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Global Scenario on Crop Biotechnology: Communication Setting

Von Mark V. Cruz and Randy A. Hautea

Among the many agricultural technologies that have enabled the resilience of societies to numerous challenges related to food, fiber and energy production, biotechnology applications offer the greatest potential in contributing solutions to problems facing agriculture today and in the next decades. Biotechnology applications have resulted in the development of new crop varieties with better adaptation, improved traits, and tremendous impact on production systems. These in turn have helped supply the increasing needs of a growing world population estimated to reach 9 billion by 2050. The broad applications of biotechnology in agriculture, specifically in crops, include the development of disease diagnostic kits, biofertilizers and biopesticides, and the use of molecular markers, tissue culture, and genetic engineering for varietal development (Teng, 2008; Ortiz, 2010).

Addressing food security has been in the headlines in recent times as it is an urgent challenge that should be tackled to avert serious crises in the next decades. Increased productivity from breeding high yielding varieties since the 1960s has contributed to conserving more than 1 billion hectares of land and has delayed or completely averted the use of pristine forest areas for new agricultural lands (Borlaug, 2007). Plant breeding has generated varieties with improved yield and superior crop traits using various methodologies that complement traditional breeding such as marker-assisted selection, chromosome engineering, and genetic engineering (Jauhar, 2006; Tester and Langridge, 2010). These specific technologies contribute to higher genetic gains in breeding and higher rates of return on research and product development investment (Brennan and Martin, 2007; Gosal et al., 2010).

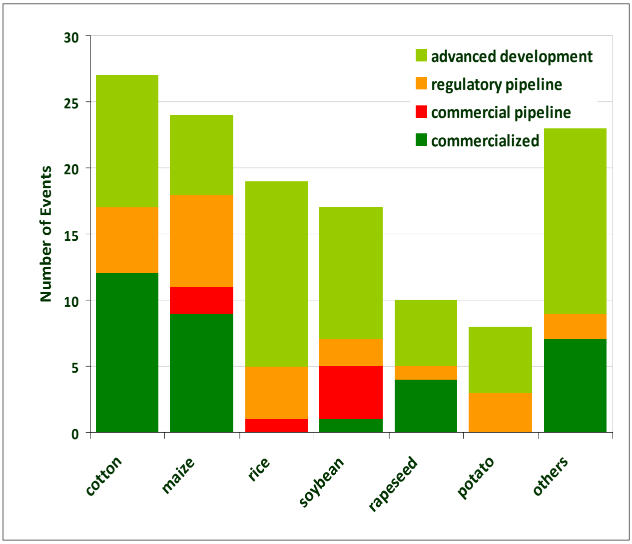
Compared to the 1970s, there are more number and types of crop varieties being released per year in recent decades (Evenson and Gollin, 2003). An analysis of global crop yield, in contrast, indicates the slowdown in crop productivity and yield growth rates for major commodity crops (maize, soybeans, wheat, and rice) during the recent period of 1990-2007 (Alston et al., 2010). This slowdown is attributed to the decreasing support for agricultural research rather than to the inadequacy of ingredient for varietal improvement. A strong correlation between the level of support to agriculture and its impact especially on citizens of developing countries has been hypothesized (Alston et al., 2000; Cervantes-Godoy and Dewbre, 2010). Looking into the future, crop improvement by far still has not fully utilized the enormous collection of plant genetic resources that the different genebanks worldwide assembled and have to offer. With molecular breeding and genomics and the ability to mine these for important traits or parental lines for further breeding, there is still a lot of possibilities and options in developing varieties that will significantly allow greater productivity and address the various challenges in crop production given the current constraints in land and water resources for agriculture (Kumar et al., 2010; Phillips, 2010).

The importance and promise of genetic modification as a component of biotechnology applications should be given attention as a component solution to these challenges. Other solutions also include addressing new pests and diseases and environmental stresses that may seriously affect crops especially the major staples, vegetables, and fruit crops (Anderson, 2010; Edgerton, 2009; Fedoroff et al., 2010). This positive outlook is based on an already documented evidence of biotech crops being able to: increase and make crop yield consistent amidst these biotic and abiotic factors to provide us food and feed for livestock, poultry, and fisheries; help preserve ecosystems and biodiversity; and increase the efficiency of the production of renewable energy (Baulcombe, 2010).

Laboratory Success to Field Deployment of Genetically Modified Crops

Research and development (R&D) activities in genetics in the 1960s eventually paved the way for genetic engineering that now makes possible the introduction of genetic material to a target crop species from the same or different plant species, or in many cases, unrelated organisms. The application of the methodology in crops started only during the 1980s with the success of experiments done in tobacco (Vines, 2002). Several transgenic crops were later developed and commercialized starting in tomato with delayed ripening, then on other agronomic and field crops such as canola, cotton, maize, soybean, sugar beet, papaya, and squash rendering them with traits such as herbicide tolerance, virus and insect resistance. In 2004, it was estimated that more than 50 other species of transgenic fruits, vegetables, field crops, and other plants were under research in the laboratory and confined facilities with a long term goal of eventual commercialization (Runge and Ryan, 2004). A recent estimate hinted that by 2015, there could be additional new biotech crops in the market. It is likely that there will be over 120 different transgenic events in biotech crops worldwide, which is about a four-fold increase in the number of current transgenic events found in commercially cultivated genetically modified (GM) crops (Figure 1). Some promising applications of genetic engineering are also presented in Table 1 which indicates the myriad activities towards some specific goals in crop improvement.

Among the tools of plant breeding, genetic engineering is able to harness, manipulate, and transfer useful genes across very wide taxonomic boundaries. It may also provide additional advantages such as reducing the number of generations of backcrossing to obtain the desired phenotype or



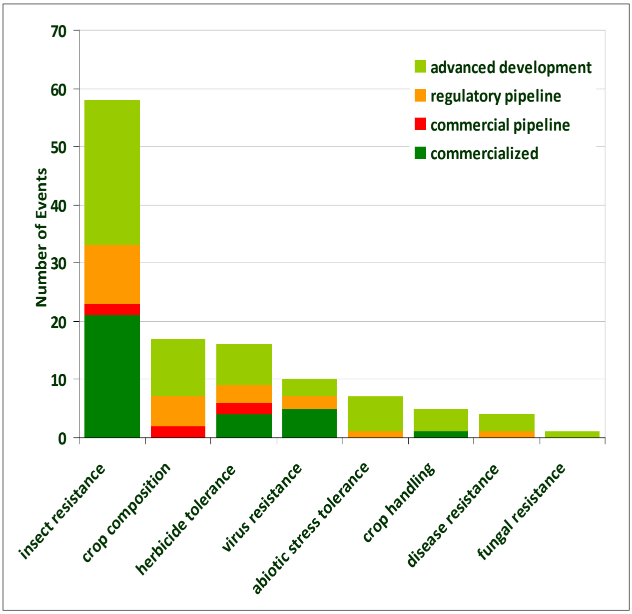


Figure 1. Overview of commercial pipeline of biotech crops to 2015, grouped by crop species (top chart) and by trait (bottom chart)

Note: Species categorized as 'Others' include papaya, eggplant, alfalfa, cabbage, chili, squash, tomato, sugarbeet, sweet pepper, okra, peanuts, and wheat (data from Stein and Rodriguez-Cerezo, 2010)

Table 1. Examples of focal areas of crop biotech research and development towards the next generation of improved crops

Focus	Detail	Reference
Nutritional enhancement and functional foods	Development of crop varieties (such as tomato, potato, cassava, and banana) with enhanced levels of beta-carotene, protein or essential amino acids and minerals	Al-Babili and Beyer, 2005; Gewin, 2003, Datta et al., 2007; Giorio et al., 2007; Lu et al., 2006; Niggeweg et al., 2004; Hirschi, 2009; Beyer, 2010
Abiotic stress tolerance	Biotech approaches to address salt, drought, and extreme temperature tolerance with emphasis on characterizing and testing genes involved in the biosynthesis of osmoprotectants, osmolytes, and temperature sensitive transcription factors	Mitchell, 2007; Cherian et al., 2006; Waterer et al., 2010
Increased digestibility	Development of cereal and oilseed crop varieties with low phytic acid that can help improve human and animal nutrition	Lucca et al., 2001; Shi et al., 2007; Raboy, 2007 and 2009; Spencer et al., 2000
Increased volumes of biomass for biofuel	Applications of biotech on crops not usually utilized or grown as source of food such as poplar, switchgrass, *Miscanthus,* and big bluestem grass	Stewart, 2007; Brumbley et al., 2007; Torney et al., 2007
Better fiber quality	Development of naturally colored cottons or those with improved fiber characteristics	Chen et al., 2007; Xu et al., 2007; Shannguan et al., 2010; Purcell et al., 2010
Flower color and scent modification	Development of flower color variants or ornamental varieties with novel traits such as more fragrant flowers	Potera, 2006; Chandler and Tanaka, 2007; Nishihara and Nakatsuka, 2010
Production of industrial and pharmaceutical compounds	Research on use of biotech plants as a production platform for novel proteins used in industry and medicine	Ventria, 2006; Qian et al., 2008; Lu and Kang, 2008; Sun et al., 2007; Brumbley et al., 2007; Gomez-Galera et al., 2007
Less allergenicity	Silenced expression of genes in carrot, tomato, and peanut to reduce allergenicity in sensitive individuals	Peters et al., 2010; Le et al., 2006; Dodo et al., 2008

Focus	Detail	Reference
Enhanced food flavor and aroma	Identification and genetic engineering of genes involved in aroma biosynthesis in apple and tomato	Davidovich-Rikanati et al., 2007; Schaffer et al., 2007
Phytoremediation	Looking into biotech crops for potential in cleaning up contaminated soils and water systems - development of biotech plants which can detoxify xenobiotic compounds in soils	Banuelos et al., 2007; Eapen et al., 2007; Hong-Bo et al., 2010
Healthier oils	Development of transgenics that can produce oils with higher amounts of omega-3 and omega-6 polyunsaturated fatty acids	Napier, 2006; Damude and Kinney, 2007; McGloughlin, 2010; Ursin, 2003

characteristic; avoiding the so-called linkage drag which is associated with wide hybridizations; and designing new gene configurations and expression patterns for traits of interest (Conner et al., 2007; Ow, 2007a; Ow, 2007b). Various biotechnology approaches to realize further gain and optimize crop yield have been enumerated by Van Camp (2005) and include targeting carbohydrate metabolism, modifying root growth, changing the plant's leaf and stem architecture, and modifying transcriptional complexes involved in plant development. With these myriad possibilities, future obstacles in crop varietal development can be hurdled in conjunction with other methods used in varietal development. At present, the adoption of available biotech crops in the market has been astounding, though not without much issues, examples of which will be mentioned in the latter part of this chapter.

Rapid Adoption of Commercialized GM or Biotech Crops

Since the commercialization of the first transgenic crop 14 years ago, the areas planted to biotech crops have steadily increased through the years. The estimated area of 1.7 million hectares planted to biotech crops in 1996, is now minuscule compared to the current estimate of more than 134 million hectares planted in 25 countries with a market value of more than US$10 billion (Figure 2). About 43% of the global area planted to respective commodity crops in 2009 was biotech. Biotech soybeans accounted for about 51% of the global area of biotech crops, followed by maize (31%), cotton (12%), and canola (5%) (James, 2009). Apart from farmers trusting biotech varieties to warrant repeat planting in successive years, the reported continued increase in adoption suggests increasingly supportive regulatory and legislative climate towards plant biotechnology around the world (CropLife, 2009).

Of the 25 countries planting biotech crops, the United States (U.S.) has continued to be the leader in adoption with a share of around half of global area (48%), while Brazil and Argentina each shares 16%. Within the U.S., biotech crops occupy a very high proportion of areas devoted to the commodity crops – 86% of all domestically grown maize are already biotech, 93% in soybeans, and 93% in cotton (USDA, 2010).

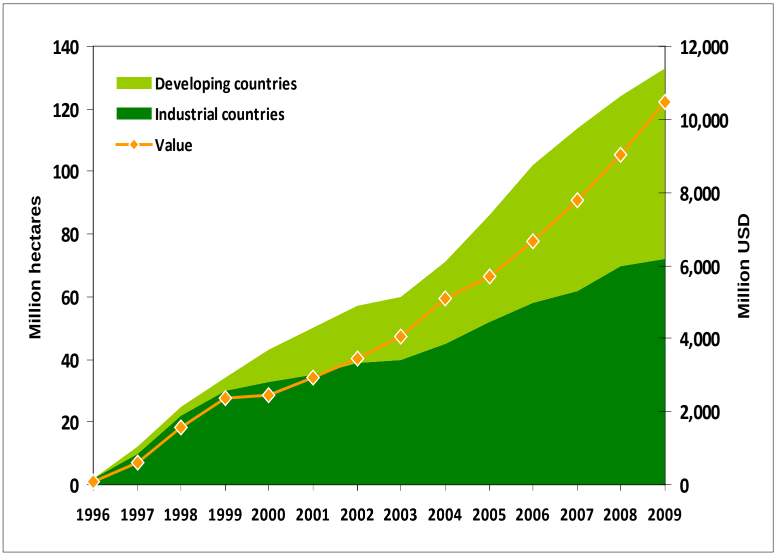


Figure 2. Trend in adoption of biotech crops in industrial and developing countries with corresponding estimated market values (James, 2009)

Of the transgenic traits commercially deployed, herbicide tolerance occupies about 62% of the total global area, followed by stacked traits (combination of one or more transgenes) at 21%, and insect resistance with 16%. Herbicide tolerance conferred to crops by introducing genes from bacterial or plant sources allowed better management of weeds especially in soybean and canola.

Various economic and environmental benefits have been documented from adopting biotech crops. A recent econometric analysis of the global aggregate farm yields has provided empirical evidence that biotech crops do contribute to increasing farm yields having the most impact in developing countries. Using global aggregate data, the average yield gain in all countries was estimated at 65% in cotton, 45% in maize, 25% in rapeseed, and 12% in soybeans (Sexton and Zilberman, 2010). Due to higher effective yields obtained by farmers, a corresponding increase in farm income benefits have totaled to more than US$52 billion since their adoption in 1996 (Brookes and Barfoot, 2010). Transgenics have also been recognized to have the potential to significantly reduce global poverty in 10-30 years (Lipton, 2007). A summary of the benefits from biotech crops from sampled literature is presented in Table 2.

There are now more than 14 million farmers in 25 countries worldwide, of which 11 are developing countries, that are planting biotech crops (James, 2009). In addition to countries that grow biotech crops, there are 15 other countries that have granted regulatory approvals for direct use of biotech crops as food and/or feed (Figure 3). In developing countries, especially those in Asia, research and development activities on genetic engineering have been increasing. This heightened research activity is also evident in the upward trend in the number of Asian publications about genetic transformation research. Analysis of literature statistics covering a 30-year period (1973–2003) revealed that publications on genetic transformation research in Asia is increasing annually at 13.9%, a much higher rate than that of North America (7.1%) and Western Europe (5.3%) (Vain, 2007a). In 2009, China surpassed the U.S. in the cumulative number of biotech publications. Five of the top ten countries publishing the most biotech-related literature are in the Asian region namely China, India, Japan, Taiwan, and Korea (Peng,

Table 2. Basis for each derived benefit from biotech crops

Benefit	Rationale	Reference
Increased well being and lower healthcare costs	Less frequent application of pesticides where misuse can cause severe health problems	Pray and Naseem, 2007; Francisco, 2007; Krishna and Qaim, 2007
Increased effective yield	Reduction of impact by pests, diseases, and other stresses	Sexton and Zilberman, 2010
Lower production costs	Less requirement for pesticides and frequent weeding	Francisco, 2007; Krishna and Qaim, 2007
Reduction of greenhouse gases	Reduced fossil fuel consumption of farm machineries due to fewer agro-chemicals application in addition to probable soil carbon sequestration because of "no till" or '"reduced-till" systems	Brookes and Barfoot, 2010
Reduction of soil erosion	Fewer tractor passes on the field leads to reduction in soil erosion due to wind and water	Pray and Naseem, 2007; Brookes and Barfoot, 2010
Healthier product	Less mycotoxin accumulation in biotech maize kernels due to less stalk and ear rot	Ostry et al., 2010
Higher insect diversity	Transgenic plants are healthier later in the season because of their resistance to pests allowing herbivores to feed on plants where there is less competition for the same resources. Use of broad-spectrum insecticides which can significantly reduce species richness is also avoided.	Arpaia et al., 2007; Cattaneo et al., 2006; Men et al., 2003

2010). Worldwide, there is also an increasing number of publications about food and feed safety assessment and related research on transgenics. This dismisses the proposition that such activities have slowed down in recent years due to the fast adoption of the technology (Vain, 2007b).

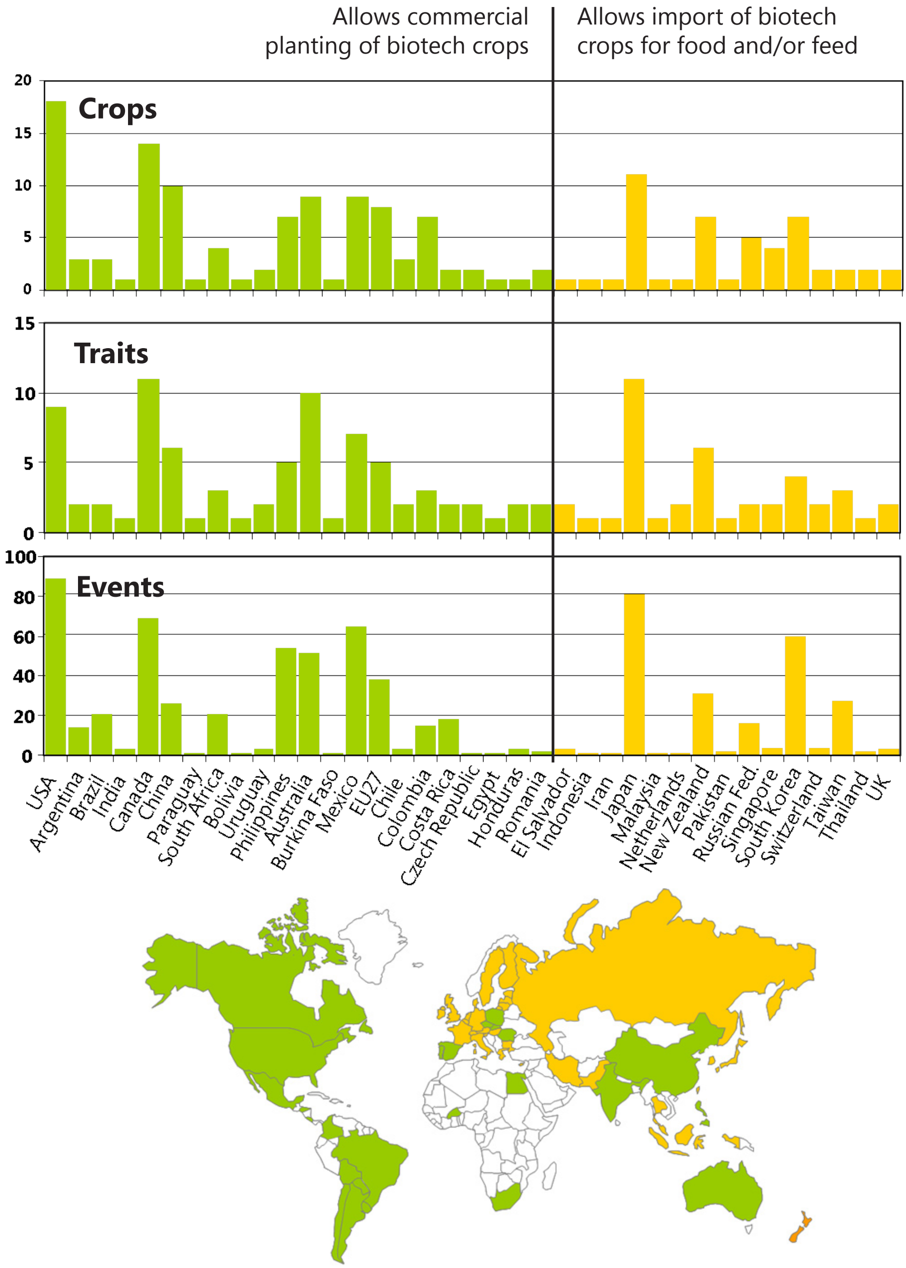


Figure 3. Relative number of approved biotech events, traits, and crop species in countries planting biotech crops and in countries that don't grow them but have granted approval for their direct use as food and/or feed (James, 2009 and CERA, 2010)

Biotech Crops as Part of the Solution to Low Productivity and Undernutrition in Asia and the Pacific

Though many of the countries in the region are emerging economies and a few already touted as economic tigers such as Singapore, Taiwan, China, and South Korea, addressing food security in Asia and the Pacific region remains on top of the list of the United Nations since more than 60% of the world's hungry is in the region. The Food and Agriculture Organization (FAO), the Asian Development Bank (ADB), and the International Fund for Agricultural Development (IFAD) have recently forged an alliance to focus more effort in addressing the hunger issue and build food security throughout the Asia and Pacific (De Vleeschauwer et al., 2010). The role of biotech applications in helping increase food production in the region is very important. Hence, the deployment of crops that address micronutrient deficiencies should be given consideration. Numerous national scientific academies in various countries have already declared their support for the technology (ASSAf, 2010; NAS, 2000). In the Philippines, the National Academy of Science has been very vocal of its optimistic view about the potentials of modern biotechnology in raising crop and livestock productivity as well as preserving natural resources (Panopio and Mercado, 2010). Biotech maize planting in the Philippines accounts for about 24% of the total yellow maize area in the country with estimated economic benefits exceeding US$88 million since it was first commercialized in 2003. It has provided farmers a positive yield advantage between 5-48% compared to traditional varieties (Brookes and Barfoot, 2010; Gonzales, 2007).

The positive view of biotechnology is also similar in Australia, where the Australian Academy of Science highly supports the use of GM technologies in agriculture (Higgins, 2007). In 2010, the first biotech bananas in Australia that contain increased levels of pro-vitamin A and iron have been picked and tested in Queensland (GMO Compass, 2010). Almost 95% of Australia's cotton crop are already biotech and Australian scientists highly perceive that the technology is truly the next 'major' agricultural technology (Peacock, 2010). These statements are paralleled by several governments in the Asia-Pacific such as those of Vietnam and Malaysia where the respective government has committed to allocating resources for developing human capital and advancement in the field (Agbiotech Vietnam, 2006; Ahmand, 2005).

The Asian region is predicted to contribute to a tremendous increase in biotech crop hectarage with biotech rice (James, 2009). China has already approved insect-resistant biotech rice, making the country the first in the world to produce biotech rice on a commercial scale (Waltz, 2010; Xia et al., 2010). There have already been discussions on whether the U.S. can still compete in the future with China's recent agricultural innovations (Sanders et al., 2010; Huang and Wang, 2002). Another event to look forward to, is the upcoming commercialization of the Vitamin A rice or Golden Rice currently under development and in an advanced testing by Asian research institutes in the region. It is expected to help significantly reduce health costs associated with vitamin A deficiency which is prevalent in the region (Qaim, 2009; Stein et al., 2006). At this time, though biotech crops are more than a decade in the market, there is still a need to strongly communicate its benefits as well as its position in augmenting traditional agricultural systems, especially in Asia and the Pacific where its expected impact on food security can be realized. To fully understand the dynamics of public acceptance of the technology as applied to food crops, however, requires a multifaceted analysis considering all stakeholders and not just focusing on consumers (Kalaitzandonakes and Bijman, 2003).

Opportunities Beyond Transgenics

The biosafety regulations put in place to provide assurance on the safety of biotech crops and products have been criticized in a lot of instances to jack up the cost of biotech crop product development and commercialization significantly. For example, it was documented that in the case of Bt maize in the Philippines, the total cost of activities related to regulatory compliance amounts to almost 67% of the total cost of all activities (Manalo and Ramon, 2006). In addition to the cost of regulations, the complex regulatory system may also cause long delays in bringing a product out to market reducing its ability to deliver timely benefits (Rommens et al., 2007; Spielman et al., 2006).

Two new developments in the field of crop breeding may provide alternatives to the current transgenics and may relax the constraints on regulatory hurdles and consumer acceptance of biotech crops. These developments include marker free transformations without linkage drag of antibiotic marker genes, and modern genomics allowing the identification and isolation of existing natural genes from plants, called cisgenes and intragenes (Jacobsen and Schouten, 2007). The use of cisgenes to produce biotech crops may make regulatory approvals as the transformed plants contain gene(s) that are already within the traditional breeders' gene pool and is native to the plant, akin to traditional breeding. Cisgenesis also has been predicted not to raise similar ethical concerns as transgenics because the introduced gene comes from the same or related plant species (Conner et al., 2007; Schouten et al., 2006). Investigations to demonstrate this proof of concept is ongoing in the Netherlands where scientists are now trying to derive durable resistance to *Phytophtora* in potato (Jacobsen and Schouten, 2009).

Various methods of removing marker genes in crops have been reviewed by Lutz and Maliga (2007) and were enumerated to be through: homology-based excision via directly repeated sequences, excision by phage site-specific recombinases, transient cointegration of the marker gene, or the cotransformation-segregation approach. A marker-free high lysine maize, LY038, through site specific recombination method has already received regulatory approval (Ow, 2007a). The use of this technology will likely increase in the future.

Gene Categories Compared

Transgene	Gene from organisms or species other than crossable plants. The source may include microorganisms, animals, or the gene may have been synthesized *in vitro* (xenogene)
Cisgene	Gene already existing in the plant itself or from crossable species. The gene contains all its native components (promoter and terminator regions).
Intragene	Gene coming from the plant or from crossable species. The gene contains natural functional elements and components which could come from other crossable plant species.

Sources: Rommens et al., (2007); Jacobsen and Schouten (2009)

Barriers to Adoption and Applications

Even with the quick uptake of biotech crops as presented in the previous sections, the controversy surrounding them has been plagued with popular misinformation and complicated by the topic which is often hard to grasp by laymen and majority of consumers. McHughen and Wager (2010) enumerated the examples of popular misconceptions about biotech crops as well as refuted respective concerns. Two examples of such misconceptions include genetic modification as unnatural, and that the presence of any biotech crop material is detrimental to the organic status of crops among others.

These beliefs could become the basis of bad policy affecting majority of the population if allowed to perpetuate. An example is the rejection of Zambia of food aid during famine on the ground that the aid contains biotech maize which was perceived not to be safe for consumption (Bohannon, 2002). Another one is the rejection of the commercial planting of Bt eggplant in India by the country's environment minister overturning a national regulatory panel's decision on its safety (Bagla, 2010; Shantharam, 2010).

Several political and cultural barriers are also evident in expanding the applications of biotech crops and their benefits to countries in Africa and Europe. Even with complete regulatory framework existing in those countries, it may prove to be an excessively expensive and a lengthy process to get a biotech crop approved for cultivation and use. Cost is a very important determining factor in participation of public institutions in such endeavors (Fedoroff, 2010; Beyer et al., 2010). Thus, it is important that planning realistic targets be done before immersing in crop biotech research and development activities, especially in developing countries (Cohen and Komen, 1995; Rommens, 2010). Other factors include the discordant regulations pertaining to international trade of biotech products and the position vis-à-vis organic crops in developing countries or specifically just dealing with transgenic crop products (Kershen, 2010; Ramessar et al., 2010). The trade offs between biotech and organic crops have been previously reviewed and the role of biotech crops has been noted as very useful in providing resource as the world population rapidly surges in the coming decade (Azadi and Ho, 2010). Others suggested the important role of integrated farming where organic farmers use transgenic crops within an ecological concept (Ammann, 2008; USDA, 2009; Ronald and Adamchak, 2008).

In all aspects, the decisions and procedures on biotech crops should be science-based, thus, correct background knowledge and adequate education for stakeholders are necessary (Ortiz, 2010; Arundel and Sawaya, 2009; Navarro et al., 2006). The role of media as well as extension agencies in portraying the benefits from the technology and the positive experiences gathered during the 14 years of commercial planting will help a lot in its uptake. This can help shape a better public perception allowing future products to reach the end users without lag. Collaborative activities among multidisciplinary teams that work closely with various stakeholder groups should also be beneficial (Rommens, 2010).

Summary

The future of crop biotechnology and the development of next generation biotech products will no doubt rely on activities in various fields such as genomics and bioinformatics. These will help unravel the interaction of genes and metabolic pathways leading to traits of interest. A favorable policy atmosphere for commercialization will likewise be critical.

The continuous delivery of benefits to consumers in terms of economic and environmental impacts will influence the increase in adoption and further acceptance of the technology as a complement to existing methods in providing our necessities. There are still tremendous opportunities in the near and long term. The numerous products in the pipeline indicate a sustained interest and investment on research and development to test and commercialize new concepts and applications of genetic modification on food and fiber production and related issues on nutrition and bioenergy.

The next generation biotech crops with superior traits, improved properties, and quality traits will likely be created and deployed in developing countries, particularly in Asia, where half of the world’s population dwells. It is important to be persistent in communicating and disseminating accurate information about the direct or indirect risks and benefits of the commercial products of next generation biotech crops and to encourage a balanced discussion on issues surrounding the products and the technology. Polarized positions on transgenics in the past and a biased view on the applications of biotechnology to crops clearly did not contribute in conserving capital and human resources.

Research and development efforts escalating in developing countries indicate the slight shift of such countries from just being end markets to being developers. The aggregate adoption of biotech crops in developing countries is clearly approaching that in developed countries. There is no doubt that locally developed products may garner higher consumer acceptance as they are tailored to specifically address local or regional concerns. Eventually, the next generation crops will contribute to poverty and hunger reduction and help attain global food, feed, fiber, and energy security in conjuction with other farming and agricultural methodologies.

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