbicide Tolerant, IR - Insect Resistant, VR - Virus Resistant

8.1.3 Potential impact of GM crops in the USA that are under development for current and longer-term constraints

The potential economic impact for 32 GM crop products involving 19 crops have been projected by Gianessi et al (2002). For a typical year, the total projected economic benefit for the 32 products is estimated at $853 million with an increased production of about 10 billion pounds/4.3 billion kg (a.i.).

The data in Table 20 summarizes the economic and production gains and pesticide savings reviewed above.

- Firstly, US farmers who planted 35 million hectares of GM soybean, corn, cotton, canola, papaya and squash in 2001 are estimated to have made an economic gain of $ 1.5 billion, increased production by about 4 billion pounds/1.8 billion kg with pesticides savings equivalent to 46 million pounds/21 million kg (a.i.)

- Secondly, expected gains were projected for the GM crops sugar beet, potato and sweet corn that have been approved in the US but not yet deployed. For a typical year, economic gains are projected at $ 158 million 1 billion pounds/453 million kg of increased production and savings of 0.6 million pounds/0.27 million kg of pesticide (a.i).

- Thirdly, potential gains for US farmers were projected for 32 GM products comprising approximately 28 crops featuring GM applications that are at the R&D stage and not approved. For a typical year the gains projected for

Table 20. Summary of Current and Potential Gains for GM Crops in USA, 2001

Product Category	Economic Gain $ Millions	Production Gain Lbs. Millions (Kgs.)		Pesticide Savings Lbs. Millions (Kgs.)	
1. 35 million ha GM crops planted in 2001	1,459	3,785	(1,717)	46	(21)
2. GM crops, approved but not deployed	158	1,094	(496)	<1	(<1)
3. GM crops in R&D current & longer-term constraints	853	9,616	(4,362)	116	(53)
TOTAL	**2,470**	**14,495**	**(6,531)**	**162**	**(73)**

Source: Gianessi et al., 2002, modified.

these crops are $ 853 in economic value, 10 billion pounds/4.5 billion kg of production and 116 million pounds/ 53 million kg less pesticides (a.i.).

- Taking the above assessment of Gianessi et al (2002) into account, the value to US farmers in 2001 could be increased from $ 1.5 billion to $ 2.5 billion with the addition of new products that have been approved but not yet deployed, and products in the R&D phase. Similarly, potential increases in crop production could be increased from the 4 billion pounds production gain (1.8 billion kg) in 2001 to over 14 billion pounds (6.4 billion kg) in future. Finally, current pesticide savings of 46 million pounds (21 million kg) in 2001 could be increased to more than 150 million pounds (68 million kg) with the commercialization of new products. Thus, the potential market for the US, based on products that are already commercialized or under development can deliver economic benefits to farmers valued at $ 2.5 billion, increased production of over 14 billion pounds (6.4 billion kg) and pesticide savings of 162 million pounds/73 million kg (a.i.). These substantial direct benefits to farmers from GM crops in the US do not include the indirect economic, environmental and social benefits to society at large, some of which are intangible but deemed important by the public at large.

8.2 Economic Benefits from RR Soybeans in Argentina, 2001

After the USA, Argentina has the second largest area of herbicide tolerant RR soybean hectarage in the world – over 11.2 million hectares out of a total area of 12 million hectares in 2002. A detailed survey conducted by Qaim and Traxler (2002) indicated a gross margin of approximately $23 per hectare or 10% in favor of RR soybean over conventional varieties. A surplus of $303 million (90%) accrued to Argentinean soybean farmers, $28 million to the technology developers (8%) and the balance of $4 million (2%) for the consumer. The adoption of RR soybean in Argentina has, through substituting the use of less toxic classes of herbicides and low tillage practices, resulted in a positive impact on the environment.

On a global scale, the authors (Qaim and Traxler 2002) estimate that over the five year period (1996 to 2001) RR soybeans globally have generated a surplus of $1.2 billion. The largest share has accrued to consumers, $652 million (53%), followed by the technology developers, $421 million or 34%, and agricultural producers, $158 million (13%).

8.3 Benefits from Bt Corn in the Philippines

In 1999 the National Committee on Biosafety of the Philippines approved the first transgenic crop field trial with Bt corn at a single location in General Santos. In 2001 Bt corn field trials were conducted at three different locations: Isabela (3), Bukidnon (1) and Camarines Sur (1). Average farm sizes were small and ranged from 1.1 to 1.9 hectares. The objective of the multilocational study was to conduct a socio-economic assessment of the performance of Bt corn, compared with conventional corn. Four different comparisons were made for yield increases, production costs, net profitability, and the subsistence level carrying capacity of corn production; the latter is defined as whether the net income from corn production could meet the cost of purchasing a daily food basket of 2,000 kilo calories per person for a farm family of five. For cost comparisons, price of Bt corn seed was assumed to be the same as the cost of conventional seed, 2,000 pesos/bag plus 800 pesos/hectare for insecticide for a total of 2,800 pesos, compared with 2,000 pesos/bag for conventional seed. Comparisons of Bt corn field-trial results were also made with best farmer practices using field yields from a group of farmers with high yields and another with low yields.

The results (Gonzalez 2002) showed that Bt corn hybrids consistently outyielded conventional corn hybrids by 41% in trials and by 60% compared with farmer practice. Cost of production of Bt corn was 24% lower than conventional corn in field trials and 13% better than farmer practice for the group of farmers with high yields, and 39% better than farmer practice for the group of farmers with low yields. The results of the comparisons re the subsistence level carrying capacity of the technology showed that whereas Bt corn could meet the subsistence requirement of a family of five, conventional corn could not. Thus, in summary, Bt corn hybrids consistently performed better than their corresponding conventional corn hybrids, in terms of yield, production cost, profitability and in terms of capacity to meet subsistence needs of farm families. Based on this experience with Bt corn in these multilocational field trials, subsistence corn farmers in the Philippines expressed their interest and willingness to adopt Bt corn because of the higher yields and less requirements for insecticide.

8.4 Ex-Ante Study on Potential Benefits of Golden Rice in the Philippines

Vitamin A deficiency (VAD) is of significant concern in the developing world as it causes blindness in half a million children annually. Women and children suffer the most serious consequences from VAD and the poor are generally at risk because they are malnourished. Several initiatives, including the provision of vitamin supplements, food fortification and educational campaigns are currently underway to address VAD. Enhancing the precursor of Vitamin A, beta carotene through crop breeding offers a complimentary strategy and is being pursued in crops such as maize and sweet potato. However, this strategy cannot be applied to rice because beta carotene is not found in the rice endosperm. With the application of GM technology, Golden Rice has been developed with beta carotene in the endosperm (Beyer et al 2002) and an international R&D program is underway to develop well-adapted varieties of rice with adequate levels of beta carotene.

A recent *ex-ante* study (Zimmermann and Qaim 2002) analyzed the potential benefits of Golden Rice in the Philippines where VAD is a major concern. This study is of seminal importance in that it is one of the first *ex-ante* studies to assess the nutritional and health benefits from second generation GM products with quality traits that improve the nutrition of crop products, more specifically vitamin enriched products.

Acknowledging that Golden Rice alone is not a solution to VAD, the study notes that it does offer an important complementary approach to other initiatives such as supplements. For example, Golden Rice is particularly suited for deployment in rural communities. The study reaffirms that Golden Rice is currently an R&D initiative. Achieving effective conversion and adequate levels of vitamin A continue to be challenges as well as gaining producer and consumer acceptance and adequate control of poor harvest losses. The study reported that the annual health cost in the Philippines related to VAD is of the order of 0.5% of GNP, equivalent to $432 million and that Golden Rice has the potential to contribute to the reduction of this cost. Two scenarios are depicted, an optimistic and a more conservative scenario. The conservative scenario suggests that Golden Rice has the potential to reduce the number of cases of blindness by 1,514 and decrease the number of deaths by 152 annually. The more optimistic scenario projects a reduction of 8,738 cases suffering from blindness and the saving of 941 lives each year. The conservative scenario translates to savings of $23 million annually compared with $137 million for the more optimistic scenario. Preliminary cost benefit analyses are favorable projecting a 81% internal rate of return for the conservative assessment and 152% for the more optimistic scenario. The study notes the distinction between the benefits of first generation GM products, which primarily provide economic benefits to producers and consumers, whereas the second generation technology contributes to lower health care costs for society which may be less visible, but can have substantial economic impact.

8.5 Performance of Bt Maize in Spain

The first study to assess performance of commercial GM crops in Europe features Bt maize in Spain which has occupied 20,000 to 25,000 hectares annually (5% of national hectarage) since its introduction in 1998 (Brookes 2002). Spain grew 485,000 hectares of maize for grain in 2001, equivalent to approximately 10% of European hectarage; 90% of the maize hectarage in Spain is irrigated and Bt maize has been planted in the areas with medium to high infestations of European Corn Borer (ECB). It is estimated that about 25% of the maize hectarage suffer from high infestations and a further 40% from medium infestations. From 6 to 20% of the maize area in Spain is treated with insecticides for ECB at a cost of $18 to $24/hectare (1.00 Euro = US$ 0.99) for control through application of insecticide in irrigation water or $36 to $42/hectare for aerial applications. The average yield loss due to ECB, despite application of insecticides to 6 to 20% of the crop is 5 to 7%, with losses as high as 10% to 15% in some regions during years of high infestation.

Yield Increases

Yield increases for Bt maize are related to the level of infestation which will vary by region and year. In the areas of high infestation where insecticides were not previously used, yield gains are about 15% and 10% where insecticides were previously used. An average yield increase of around 6% has been reported for several regions with other regions with low level of infestation gaining only 1% in yield. Premium for Bt seed ranges from $18 to $31/hectare with the lower end of the range applying to the majority of purchases.

Overall Economic Gains

Reduced insect control costs that range from $24 to $101/hectare, offset with a premium of $19 for Bt maize seed, result in net overall economic gains of $5 to $82/hectare. In the Huseca region of Spain, net economic gains ranging from $66 to $327/hectare, with an average of $146/hectare are typical in the Sarinena sub-region where ECB levels are normally high. In the Barbastro sub-region, with low to medium ECB levels, there has been no net loss or gain for Bt corn over the last three years. At current maize prices, farmers who do not apply insecticide for ECB control require a gain of only 0.15 tonne/hectare (1.5% yield increase) before Bt maize starts to become profitable.

Other Benefits

Bt maize decreases production risk, and contributes to more stable yields that are not subject to variability from ECB damage and yield losses. From the famers' perspective the convenience of not having to spray insecticides and monitor borer populations is a plus. Other benefits include: reduced exposure to insecticides and lower level of mycotoxin levels, both of which have health implications; and potential environmental benefits associated with fewer applications of insecticide. The Bt maize technology is equally appropriate for small farms (20 hectares in Zaragossa region) and larger farms (50 hectares in Huseca region) and in Spain no segregation of GM maize is required because the grain is used for feed in the same regions where Bt maize is grown.

The study (Brookes 2002) reports that provided Bt is available in the leading maize varieties, 36% (173,000 hectares) of the maize hectarage in Spain could be planted to Bt maize in the future. Assuming a 5 to 7% yield advantage for Bt maize over conventional maize, this could result in an increase of 88,000 to 123,000 tonnes, equivalent to a 1.8% to 2.5% increase in national maize production, with an increased additional annual value of $11 to $15 million. Assuming that current foliar insecticides applied to maize are only for ECB control, the potential increase in production and productivity would coincide with a net reduction of 59,000 to 98,000 hectares of maize sprayed with foliar insecticides. This would result in savings in insecticide of 35,000 to 40,000 kg a.i. - equivalent to a reduction of 26 to 45% of all insecticides (a.i.) applied to maize in Spain. If some foliar sprays were required for the control of other maize insects, a reduction of approximately one third of the above estimates would be realized.

In summary, the performance of Bt maize in Spain, reported by Brookes (2002) is positive and consistent with the corresponding assessment for Bt corn in the US. In 2001, Bt maize occupied 20% of the maize area in the US, compared with 5% in Spain but where the potential for the latter is estimated to be 36% of the Spanish national hectarage. The economic benefit per hectare in the US for 2001 was $22 per hectare compared with potential benefits in Spain in the range of $5 to $82 per hectare, with an average gain of $146 per hectare in the high infestation regions of Huseca. Thus, the assessment of the potential benefits of Bt maize in Spain (Brookes 2002) is positive due to the agronomic, environmental and economic benefits that it can deliver and consistent with experience with Bt corn in the US over the last five years.

8.6 China's Investments in Crop Biotechnology

China has 70,000 scientists in its agricultural research system of which approximately 2,000 are dedicated to crop biotechnology (Huang et al 2002).Work was initiated on crop biotechnology in the mid 1980s. A program on rice genomics was started in 1997. Chinese biotechnologists are amongst the world leaders in crop biotechnology and conduct research on more than 50 crop species utilizing more than 120 genes. Field trials have been conducted on 16 crops, some of which, like Bt cotton have been commercialized and adopted by up to 5 million small farmers in 2001. The range of crops (Table 21) includes all the major food/ feed crops: rice with insect, disease and herbicide tolerance traits; maize with improved quality and insect resistance; soybean with herbicide tolerance; wheat with improved quality and resistance to barley yellow dwarf virus; potato with improved quality and disease resistance. Orphan crops and vegetables such as virus resistant papaya, cabbage, chili and sweet pepper, all of which are generally assigned low priority in the global R&D agenda, are much more important for China and other developing countries. Resistance to the biotic stresses associated with viruses, insects, and diseases are the most important traits for China. Accordingly, 30% of the 26 GM applications listed in Table 21 confer improved virus resistance, 20% to insect resistance, 15 % to disease resistance, 12% to quality traits, 7% to herbicide tolerance and the balance with less than 5% each to salt tolerance, cold tolerance, shelf life and color change in petunias.

China was investing $ 112 million/annum on crop biotechnology in 1999 and plans to

Table 21. China's 26 GM Crops Applications (Commercialized and in Trials) in 2001

Trait	Crops
1. **Virus resistance** (8 crops)	Wheat, BYDV
	Peanut
	Cabbage
	Tomato
	Melon
	Sweet Pepper
	Chili
	Papaya, PRSV
2. **Insect resistance** (5 crops)	Cotton, Bt and CpTi
	Rice, Bt
	Wheat
	Maize
	Tobacco, TMV and CMV
3. **Disease resistance** (4 crops)	Cotton
	Rice
	Potato
	Rape Seed
4. **Quality improvements** (3 crops)	Wheat
	Maize
	Potato, starch improvement
5. **Herbicide tolerance** (2 crops)	Rice
	Soybean
6. **Salt tolerance** (1 crop)	Rice BADH
7. **Cold tolerance** (1 crop)	Rice
8. **Shelf life** (1 crop)	Tomato
9. **Color change** (1 crop)	Petunia

Source: Modified from Huang et al., 2002 and James, C., 1999. BADH betaine aldehyde dehydrogenase, BYDV barley yellow dwarf virus, PRSV Papaya Ringspot Virus, TMV Tobacco Mosaic Virus, CMV Cucumber Mosaic Virus, CpTi Cowpea Trypsin increase its investments by 400% by 2005. The Ministry of Science and Technology is the principal investor in biotechnology in China, and it increased its investment in crop biotechnology from $ 8 million in 1986 to $ 48 million in 1999. China allocates a high proportion, 9.2%, of its national crop R&D budget to crop biotechnology. Whereas China's budget for R&D in crop biotechnology represents more than half the corresponding investments of all developing countries estimated at $ 180 million, it is currently less than 5% of crop biotechnology investments by industrial countries (Huang et al 2002). However, taking into account China's planned increase of 400% in crop biotechnology expenditures by 2005, this will bring China's investment close to $ 0.5 billion, equivalent to 10% of current global R&D expenditures in crop biotechnology, and more in line with its 20% proportion of world population.