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Review

Commercial Production of Genetically Modified Crops: A Prognosis Towards Global Acceptance

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ABSTRACT

The improvement of plant growth, crop productivity and supply of agricultural products in adverse environmental conditions are the major objectives of plant molecular biology research. Genetically modified crops (GMCs) have provided a unique and successful way of addressing some severe environmental constraints. Therefore, the production of GMCs has continued to cover increasing areas in the world despite the controversies over the risks of GMCs to human heath and to the environment. This review addresses the impact of the European Union's approval of commercial production of transgenic maize, MON 810, on the worldwide acceptance of GMCs. Rather than concentrating on GMC conflict between opponents and proponents, we highlight a new dimension of concerns i.e. how to accurately use this new technology and GMCs to alleviate poverty across the world.

Key Words: *Bacillus thuringiensis*; Transgenic crops; EU; Maize MON 810

INTRODUCTION

Genetically modified crops (GMCs) also known as transgenic crops are those in which a foreign genetic material (gene) has been introduced in order to gain additional specific trait (Somerville, 2000; Kotchoni & Bartels, 2003). The introduction of the foreign gene is generally performed by either an infection process of bacteria (*Agrobacterium tumefaciens*-mediated transformation) carrying the desired gene or by a direct shooting of microscopic pellets containing the transgene into the host-cells (Gachomo *et al.*, 2003). The primary objective of genetic manipulation is to provide insight into the behaviour of plants in a given environment and further to generate plants that can tolerate/resist various biotic and abiotic stresses (Conrath *et al.*, 2002; Ramanjulu & Bartels, 2002). GMC technology has become increasingly important since it aims to improve crop yield even under environmental challenges. For example, crop improvements have been realised in nutritional quality (James, 2003; Nap *et al.*, 2003; Conner *et al.*, 2003), insect and disease resistance (James, 2002; Chen *et al.*, 2003), herbicide resistance (Hofte & Whiteley, 1989; Chen *et al.*, 2003) and abiotic stress tolerance such as salt stress, drought, and heavy metal contamination (Gachomo *et al.*, 2003; Shinozaki *et al.*, 2003; Kroemer *et al.*, 2004, Bartels & Sunkar, 2005). However, controversies continue to arise concerning the GMC risks on human health, high cost of GMC establishment and their threat to biodiversity. Europe is that part of the world where the introduction of genetically modified organisms (GMOs) is facing stiff opposition (Somerville, 2000). Somerville (2000) reported that the greatest threat to biodiversity is rather the expansion of agricultural land. In this regard any technology that can help to stop the expansion of agricultural land and minimize chemical inputs will probably be welcome. Farmers searching for more productive land cleared approximately 11 million ha of forest every year (Herrera-Estrella, 2000; James, 2003). Conversion of tropical forest land into agricultural land might have more adverse ecological consequences than the use of GMCs (Herrera-Estrella, 2000).

Knowing the coldness of the Europeans towards GMOs, the year 2004 can be viewed as a year of breakthrough for the GMC technology. This is because the European Union (EU) has approved the commercial production of 17 different transgenic maize MON 810 strains engineered by the big US biotech company Monsanto (www.agbios.com). The maize MON 810 (trade name yieldGrade®) was developed through a specific genetic modification to be resistant to the attack of European corn borer (ECB) *Ostrinia nubilalis*, a major insect pest of maize. This maize transgene produces a truncated form of the insecticidal protein, Cry1Ab, isolated from *Bacillus thuringiensis* (Nap *et al.*, 2003). The introduction of transgenes into plants by *Agrobacterium*-

mediated transformation results in a stable random integration of one or a few copies of the genes (Gheysen *et al.*, 1989) leading to different epigenetic effects in independent transgenic seed strains. The resulted transgenic seeds often show very different levels of trangene expression (Peach & Velten, 1991). The US has approved the commercial production of MON 810 in 1995, but it has taken almost 10 years for EU to take this decision. Although in the past, this transgenic maize MON 810 had been authorized in France and Spain, farmers in the rest of the EU country members were not allowed to buy or sow transgenic maize seeds for commercial purposes before this decision was made (James, 2003).

It is not the purpose of this review to cover the recurrent worldwide conflict on GMCs. We rather briefly summarize here the current debates about the commercial production of GMCs around the world and mainly focus our attention on the global status of GMCs by viewing the impact of EU approval of commercial production of transgenic maize, MON 810, on a probable worldwide acceptance of GMCs. It is unfortunate to notice the extent to which the public debate on GMC is highly polarised. Meanwhile, both opponent and proponent of GMC could help to improve the yield of agricultural products by jointly viewing or accurately estimating the risks and benefits of GMCs on a case to case basis.

***Bacillus thuringiensis* (Bt): A beneficial discovery in Gmc technology.** *Bacillus thuringiensis* is one of the most common gram-positive bacteria in the soil, first discovered in Japan in 1901 by Ishawata and then reported in Germany in 1911 by Berliner (Baum *et al.*, 1999). *Bt* gained popularity due to its ability to control certain insect pests in an environment friendly manner. During sporulation, this bacterium produces specific crystalline inclusions known as insecticidal or crystalline pesticidal proteins (CPPs), which are toxic to specific insects and harmless to non-targeted insects such as insect predators, parasitoids and pollinators (Hofte & Whiteley, 1989; Chen *et al.*, 2003; Kraur, 2000). The pesticidal protein is easily degradable biologically or under sunlight. These factors make *Bt* toxins a favourable choice worldwide. The genes responsible for the production of *Bt* toxins have been widely characterized (Schnepf & Whiteley, 1981). Plants bearing such genes can then produce the toxins and become resistant to specific insect pests.

The genes encoding the specific CPPs are carried on plasmid DNAs harboured by the *B. thuringiensis* (Whalon & McGaughey, 1998). Each strain of the bacterium produces its own unique CPP (Whalon & McGaughey, 1998). Many *Bt* strains have been subsequently identified and successfully used in agriculture (e.g. Rice, 1999). Some of the most successfully and commonly used subspecies of *B. thuringiensis* include subspecies *kurstaki* used against Lepidoptera; subspecies *israelensis* used against Diptera, larva of mosquitoes and blackflies, and subspecies *tenebrionis* used against *Leptinotarsa decemlineata* (Whalon & McGaughey, 1998). The first reports of insertion of genes encoding for *Bt* delta-endotoxins into plants came in 1987 (Van Frankenhuyzer, 1993). The first transgenic plants to express *Bt* toxins showing resistance to pests were tobacco and tomato (Van Frankenhuyzen, 1993). A great success in GMC technology was the generation of *Bt* corn that was resistant to the European corn borer *Ostrinia nubilalis* (Montesinos, 2003). Thereafter, other *Bt* transgenic crops including cotton, potatoes and rice were produced (Montesinos, 2003; Nap *et al.*, 2003). In 1997, *Bt* cotton, corn, and potatoes covered nearly 10 million acres of land in the United States alone (Nap *et al.*, 2003). In 2000, about 109.2 million acres were planted with transgenic crops worldwide; the most common ones being herbicide- and insecticide-resistant soybeans, corn, cotton and canola (Nap *et al.*, 2003).

Genetically modified crops: potential benefits versus risks. Genetic engineering has achieved a prominent goal in basic and applied research in plants. Following few benefits and risks of GMCs are discussed to fit in the scope of this review.

Potential Benefits of GMCs

Improvement in nutrition and production constraints. Certain crops are difficult to grow in particular climates for different reasons. For example, strawberries are not very frost hardy, which makes them difficult to grow in cold climates. Recently researchers have discovered that the arctic flounder produces an anti freeze protein to protect itself in arctic waters. Genetically engineered strawberries or soybeans expressing this anti freeze gene can protect themselves against the damaging effects of the frost, thereby sustaining under environmental constraints. Progress has been made towards production of transgenic rice resistant to insect and disease of which some lines have already been field-tested (Conway, 2000; James, 2003). Oilseed crops like canola have been modified to produce oils of a particular composition in order to enhance nutritive value, while cereals on the other hand have been modified for specific starch or protein content (Nap *et al.*, 2003). Progress was also made in transferring genes to rice and maize that help them tolerate high concentrations of aluminium; a soil toxicity problem that impedes cereal production over vast areas of the tropics (Nap *et al.*, 2003). Increased tolerance to pests in hostile environments is expected to enhance yields with eventual improvements in human nutrition.

On the other hand, the quality of farmable land is in many places poor or actually decreasing, due to erosion, salinization, loss of micronutrients and accumulation of heavy metals (Bartels & Sunkar 2005). Soil salinity and drought, are the major abiotic stresses reducing agricultural productivity and it is estimated that more than a third of all irrigated land in the world, excluding the arid and desert lands is presently affected by salinity (Blumwald *et al.*, 2004). Therefore, increasing the yield of crops in optimal soils and even in less productive lands such as salinized lands and desiccated lands is essential for feeding the world population, which is expected to increase by 1.5 billion in the next 20 years (Blumward *et al.*, 2004).

The recent contributions of GM technology include the engineering of (a) ectoine (an osmo-compatible solute) synthesis with enzymes from the halophylic bacterium *Halomonas elongata* (capable of living in salty water of a concentration far above that of the sea water) into plants (Nakayama *et al.*, 2000; Blumwald *et al.*, 2004) and (b) the trehalose synthesis found in bacteria, yeast and in extremely desiccation-tolerance plants (Bartels & Sunkar, 2005) into potato (Yeo *et al.*, 2000), rice (Garg *et al.*, 2002) and into *Arabidopsis thaliana* (Bartels & Sunkar, 2005). In 2002, researchers at Cornell University successfully tested under greenhouse conditions a variety of GM rice that maintained yields under abiotic stresses such as cold, drought and salty soil (James, 2003). In addition, the overexpression of osmolytes (mannitol, glycine-betaine) and aldehyde dehydrogenase proteins has been shown to contribute to enhanced drought and salt stress tolerance in transgenic plants (Kirch *et al.*, 2005; Kotchoni *et al.*, 2005).

The loss of farmable land due to abiotic stresses is directly in conflict with the needs to grow enough crops to feed the world. It is estimated that through GM technology, the modified variety has the potential to increase yields under poor conditions by as much as 20%. Currently, researchers are planning to seek patent protection for the modification and thereafter ensure public availability of the modified crop, particularly for farmers in developing countries. They also hope to introduce the trait in other crops, such as maize, wheat or millet (James, 2003). Although GM technology has a significant contribution to make towards production of plants that are more resistant to water stress, highly salty soils and drought stress, commercial companies are unlikely to be interested in producing such varieties, primarily because it would be difficult to enforce property rights and to secure profitable markets for such improved abiotic stress tolerant seeds (Blumwarld *et al.*, 2004).

Improvements in human health. GMC technology has aimed at providing a cheap and promising way for human therapy (James, 2003; Nap *et al.*, 2003). In developing countries, for example, millions of people suffer from vitamin A deficiency, especially in Asia where the basic diet consists of rice. Rice has been genetically modified to produce beta-carotene, a precursor of vitamin A, which could then be converted into vitamin A in humans. This is one of the promising strategies to solve the vitamin A deficiency. GMCs also offer an opportunity to develop oral vaccines contained in fruits such as banana. In 1996, US researchers were able to genetically engineer banana to produce an antigen found in the outer coat of the hepatitis B virus. If successful this banana can immunise children around the world. Currently hepatitis B vaccines cost between $ 100 and $ 200 per dose. More than 70% of the world population especially those in the developing countries can hardly afford a dose of these vaccines (James, 2003). Therefore, promoting the production of such vaccines via GMCs is crucial for a better health for the generations to come. In Australia, reports indicate that tests on an oral vaccine against the enteric pathogen *Escherichia coli* have been initiated (James, 2003). Other efforts are aimed at modifying rice to increase the iron content in order to reduce anemia. Plant oils were also being modified to adjust cholesterol levels. GM foods containing sweet proteins like thaumatin may be helpful to diabetics (James, 2002; James, 2003).

Improvements to the environment. Development of pest resistant varieties could lead to a reduced application of pesticides, which will correlate with less pollution of the environment and less chemical residues on foods. The generation of transgenic Maize MON 810 that resist *Ostrinia nubilalis*, the European corn borer, is one of the typical examples of the benefits of GMC technology to the environment (Nap *et al.*, 2003). The introduction of insect-tolerant varieties of cotton to Australian agriculture is reported to curtail the pesticide use by 50% (ERS-USDA, 1999). The development of herbicide resistant crops, which overexpress resistant genes to environmental friendly herbicides such as Glyphosate (round up) has allowed growers to spray such herbicides without damaging crops (Nap *et al.*, 2003). GMCs for animal feed can deliver vaccines to animals and therefore minimize the antibiotics entry into the body of animals. In addition, plants could be engineered to produce industrial raw materials that are biodegradable (e.g. bioplastics) and thus reduce loading of non-degradable plastics in the environment. Heavy metal pollutants can also be managed through bioremediation using GM trees (James, 2003).

Improvement of business and economy. Savings by farmers are expected through reduced inputs e.g. pesticides, fertilizers and water. Less damage due to pests will also increase expected yield and profits. In Australia, farmers currently spend up to $ 5 million yearly on insecticides to control the pea weevil, which reduces yields by 25 to 30%. GM peas, which have been developed by introducing a gene from the kidney bean, are 99.5% resistant to weevil attack and have substantial economic benefits. In addition, plants are expected to be producers of raw materials needed to make industrial chemicals and polymers, such as plastics, detergents, nylon, glues, paints and lubricants. They can provide a renewable, biodegradable source of raw materials leading to the development of new industries. GMCs with enhanced time span of shelf life and improved storability increase the time that might be spent between harvests and marketing. This should augur well for the economy of developing countries; especially those relying on export of fresh agricultural products. The production of GMCs at commercial scale has an overwhelming potential. The financial value of GMC global market is estimated currently at 12 billion dollars (James, 2003), and is expected to double the present rate in the next five years with the EU's approval of commercial production of transgenic maize MON 810. The biotechnology is now the fastest growing sector. Presently, there are about 1500-2000 biotechnology companies in the USA, and further 700 in Europe (James, 2003). In food and farming sector, six international conglomerates now dominate the market: Monsanto, Novartis, AgrEvo, Dupont, Zeneca and Dow. These companies have already invested 23 billion dollars in biotechnology development; Monsanto alone spent 730 million dollars on biotechnology research in 1997 and currently have double its financial input. Ten companies account for 30% of the global 23 billion dollars of commercial seed trade, including Pionneer Hi-Bred (1.7 billion dollars) and Novartis (0.93 billion dollars) (James, 2003). From the financial input, it is clearly understood that GMCs constitute a sector of business.

Potencial risks of GMCs. On the other hand, the production of GMCs is not free of risks (Conner *et al.*, 2003). Opinion on benefits and risks of GMCs differs for various reasons. Regardless of people's opinion, it is of mankind advantage to look at risks (if any) of the commercial production of GMCs in order to draw tangible conclusions concerning the up-roaring of conflicts about this new technology.

GMC risks to human health. The general concerns of GMCs on human health are mainly concentrated on antibiotic resistance, toxicity, allergy and their related side effects, and carcinogenic-mediated potential. GMCs generally contain antibiotic-resistant genes subsequently used as markers to select the transgenic crops. Physicians in the US and Britain have warned that this could lead to diminished effectiveness of antibiotics as medicines and to the development of new antibiotic-resistant strains of infectious human pathogens (AMA, 2000; BMA, 1999). Certain GMCs could be toxic even to human health. The Showa Denko case (Boyens, 1999) is often quoted as an example of death resulting from the use of genetically modified organisms. In this case, 37 people died and 1535 were left disabled after using l-tryptophan produced via a genetically modified bacteria strain. Serious human health problems have not been often linked to GM foods but scepticism arose because there is as yet no standard labelling of GM foods worldwide. People are afraid that allergies and cancers could develop from new proteins. Such apprehensions are based on report of the 2S-protein of Brazil nut, which was allergenic when added to enhance methionine content in transgenic soybean (James, 2002). There has also been substantial but inconclusive debate on the role of snowdrop lectins on insects and mammalian immune systems (Jame, 2002). However, transgenic maize MON 810 was thoroughly assessed to be safe for human health and has been grown in the US and Spain for years without any known problems (James, 2003). The expression of Cry-protein in the transgenic maize (MON 810) acts by selectively binding to specific sites localised on the brush border midgut epithelium of susceptible insect species. Following binding, cation-specific pores are formed that disrupt midgut ion flow and thereby cause paralysis and eventually death of the target insect (Schnepf & Whiteley, 1981; Kraur, 2000). This target specificity is based only on the selective binding of Cry1Ab to specific receptor sites localised on the target insects (Hofte & Whiteley, 1989; Chen *et al.*, 2003). There is no binding site for this toxin (Cry1Ab) on the surface of mammalian intestinal cells, therefore, livestock animals and humans are not susceptible to these proteins (Schnepf & Whiteley, 1981; Crickmore *et al.*, 1998; Kraur, 2000).

There might be situations in which the potential benefits of GMCs are outweighed by their associated risks. Intelligent public policy should seek to discriminate against such cases and find ways of developing regulations to minimize any potential risks.

Ecological and environmental risks. GMC risks to environment and ecology include the crop-to-wild hybridization resulting in the evolution of increased weediness in wild relatives, the evolution of pest resistance to *Bt* toxins, the impacts of *Bt* toxin on non-target species in associated ecosystems, e.g. an unintentional poisoning of beneficial insects (Snow & Palma, 1997; Hails, 2000; Rissler & Mellon, 1996). Ellstrand (2001) reported the ecological aspect of GMCs in the environment. His and related findings of others suggested that natural movements of transgenes is possible but the risk of such movements are absolutely restrained due to species and ecotype barriers and environmental factors. GMCs (*Bt* crops) were reported to harm beneficial insects. Losey *et al.* (1999) reported that pollen from *Bt* corn might kill monarch butterfly larvae in laboratory experiments. According to their investigations, when pollen from a commercial variety of *Bt* corn (N4640) was sprayed onto milkweed leaves (*Asclepias syriaca*, the feed plant of monarch butterfly larvae) and the leaves fed to monarch butterfly caterpillars in the laboratory, the caterpillars died (Losey *et al.*, 1999). Follow-up studies to investigate the impact of *Bt* corn on the monarch butterfly essentially revealed that the impact of widespread planting of *Bt* corn pollen from current commercial hybrid corn on monarch butterfly populations was negligible (Hellmich *et al.*, 2001; Oberhauser *et al.*, 2001; Pleasants *et al.*, 2001; Sears *et al.*, 2001; Berenbaum, 2001, Stanley-Horn *et al.*, 2001). Other reports indicate that GMCs may harm ladybugs and green lacewings (Hilbeck *et al.*, 1998 a, b). The use of insecticidal proteins such as snowdrop (*Galanthus nivellus*) lectin (GNA) in transgenic potato affected the growth of the two-spot ladybird (*Adalia bipunctata* L.) after it was fed on aphids colonizing GNA-expressing plants (Hilbeck *et al.*, 1998 a, b). One should be careful while interpreting field/laboratory results to find conclusive impacts on real field experiments because several environmental factors are mixing in laboratory tests. The need for appropriate ecological studies to support the perceptions of risks should always be mentioned. It should be kept in mind that every endeavour involves a certain amount of risk and working to clarify the acceptable risk level in biosafety issues can eventually be satisfactory.

There is apprehension that viral genes added to a plant to confer resistance could recombine with others viruses to create new variants that could be difficult to control. Another concern is the constitutive expression of single gene strategies for imparting resistance to pathogens, which might escape the control and result in the evolution of new pathogenic strains that will be immune to the transgenic plants. Lukow *et al.* (2000) showed that planting GM potatoes changes bacterial communities in the soil and this can have a negative impact on the balance between pathogens and their antagonists, leading to increased disease incidences. Disturbance of the natural balance between soil biota and plants may also affect symbiotic nitrogen fixation, which can negatively affect soil fertility.

It is possible that new genes added to GMCs might escape via pollen to nearby weeds or other plants. To avoid this, field-test facilities should be designed with an extra degree of caution, and be located at considerable distances from any wild relatives (Conway, 2000). Horizontal transfers of herbicide tolerant transgenes to weeds or wild plants could occur, resulting in a super weed that may be difficult to control. This could happen for example between sorghum and the Johnson grass weed because these two plants can cross-hybridize. MacArthur (2000) reported about a triple-resistant canola weed in Canada, which had developed from inadvertent crossing of three different canola systems genetically engineered to the herbicides RoundUp (glyphosate), Liberty (glufosinate-ammonium) and Pursuit (imazethapyr). Pollination via bees and wind between two fields was thought to be the cause of this occurrence. However, Conner *et al.* (2003) asserted that common distinctive attributes of weeds such as seed dormancy, phenotypic plasticity, indeterminate growth, continuous flowering, seed production and its dispersal (Baker, 1974) have been bred out of the most important crop plants over thousands of generations. Such changes appeared early in the domestication of crop plants and arose as a consequence of repeated sowing and harvesting cycles of plants without any conscious selection for change (Harlan, 1992). These characters are not vectors of gene transfer into crops whether by genetic modification or traditional breeding (Conner *et al.*, 2003).

Economic risks of GMCs. The economic risks of GMC technology are highly diversified and ranging from the risk of terminator gene technology, patent of crop variety to the increase input requirement.

Once a transgenic crop with a substantially higher yield or other useful characters is developed, it is possible that one can use a terminator gene to prevent farmers from producing or propagating that seed, and therefore protect his commercial interest. Farmers will have to depend on the developer for that type of seeds in each growing season. Others may develop traitor seeds that will not mature unless they are sprayed with specific chemicals (Potrykus, 2001). In such conditions, farmers, especially in developing world would become dependent on a few companies for their livelihoods.

The issue of patent is another growing concern that could have a negative effect on the economy (Potrykus, 2001). A company that inserts a few genes into an existing variety, patents it, and then sells the seeds as a new variety could have the monopoly of the market for that particular seed variety. Although the addition of one or two traits adds values to the wild type, but the holder of the patent captures the entire worth of the pre-existing variety. This is a cause of concern, especially the aggressive pursuit of patents on varieties containing traits of special national importance, like basmati or jasmine rice, which originated from Thailand and Pakistan (Potrykus, 2001; Conner *et al.*, 2003). Chrispeels (2000) revealed that GMC technology could primarily benefits the multinational corporations that sell the transgenic seeds to the farmers. These corporations are more interested in recovering the costs of their investments and even make profit (Chrispells, 2000). For example, many crops such as cassava, sweet potatoes, white maize, millet, sorghum, yams and cocoyams, which provide food and employment income for the people in developing countries have been ignored by the private funding sectors. For these reasons, the GM research-funding sector is based on interest and marketability of the crop in the world. Most of the GMCs (Table I) were generated to serve the interest of the big corporative funding sectors. Consequently the needs of small-scale farmers in developing countries will be neglected. We therefore urge the scientists and the public sector in developing world to actively get involved in improving their so-called neglected crops.

On the other hand, Shiva and Jafri (2003) reported that *Bt* cotton, for example had a significant increase in attacks by non-target pests like aphids, white flies and thrips in India. Farmers had to spend more on pesticides to contain the increased attacks by the *Bt* non-target pests. Benbrook (1999) reported that in more than 8200 field trials planting RoundUp Ready soybean (RRS) seeds yielded less than non-modified soybean varieties, and that farmers with RRS still used herbicides, with more herbicides being applied in some cases.

Worldwide expansion of GMCs and new dimension of debates. The expansion in the cultivation of GMCs has been very rapid in the last 10 years (James, 2002; James, 2003; Nap *et al.*, 2003). Now with the EU on board, the global area under GMCs is expected to even double in the very near future. In 1994, there were no GMCs grown commercially anywhere in the world. In 1997 and 1998, GMCs were cultivated on 12 and 29 million hectares respectively in the USA, Australia, Argentina, Canada and Mexico (James, 2002; Nap *et al.*, 2003). The then most dominant GMCs planted were cotton (43%), maize (20%) and soya (14%). The estimated global area of GMCs for 2003 was 67.7 million hectares (James, 2003; Nap et al 2003) (Table I). Six lead countries grew 99% of the global

Table I. Ranking (in descending order) of the world's leading countries producing GM crops

Countries	Area under GMCs (Mha)	GM crop species
USA	42.8	Soybean, Maize, Cotton, Canola
Argentina	13.9	Soybean, Maize, Cotton
Canada	4.4	Canola, Maize, Soybean
Brazil	3.0	Soybean
China	2.8	Cotton
South Africa	0.4	Maize, Soybean, Cotton
Australia	0.1	Cotton
India	0.05	Cotton
Romania	0.05	Soybean
Uruguay	0.05	Soybean, Maize
Spain	0.05	Maize
Mexico	0.05	Cotton, Soybean
Philippines	0.05	Maize
Colombia	0.05	Cotton
Bulgaria	0.05	Maize
Honduras	0.05	Maize
Germany	0.05	Maize
Indonesia	0.05	Cotton

Source: James (2003); Nap *et al.* (2003).

transgenic crop area in 2002. This reflects the broadening participation of the GMCs growing countries with at least ten out of them now growing 50000 hectares (Table I).

The EU decision is likely to positively affect the approval and global realization of GMCs. Presently, 30% of the GMC areas are found in developing countries where growth has continued to be strong (James, 2002; Nap *et al.*, 2003). Contrarily, several other developing countries especially in Africa show scepticism. In Asia, Japan and China are leading in plant biotechnology (Nap *et al.*, 2003). Presently, the interest in the use of GMCs across the developing world is growing. China has presently the largest plant biotechnology capacity after USA (Huang *et al.*, 2002). Likewise, in many other countries of Asia, South America and Eastern Europe, the number of field trials is also increasing (James, 2003). India the third largest cotton growing country in the world approved the commercial application of insect-resistant GM cotton in 2002 (James, 2002). In Africa there is an attitude of "wait-and-see what happens in the developed world". The opponents of commercial production of GMCs argued that EU decision would lead to a rapid and widespread use of GMCs, while many EU countries have no laws on separating GMCs and conventional crops. Most countries of the world have no proper rules on how farmers should separate organic, conventional and GMCs to minimize cross-contamination (Nap *et al.*, 2003). Facing such a situation, the European Commission has urged EU member countries to be responsible for how their farmers segregate the farming type.

Future prospects. There are promising ideas such as transgenic fruit plants and nut trees that can yield years earlier, and plants that can produce bioplastics. Strategies to inform and educate both the public and policy makers should be encouraged so as to correct the wrong impressions and notions about GMCs. Without the consent of society at large; GMCs will face opposition in the market place. It would be unfortunate if some parts of the world, especially the developing parts, felt excluded and did not have a chance to take advantage of the potential benefits the GMCs would provide.

In future, a biotechnological strategy will be needed to prolong the usefulness of *Bt* toxin genes. The use of two or more toxin genes in a transgenic plant, each with a different molecular target in the pest should be implemented to reduce the chance of outbreak of insect resistant population. There is need to continue close monitoring of the impact of *Bt* crops on non-target insects. The application of antibiotics selection markers of GMCs could be discontinued because alternative methods for the selection of transgenic crops are available. Products containing transgenes should also be clearly labelled for easy identification.

Companies that invest in GMC technology should explore alternative control strategies instead of the use of controversial applications such as the terminator gene. In addition, they should be more flexible when pursuing entitlements accrued from patents. A willingness to share profits from patents on varieties such as jasmine or basmati rice with the countries of origin may also ease anxieties and enhance public acceptance. Increasing investment in training and research capacity so as to enable effective participation in the global market will promote a global acceptance of GMCs. Like all newly evolved technologies, GMC biotechnology can expect to be met with reluctance. Undeniably, much remains to be done to convincingly counteract the arguments raised in the risks posed by GMCs to human health, food security, biodiversity, environmental conservation, and intellectual property rights.

CONCLUSION

It is clear that food production has to be increased in order to meet the requirements of the increasing world population, but this has to come from existing farmland. The situation points to an increasing gap between demand and food production. Plant biotechnology might be a promising way to produce higher crop yields. Nevertheless, the important factor that still needs to be addressed remains the poverty. More than 70% of the world population do not have the money to buy enough food to cater for a daily need and the poor farmers cannot afford expensive technology (modern), even if this could practically increase yield. Although GMCs could be of tremendous benefit (still to be proven), they will profit the majority of the world (especially the most needed) only when the buying price is cheap and available. Poor people will never go for expensive technologies; being GMCs or not. In other words, it is important to significantly reduce the cost of the GM seeds for the sake of global accessibility and to consider alternative ways such as sustainable agriculture because the poor will simply be forced to find a solution through the existing agricultural systems.

The global expansion of GMCs within the last 10 years proved that they have partially met the expectation of farmers in both industrialized and developing world (James, 2002; James, 2003). We must not deny the fact that monocultures of GMCs at commercial scale represent a potential threat to the wild ecotypes and must therefore be discouraged. However, the idea of ignoring or stopping the use of GMCs especially in parts of the world where this technology might be successful can simply be viewed as unrealistic. A crucial baseline for risk assessment is to define the specific risk parameters, which should allow simple comparisons between traditional breeding systems, GMC approaches and the impacts of both on environments and health. The outlook of GMC acceptance in the nearest future points to a continued growth with probably more diversified GMC products available in the markets. Taking all this into account, it is worthwhile to design an appropriate and global management to efficiently monitor the flooding of the markets with GMCs in the years to come.

REFERENCES

AMA (American Medical Association)., 2000. Council on Scientific Affairs, *Genetically Modified Crops and Foods*, (American Medical Association, Chicago, IL).

Baker, H.G., 1974. The evolution of weeds. *Annu. Rev. Ecol. Syst.*, 5: 1–23

Bartels, D. and R. Sunkar, 2005. Drought and Salt Tolerance in Plants. *Crit. Rev. Plant Sci.*, 24: 23–58

Baum, J.A., T.B. Johnson and B.C. Carlton, 1999. *Bacillus thuringiensis*: natural and recombinant bioinsecticide products. *In*: Hall, F.R. and J.J. Menn (eds.). *Biopesticides: Use and Delivery*. pp. 189–210. Humana Press, Totowa, NJ.

Benbrook, C., 1999. "Evidence of the Magnitude and Consequences of the Roundup Ready Soybean Yield Drag from the University–based Variety Trails in 1998. AgBiotech InfoNet Technical Paper 1, July, 13, 1999.

Berenbaum, M.R., 2001. Interpreting the scientific literature: differences in the scientific and lay communities. *Plant Physiol.*, 125: 509–12

BMA (British Medical Association), 1999. *The Impact of Genetic Modification on Agriculture,* Food, and Health. London, U.K.

Blumwald, E., A. Grover and A.G. Good, 2004. Breeding for abiotic stress tolerance: challenges and opportunities. *Proceed. of the 14th International Crop Science Congress,* 26 Sep–1 Oct 2004. Brisbane, Australia. pp 15.

Boyens, I., 1999. *Unnatural Harvest: How Corporate Science is Secretly Altering our Food.* p. 278. Doubleday, Toronto, Canada

Chen, J., F. Sun, L. Tang, M. Tang, Y. Shi, J. Yu and Y. Pang, 2003. Expression of *Bacillus thuringiensis* full–length and N–terminally truncated vip184 gene in an acrystalliferous strain of subspecies *kurstaki*. *World J. Microbiol. Biotechnol.*, 19: 883–9

Chrispeels, M.J., 2000. Biotechnology and the poor. *Plant Physiol.*, 124: 3–6

Conner, A.J., T.R. Glare and J–P. Nap, 2003. The release of Genetically modified crops into the environment: Overview of ecological risk assessment. *Plant J.*, 33: 19–46

Conrath, U., C.M.J. Pieterse and B. Mauch–Mani, 2002. Priming in plant–pathogen interactions. *Trends Plant Sci.*, 7: 210–16

Conway, G., 2000. Genetically modified crops: risks and promise. *Cons. Ecol.*, 4: 2

Crickmore, N., D.R. Zeigler, J. Feitelson, E. Schnepf, J. Van Rie, D. Lereclus, J. Baum and D.H. Dean, 1998. Revision of the nomenclature for the *Bacillus thuringiensis* pesticidal crystal proteins. *Microbiol. Mol. Biol. Rev.*, 62: 807–13

Ellstrand, N.C., 2001. When transgenes wander, should we worry? *Plant Physiol.*, 125: 1543–5

ERS–USDA, 1999. *Genetically Engineered crops for Pest Management*

Gachomo, W.E., O.O. Shonukan and O.S. Kotchoni, 2003. The molecular initiation and subsequence acquisition of disease resistance in plants. *African J. Biotechnol.*, 2: 26–32

Garg, A.K., J.K. Kim, T.G. Owens, A.P. Ranwala, Y. Do Choi, L.V. Kochian and R.J. Wu, 2002. Threhalose accumulation in rice plants confers high tolerance levels to different abiotic stresses. *Proc. Natl. Acad. Sci. USA*, 99: 15898–903

Gheysen, G., L. Herman, P. Breyne, M. Van Montagu and A. Depicker, 1989. Agrobacterium tumefaciens as a tool for the genetic transformation of plants. *In*: Butler, L.O., C. Harwood and B.E.B. Mosely (eds.). *Genetic transformation and expression*. pp. 151–74. Intercept, Andover.

Hails, R.S., 2000. Genetically modified plants: the debate continues. *Trends Ecol. Evol.*, 15: 14–8

Harlan, J.R., 1992. Crop and man. *In*: Madison, W.I. (2nd Eds.). *American Society of Agronomy and Crop Science Society of America*.

Hellmich, R.L., B.D. Siegfried, M.K. Sears, D.E. Stanley–Horn, M.J. Daniel, H.R. Mattila, T. Spencer, K.G. Bidne and L.C. Lewis, 2001. Monarch larvae sensitivity to *Bacillus thuringiensis*–purified proteins and pollen. *Proc. Natl. Acad. Sci. USA*, 98: 11925–30

Herrera–Estrella, L.R., 2000. Genetically modified crops and developing countries. *Plant Physiol.*, 124: 923–5

Hilbeck, A., *et al.*, 1998a. Effects of transgenic Bacillus thuringiensis corn–fed prey on mortality and development time of immature Chrysoperla Carnea (Neuroptera: Chrysopidae). *Environ. Entomol.*, 27: 480

Hilbeck, A., *et al.*, 1998b. Toxicity of Bacillus thuringiensis Cry 1 Ab Toxin to the Predator Chrysoperla carnea (Neuroptera:Chrysopidae). *Environ. Entomol.*, 27: 1255

Hofte, H. and H.R. Whiteley, 1989. Insecticidal crystal proteins of *Bacillus thuringiensis*. *Microbiol. Rev.*, 53: 242–55

Huang, J., S. Rozelle, C. Pray and Q. Wang, 2002. Plant biotechnology in China. *Sci.*, 295: 674–7

James, C., 2002. World–wide deployment of G M crops: aims and results–state of the art. In: *Discourse on Genetically Modified Plants*. Bad Neuenahr, Germany: Bundesministerium fuer Verbraucherschutz, Ernaehrung und Landwirtschaft, April 19, 2002.

James, C., 2003. Preview: Global status of commercialised transgenic crop. *ISAAA brief*, 30. ISAAA: Ithaca, NY, ISBN: 1–892456–34–6. pp. 1–8

Kirch, H–H., S. Schlingensiepen, S.O. Kotchoni, R. Sunkar and D. Bartels, 2005. Detailed expression analysis of selected genes of the aldehyde dehydrogenase (ALDH) gene superfamily in *Arabidopsis thaliana*. *Plant Mol. Biol.*, 57: 315–32

Kotchoni, O.S. and D. Bartels, 2003. Water stress induces the up–regulation of a specific set of genes in plants: aldehyde dehydrogenases as an example. *Bulg. J. Plant Physiol.*, (special issue 2003): 37–51

Kotchoni, O.S., C. Kuhns, A. Ditzer, H–H. Kirch and D. Bartels, 2005. Overexpression of different aldehyde dehydrogenase genes in *Arabidopsis thaliana* confers tolerance to abiotic stress and protects plants against lipid peroxidation and oxidative stress. *Plant Cell Environ.*, (in press).

Kraur, S., 2000. Molecular approaches towards development of novel *Bacillus thuringiensis* biopesticides. *World J. Microbiol. Biotechnol.*, 16: 781–93

Kroemer, K., R. Reski and W. Frank, 2004. Abiotic stress response in the moss *Physcomitrella patens*: evidence for an evolutionary alteration in signaling pathways in land plants. *Plant Cell Rep.*, 22: 864–70

Losey, J.E., L.S. Rayor and M.E. Carter, 1999. Transgenic pollen harms monarch larvae. *Nature*, 399: 214

Lukow, T., P.F. Dunfield and W. Liesack, 2000. Use of the T–RFLP technique to assess spatial and temporal changes in the bacterial community structure within an agricultural soil planted with transgenic and non–transgenic potato plants. *FEMS Microbiol. Ecol.*, 32: 241

MacArthur, M., 2000. Triple–resistant canola weeds found in Alberta. *The Western Producer.*

Montesinos, E., 2003. Development, registration and commercialisation of microbial pesticides for plant protection. *Inter. Microbiol.*, 6: 245–52

Nakayama, H., K. Yoshida, H. Ono, Y. Murrooka and A. Shinmyo, 2000. Ectoine, the compatible solute of *Halomonas elongata*, confers hyperosmotic tolerance in cultured tobacco cells. *Plant Physiol.*, 122: 1239–47

Nap, J–P., P.L.J. Metz, M. Escaler and A.J. Conner, 2003. The release of genetically modified crops into the environment: overview of current status and regulations. *Plant J.*, 33: 1–18

Oberhauser, K.S., M.D. Prysby, H.R. Mattila, D.E. Stanley–Horn, M.K. Sears, G. Dively, E. Olson, J.M. Pleasants, W–K.F. Lam and R.L. Hellmich, 2001. Temporal and spatial overlap between monarch larvae and corn pollen. *Proc. Natl Acad. Sci. USA*, 98: 11913–8

Pleasants, J.M., R.L. Hellmich, G.P. Dively, M.K. Sears, D.E. Stanley–Horn, H.R. Mattila, J.E. Foster, T.L. Clark and G.D. Jones, 2001. Corn pollen deposition on milkweeds in and near corn–fields. *Proc. Natl. Acad. Sci. USA*, 98: 11919–24

Peach, C. and J. Velten, 1991. Transgene expression variability (position effect) of CAT and GUS reporter genes driven by linked divergent T–DNA Promoters. *Plant Mol. Biol.*, 17: 49–60

Potrykus, I., 2001. Golden rice and beyond. *Plant Physiol.*, 125: 1157–61

Ramanjulu, S. and D. Bartels, 2002. Drought– and desiccation–induced modulation of gene expression in plants. *Plant Cell Environ.*, 25: 141–51

Rice, W.C., 1999. Specific primers for the detection of *vip*3A insecticidal gene within a *Bacillus thuringiensis* collection. *Letters Appl. Microbiol.*, 28: 378–82

Rissler, J. and M. Mellon, 1996. *The Ecological Risks of Engineered Crops.* The MIT Press, Cambridge, MA.

Schnepf, H.E. and H.R. Whiteley, 1981. Cloning and expression of the *Bacillus thuringiensis* crystal protein gene in *Escherichia coli*. *Proc. Natl. Acad. Sci. USA*, 78: 2893–7

Sears, M.K., R.L. Hellmich, D.E. Stanley–Horn, K.S. Oberhauser, J.M. Pleasants, H.R. Mattila, B.D. Siegfried and G.P. Dively, 2001. Impact of Bt corn pollen on monarch butterfly populations: a risk assessment. *Proc. Natl. Acad. Sci. USA*, 98: 11937–42

Shinozaki, K., K. Yamaguchi–Shinozaki and M. Seki, 2003. Regulatory network of gene expression in the drought and cold stress responses. *Curr. Opin Plant Biol.*, 6: 410–7

Shiva, V. and A.H. Jafri, 2003. Failure of the GMOs in India. Research Foundation for Science, *Technol. Ecol. Rep.*, 2003

Snow, A.A. and P. Palma, 1997. Commercialisation of transgenic plants: potential ecological risks. *BioSci.*, 47: 86–96

Somerville, C., 2000. The genetically modified organism conflict. *Plant Physiol.*, 123: 1201–2

Stanley–Horn, D.E., G.P. Dively, R.L. Hellmich, H.R. Mattila, M.K. Sears, R.R. Laura, C.H. Jesse, J.E. Losey, J.J. Obrycki and L. Lewis, 2001. Assessing the impact of Cry1Ab–expressing corn pollen on monarch butterfly larvae in field studies. *Proc. Natl. Acad. Sci. USA*, 98: 11931–6

Van Frankenhuyzen, K., 1993. The challenge of *Bacillus thuringiensis*. *In:* Cory, J.S., M.J. Bailey and S. Higgs (eds.). *Bacillus thuringiensis*, *An Environmental Biopesticide: Theory and Practice.* pp. 1–35. Entwistle, P.E., John Wiley & Sons, Chichester, UK.

Whalon, M.E. and W.H. McGaughey, 1998. *Bacillus thuringiensis*: use and resistance management. *In*: Ishaaya, I. and D. Degheele (eds.). *Insecticides with Novel Modes of Action: Mechanism and Application*. pp. 106–37. Springer Berlin.

Yeo, E.T., H.B. Kwon, S.E. Han, J.T Lee, J.C. Ryu and M.O. Byu, 2000. Genetic engineering of drought resistant potato plants by introduction of the trehalose–6–phosphate synthase (TPS1) gene from *Saccharomyces cerevisiae*. *Mol. Cells*, 10: 263–8

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