# Global Status of Genetically Modified Crops: Current Trends and Prospects

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Modern biotechnology-facilitated crop improvement is undoubtedly one of the most significant technological developments in agriculture. The first wave of genetically-modified (GM) or transgenic crops include cultivars with important input traits such as herbicide tolerance and insect resistance. Future products are expected to provide benefits that could include tolerance to environmental stresses and enhanced nutritional content, which can be particularly valuable in crops that are important to many developing countries, where the challenges of sustainable food production are more critical. Rates of adoption of GM crops are unprecedented and are among the highest for any new technologies by agricultural industry standards. The global area of GM crops expanded by around thirty-fold from 1996 to 2001 and the number of countries growing these crops has more than doubled. The unprecedented growth in adoption of GM crops worldwide speaks well of the multiple benefits that they provide to growers, and the growing confidence and acceptance of the technology by large and small farmers in both industrial and developing countries. Equitable access to the technology, and an open and broader exchange of information, knowledge and experience on biotechnology will help provide the opportunity to link the needs of societies, particularly in developing countries, with an increasing array of crop biotechnology applications and related innovations that could help achieve food security.

## Introduction

Crop improvement facilitated by modern biotechnology is undoubtedly one of the most significant technological developments in agriculture.

Advances in gene mapping and gene transfer have allowed the transformation of plants that would be difficult or impossible through conventional breeding techniques. As the disciplines of genomics and proteomics mature, an even deeper understanding of underlying biological processes will yield more sophisticated research tools and a wealth of new data from gene sequencing. Advances such as the identification of genes controlling photosynthesis, abiotic stress tolerance and nutrient utilisation will undoubtedly bring major benefits in the near future.

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The first wave of genetically modified (GM) crops included cultivars with important traits such as insect resistance and herbicide tolerance. Today, many of these first-generation GM crops are already demonstrating their value to farmers, both in the developed and developing world. Biotechnology research is also making rapid progress on developing GM crops with more direct benefits to consumers, such as improved food quality and nutritional profile.

This paper presents an overview of the global status of commercialized GM crops and highlights recent developments in the international scene in the area of crop biotechnology. The potential contribution of crop biotechnology in improving productivity and sustainability in agriculture, and in meeting global food security demands, is also discussed.

## Global status of genetically-modified crops

Between 1996 and 2001, there was a dramatic increase in the adoption of GM crops worldwide (Fig. 1). The global area of transgenic crops expanded by more than 30-fold and the number of countries growing these crops more than doubled. From 1.7 million ha in 1996, the global area of transgenic crops increased to 52.6 million ha in 2001.

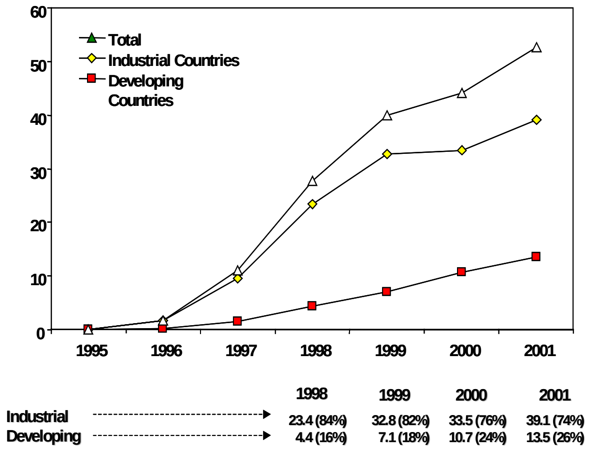


***Figure 1. Global area of transgenic crops (million ha), 1996-2001 (Source: James 2001)***

This rapid increase in area indicates growing appreciation of the technology by farmers in both industrialized and developing countries. Transgenic plants are now adopted in 14 countries including, most recently, India.

More than 120 transgenic crops have been approved worldwide for planting for food or feed use (see AGBIOS database 2001). Most of the plantings have occurred in industrialized countries, with USA accounting for 68% of the total area planted in 2001 (Table 1). There is a similar increase in favor of GM crops across developing countries. In 2001, their combined area accounted for nearly 25% of the total area planted to GM crops. Significant growth in adoption rates in developing countries is expected as candidates in the large pipeline of GM crops undergoing field testing are approved for commercialization. To date, the dominant GM crops grown worldwide are soybean, maize, cotton, and canola (Table 2).

***Table 1. Global area of GM crops, by country, 2000 and 2001 (million hectares)***

| Country | 2000 | | 2001 | | Change | |
|---|---|---|---|---|---|---|
| | Area | % | Area | % | Area | % |
| 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 | +0.1 | +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***: James (2001)

*Table 2. Global area of GM crops, by crop, 2000 and 2001 (million hectares)*

| Crop | 2000 | | 2001 | | Change | |
|---|---|---|---|---|---|---|
| | Area | % | Area | % | Area | % |
| Soybean | 25.8 | 58 | 33.3 | 63 | +7.5 | +29 |
| Corn | 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 | (--) | -- |

***Source***: James (2001)

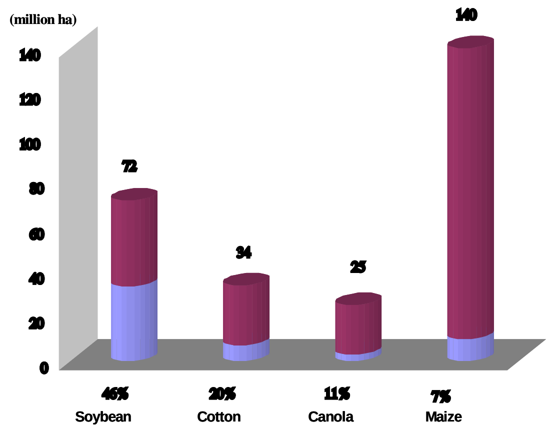


***Figure 2. Global area adoption rates (%) of principal transgenic crops, 2001 (Source: James 2001)***

Figure 2 shows rates of adoption of the principal transgenic crops. In 2001, of the total 72 million ha of global area devoted to soybean production, 46% was to GM soybeans; and transgenic cotton was planted to 20%; GM canola to 11% and GM maize to 7% of the global area planted to these respective crops. The combined area of these crops totaled 271 million ha, of which 19% was planted to transgenic varieties.

Herbicide-tolerant crops represented 77% of the global transgenic crop area in 2001, followed by insect-resistant GM crops containing *Bt* genes (Table 3). Transgenic crops with expressed traits of both herbicide tolerance and insect resistance (stacked genes) occupied 8% of the global area of transgenic crops. Between 2000 and 2001, herbicide-tolerant crop plantings increased by 24% and 31% for crops with stacked genes. Disease and virus resistance are expected to assume much more significance in the future as these traits are incorporated into key crop plants.

***Table 3. Global area of transgenic crops by trait (million hectares)***

| Trait | 2000 | | 2001 | | Change | |
|---|---|---|---|---|---|---|
| | Area | % | Area | % | Area | % |
| 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 | <0.1 | <1 | <0.1 | <1 | <0.1 | — |
| Global totals | 44.2 | 100 | 52.6 | 100 | +8.4 | +19 |

## Global agricultural biotechnology initiatives

Worldwide, there remains a disparity in the acceptance of agricultural biotechnology in various regions and countries. In aggregate terms, however, there appears to be a steady growth in acceptance of the technology, especially among producers. Current interest in crop biotechnology generally stems from the rapid diffusion of the technology and the earlier experiences on benefits derived from GM crops. Crop biotechnology has also been largely acknowledged as a key component of a multi-pronged strategy to help achieve food security, particularly in developing countries. The following are some recent developments and agricultural biotechnology initiatives in the European Union, the African continent, Latin America, and the Asian region.

### *The European Union*

Strong opposition to genetically modified organisms (GMOs) in the EU is well known. Environmental release of GMOs is tightly regulated under Directive 90/220 which will be replaced by Directive 2001/18 by October 2002. Under the new directive, an exhaustive assessment of safety data is needed before an approval for the commercial release of GMOs is granted. Further regulations on labeling and traceability for foods and animal feed containing GMOs are to be imposed.

While field trials continue to be conducted across Europe (Table 4) concentrating on maize, oilseed

***Table 4. Environmental releases of GMOs in the EU, 1991-2002***

| Country | 1991 | 1992 | 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Austria | | | | | | 2 | 1 | | | | | | 3 |
| Belgium | | 26 | 16 | 17 | 11 | 7 | 7 | 6 | 8 | 16 | 5 | 7 | 126 |
| Denmark | | 5 | 1 | 5 | 4 | 5 | 10 | 4 | 5 | 1 | | | 40 |
| Finland | | | | | 1 | 3 | 6 | 3 | 3 | 3 | 1 | | 20 |
| France | | 1 | 35 | 57 | 69 | 91 | 72 | 70 | 64 | 34 | 17 | | 510 |
| Germany | | 3 | 1 | 8 | 12 | 17 | 20 | 18 | 23 | 7 | 8 | 5 | 122 |
| Greece | | | | | | 1 | 5 | 7 | 6 | | | | 19 |
| Ireland | | | | | | | 2 | 2 | | | | 1 | 5 |
| Italy | | | 5 | 19 | 43 | 50 | 46 | 43 | 51 | 18 | 5 | 9 | 289 |
| Netherlands | 4 | 15 | 9 | 25 | 16 | 10 | 14 | 19 | 5 | | 19 | 4 | 140 |
| Norway | | | | | | | | | 1 | | | | 1 |
| Portugal | | | 2 | 2 | 1 | | 3 | 3 | 1 | | | | 12 |
| Spain | | | 3 | 10 | 11 | 16 | 44 | 39 | 39 | 19 | 19 | 3 | 203 |
| Sweden | | | | | 8 | 10 | 9 | 8 | 19 | 6 | 2 | 2 | 64 |
| UK | | 16 | 17 | 23 | 37 | 27 | 25 | 22 | 13 | 25 | 12 | 4 | 221 |
| Total | 4 | 66 | 89 | 166 | 213 | 239 | 264 | 244 | 238 | 129 | 88 | 35 | 1775 |

Note: year 2002 as of 10 July
*Source*: EC Joint Research Centre *http://biotech.jrc.it/gmo.asp*

rape, sugarbeet, and potato, the number has significantly declined. GM crops are not yet grown on a significant commercial scale in the EU. So far, only 18 GMOs – 13 for food and 8 for feed use – have been authorized for commercial release in the EU, and no further approvals have been granted since a moratorium on new approvals took effect in 1998.

Some EU member state ministers still say no to lifting the de facto moratorium before Directive 2001/18 is transposed into national law and rules on labeling and traceability are in place, which could be several years away. This is despite the fact that the industry has given commitments to respect the stricter rules even before they become law, in an effort to put the approval process back on track.

## The African continent

Across the African continent, South Africa is the only country to commercialize transgenic crops. *Bt* cotton is grown extensively in the Makhatini Flats of KwaZulu Natal Province. Yellow *Bt* maize for feed and white *Bt* maize for food also occupy considerable areas of land across South Africa. Government allocation for biotechnology research runs at R100 million annually, part being invested in the plant and medical sector (AfricaBio 2002). Current plant biotechnology research focuses on developing fungal-resistant strawberry, insect-resistant sugarcane, virus-resistant potatoes, and fungal-resistant maize and sorghum.

Kenya largely focuses its research on sweet potato and maize. In 2000, field trials were conducted for sweet potatoes resistant to feathery mottle virus, a very important disease of sweet potato in East Africa. Research at the Kenya Agricultural Research Institute (KARI) on GM maize for insect resistance is also underway. Seventeen corn genes identified worldwide are currently undergoing trials for insect resistance in maize (Crop Biotech Update 2002).

Products resulting from agri-biotechnology initiatives in Egypt are three GM crops approaching the stage of commercial release (Cohen 2001). These include transgenic potatoes resistant to potato tuber moth (PTM); virus-resistant squash; and yellow and white maize resistant to stem borer. Research at the Agricultural Genetic Engineering Research Institute (AGERI) is in progress on tomato, cotton, faba bean, cucurbits, wheat, banana and date palm (Madkour 2000).

In other parts of Africa, substantial research in plant biotechnology is being carried out, although many countries have not yet reached the commercial stage for the development of local and regional GM crop markets (Brink *et al.* 1998). Private-sector engagement in biotechnology is limited, with universities and agricultural research institutions taking most of the lead in research and development (Ndiritu 2000).

### Latin America

Adoption of GM crops in Latin America is steadily growing. Argentina is leading the way on the adoption of transgenic crops, limited almost exclusively to commodity crops such as soybeans, maize and cotton. Six transgenic crops are already approved for commercial use. Much of the investment in crop biotechnology research has come from the private sector, with fairly limited research and development (R&D) activities initiated by national public research institutes such as the National Institute of Agricultural Technology (INTA) and the University of Buenos Aires (Bottino 2000).

Research on GM crops had been initiated in Mexico in the late 1980s, with research on delayed-ripening tomatoes. To date, 144 permits have been issued for research and experimentation (Bottino 2000). The main crops tested are maize, tomato and cotton. In 2001, less than 100 000 ha of land were planted to transgenic crops, mostly GM soybean and GM cotton. The Inter-ministerial Commission on Biosafety and Genetically Modified Organisms (CIBIOGEM), created in November 1999, is the national authority that oversees the import, export, and environmental release of GMOs in the country.

Modern biotechnology research in Brazil has produced a number of beneficial plant biotechnology products. Examples of transgenic plants developed include maize that produces growth hormone, GM papaya resistant to the Brazilian strain of ringspot virus, and common beans resistant to golden mosaic virus (Sampaio 2000). Commercialization of GMOs, however, remains prohibited. A new directive (Decree No. 3871) on food labeling that became effective 1 January 2002 allows 4% tolerance limit in packaged food products containing GMOs (USDA 2001).

### The Asian region

Recent developments indicate a modest but expanding acceptance of biotechnology, including GM crop technology, in the Asian region. Many governments in Asia give high priority to agricultural biotechnology research, with increasing interest on orphan crops, in the hope of addressing the pressing problems related to improving productivity, increasing farmers' income, and meeting food security demands.

China has invested heavily in agricultural biotechnology research, now ranking second to USA in terms of public-sector investment (about US$112 million in 1999). Huang *et al.* (2002) reported that public research institutes have developed 141 GM crops, 45 of which have been approved for field trials, 65 for environmental release, and 31 for commercialization. GM crops already approved for commercialization include cotton, tomato, petunia and sweet pepper. Field trials for other traits of several major GM crops such as rice, potato, soybean, cucumber, papaya, maize and tobacco are ongoing. No other approval for commercial planting, however, has been granted in the last two years.

Plant biotechnology initiatives in India focus on developing crops with desirable traits through tissue culture and genetic engineering (Sharma 2000, cited in ADB 2001). R&D priorities include new regeneration techniques for tissue culture production of citrus, coffee, mangrove, vanilla and cardamom. Research is also focused on developing transgenic rice, maize, wheat, cotton, brassica, mungbean and potato. The Indian government allocates an estimated US$15 million annually to plant biotechnology research and about US$10 million comes from the private sector (Huang *et al.* 2002).

Through its Genetic Engineering Approval Committee (GEAC), India has recently approved the commercial planting of three *Bt* cotton cultivars. This event is regarded as a significant milestone for Indian agriculture as it is the country's first GM crop to be grown on a commercial scale. India is emerging as a significant contributor in the field of biotechnology within Asia (Ernst & Young 2002).

The Indonesian government has also placed high priority on the application of biotechnology in agricultural development. At present, several public institutions and private companies are engaged in biotechnology research for food crops, focusing on maize, peanut, soybean, potato, sweet potato, sugarcane, cacao, oil palm and rice. Indonesia earned the distinction of being the first Southeast Asian country that produced GM crops on a commercial scale, with *Bt* cotton now extensively grown in South Sulawesi province.

Biotechnology has received strong government support and commitment in Malaysia, with significant funding support for R&D, infrastructure and human resource development. In the Eighth Malaysia Plan (2001-2005), RM100 million (US$26.3 million) is allocated for research in agri-biotechnology, health care, and the environment and energy sector. Malaysia hopes to become a regional center for biotechnology industries with the setting-up of a BioValley, a concentration of biotechnology research institutions, universities and companies within the Multimedia Supper Corridor (MSC). BioValley will include research institutions in agricultural biotechnology, nutraceuticals and pharmaceuticals, and genomics and molecular biology.

Development of transgenic crops in Malaysia has been conducted primarily in public research institutes and universities, and is currently limited to laboratory work and glasshouse evaluation. Significant progress is being made on citrus pomelo, rice, papaya, banana, orchid, oil palm, chili and rubber. While no GM crops are being field tested yet, steps have already been taken to familiarize regulatory bodies with the applications and protocols for field testing and biosafety assessment.

Current research programs on plant biotechnology in the Philippines focus on developing transgenic banana with resistance to bunchy top virus and papaya resistant to ringspot virus; delayed ripening of papaya and mango; *Bt* maize; and coconut with high lauric content. A number of multi-locational field trials have already been conducted for *Bt* maize. Recently, the government released guidelines regulating the importation and commercialization of GM crops and products in the country.

Thailand focuses on improving crop traits of traditional foods, fruits, and export commodities. R&D priorities are rice, cassava, sugarcane, rubber, durian and orchids. Large-scale pre-commercialization field trials have been and continue to be conducted for *Bt* cotton and herbicide-tolerant maize. About 17 transgenic plants/materials are undergoing biosafety assessment (Hiranpradit 2000). These include delayed-ripening tomato, ringspot-virus-resistant papaya, insect-resistant (*Bt*) cotton, insect-resistant (*Bt*) and herbicide-tolerant maize, and rice.

Agricultural biotechnology R&D in Vietnam is largely at the stage of improving technology imported from advanced countries (Nguyen 2000). Current research is focused on developing disease- and pest-resistant crops, as well as plants tolerant to adverse environmental conditions. Genetic improvement of rice, maize, potato, sweet potato, cassava, soybean, sugarcane, fruits and vegetables, and cotton is being undertaken in various public research institutes.

## Crop biotechnology and food security

Significant economic benefits from the use of transgenic crops are increasingly becoming evident in countries adopting the technology. Documented benefits include increased farm productivity and income, reduced use of chemical inputs, and cost savings to farmers. Examples of such benefits and utility to farmers have been documented in the USA (Cornejo and MacBride 2000; Gianessi *et al.* 2002; Marra *et al.* 2002) and in developing countries such as China (Pray *et al.* 2001), South Africa (Ismaël *et al.* 2001a,b; Stewart *et al.* 2001), and Mexico (Traxler *et al.* 2001).

Biotechnology has become of greater concern, particularly in developing countries, because of the need for increased and efficient agricultural production to provide sufficient food for the growing population. Moreover, environmental problems are also putting tremendous pressures on the already-degraded natural resource base. It is estimated that by 2050, 90% of the world population will reside in developing countries. Over the next 50 years, world population is set to increase by 3 billion, and possibly by as much as 4.5 billion. The International Food Policy Research Institute (IFPRI) has estimated that by the year 2020, global demand for staple foods such as rice, wheat, and maize will increase by 40%.

It is widely perceived that production from traditional crop production systems, including the use of current plant types and varieties developed through conventional breeding programs, cannot provide sufficient food, feed and natural fiber to meet projected demands. Modern plant biotechnology, responsibly and prudently developed and deployed, is seen as an important tool to help achieve food security and sustainable agriculture, particularly in developing countries (FAO 1999; Serageldin and Persley 2000; UNDP 2001).

## Concluding remarks

There is an increasing realization, bolstered by experience and a growing body of evidence, that crop biotechnology has immense potential to contribute to improved agricultural productivity and sustainability. Documented benefits of GM crops include higher farm incomes, increased and protected yields, significant reductions in pesticide use, and greater flexibility in crop management.

If modern biotechnology, particularly genetic engineering technology, is harnessed within an enabling and responsible regulatory environment, the technology may find broader public acceptance and wider applications to help address pressing agriculture, food and environmental problems. Equitable access to the technology, and an open and broad exchange of information, knowledge and experience on biotechnology may help provide the opportunity to link the needs of societies, particularly in developing countries, with an increasing array of crop biotechnology applications and related innovations that could help their quest for food security.

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