PERSPECTIVE
GM Crops and Food: Biotechnology in Agriculture and the Food Chain 4:1, 1-9; January/February/March 2013; © 2013 Landes Bioscience

Biotech crops

Imperative for achieving the Millenium Development Goals and sustainability of agriculture in the climate change era

Amjad M. Husaini[1,*] and Narendra Tuteja[2]

[1]Centre for Plant Biotechnology; Division of Biotechnology; Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir; Jammu and Kashmir, India; [2]Plant Molecular Biology Group; International Centre for Genetic Engineering and Biotechnology; New Delhi, India

Keywords: agriculture, climate, drought, Millennium Development Goals, stress, temperature, mitigation, resilience

Submitted: 07/04/12

Revised: 10/28/12

Accepted: 11/01/12

http://dx.doi.org/10.4161/gmc.22748

*Correspondence to: Amjad M. Husaini; Email: amjadhusaini@yahoo.com

Biotechnological intervention in the development of crops has opened new vistas in agriculture. Central to the accomplishment of the Millennium Development Goals (MDGs), biotech-agriculture is essential in meeting these targets. Biotech crops have already made modest contributions toward ensuring food and nutrition security by reducing losses and increasing productivity, with less pesticide input. These crops could help address some of the major challenges in agriculture-based economies created by climate change. Projections of global climate change expect the concentration of greenhouse gases to increase, aridization of the environment to increase, temperature fluctuations to occur sharply and frequently, and spatial and temporal distribution of rainfall to be disturbed—all of which will increase abiotic stress-related challenges to crops. Countering these challenges and to meet the food requirement of the ever-increasing world population (expected to reach 9 billion by 2030) we need to (1) develop and use biotech crops for mitigating adverse climatic changes; (2) develop biotech crops resilient to adverse environmental conditions; and (3) address the issues/non-issues raised by NGO's and educate the masses about the benefits of biotech crops.

Introduction

In 1800 the global population was less than 1 billion and it was reasonably simple to increase food production over the following 100 y to feed the growth in population, another 0.6 billion, by increasing the area of land under cultivation. Agricultural practices were extended into new productive areas: the prairies of North America, the pampas of South America, the steppes of Eastern Europe and Russia and the outback of Australia. In 1900 the world's population was 1.6 billion and an increase in global food production over the following century was achieved mainly by radically increasing crop productivity through a "green revolution." Large-scale mechanization and an increase in the use of fossil fuel-based ammonium fertilizers were the prime catalysts. In the current century, the global population has reached 6.1 billion and is estimated to be 9 billion by 2030. The task of providing nutrient-rich food to such a large population is more challenging. Food must be grown "sustainably" on approximately the same amount of arable land using less resources and despite the enormous, new challenges associated with climate change. For the first time in the history of the world, we face a daunting humanitarian need to alleviate poverty, hunger and malnutrition that afflicts more than 1 billion people.

To meet this challenge, the Millennium Development Goals (MDGs) were framed at the turn of the 21st century—when the world economy was dynamic and the benefits of globalization were to be shared with the poor to help alleviate poverty, hunger and malnutrition. The severe impact of climate change, the global financial crises of 2008 and 2011 and soaring food and fuel prices, however, have swung the pendulum of the economy to the opposite extreme. In the future, the situation will continue to be grim as food prices may rise substantially with an increased population, severe land and water constraints, an increase in demand for biofuels and climate change.[1-3] Besides leading to substantial increase in food prices[4] these factors will have adverse implications for poverty, too.[5] The MDG1C target to "reduce by half the proportion of people who suffer from hunger," is already among the worst performing of all MDG targets, with more than 1 billion people undernourished in 2009.[6] Failure to tackle hunger and under-nutrition has jeopardized the achievement of other MDGs, specifically MDG2 (achieve universal primary education), MDG3 (promote gender equality), MDG4 (reduce child mortality), and MDGs 5 and 6 (improve health). A Synthesis Report from the United Nations Development Programme (UNDP), assembled the knowledge from countries working toward achieving the MDGs over the past decade and summarized the bottlenecks that hampered the accomplishment of MDGs as (1) a surge in food and fuel prices, (2) climate change and (3) global financial crises.[7]

Agriculture is central in the global battle against poverty. This sector can reduce poverty, particularly among the poorest of the poor, more effectively than the non-agricultural sector. It is estimated that the farming sector is up to 3.2 × better than the non-agricultural sector at reducing the $1 a day poverty headcount ratio in low-income and resource-rich countries.[8] The dominant role of agriculture in poverty reduction occurs via a variety of interactions: the farming sector primarily supplies both rural and urban areas with food while making available surplus savings and labor for promoting industrialization. Rural production and consumption links emerge from the utilization of agricultural output as input to the industrial sector and from the demand for inputs that are generated by agriculture. The importance of small-scale farmers in this sector is also significant and cannot be overlooked. About 2 billion people, one-third of the global population, belong to farming households that cultivate less than 2 ha of land each. These smallholders, many of them women, constitute over 85% of the world's farmers, and a majority of the poor and food insecure. The failure of this population in securing adequate livelihood in their birthplace leads to rural-urban migration and an escalation in the number of urban poor. Enhancing the productivity of these smallholders' farms (and improving their livelihoods) is thus central to any solution for hunger and poverty.

Climate change is an additional challenge to sustainable agriculture, threatening not only to undo efforts made to meet the targets of the MDGs, but also to destabilize the food production system.[6] About 1.8 billion people are expected to suffer from the scarcity of fresh water by 2025, mostly in Asia and Africa. In June 2008, the Food and Agricultural Organization (FAO), together with the International Fund for Agricultural Development (IFAD), the United Nations World Food Programme (WFP) and the Consultative Group on International Agricultural Research (CGIAR) system, convened the "High-Level Conference on World Food Security: the Challenges of Climate Change and Bioenergy." One hundred and 81 countries adopted the declaration that "It is essential to address the question of how to increase the resilience of present food production systems to challenges posed by climate change" (www.fao.org/foodclimate).[9]

Impact of Climate Change

Predicting the precise impact of climate change on a crop across all current areas of cultivation is complex and perhaps impossible. Nevertheless, impact can be predicted in general terms and global climate change will alter many elements of the future crop production environment. Atmospheric carbon dioxide (CO_2) concentration, average temperature and tropospheric ozone (O_3) concentration will be higher, droughts will be more frequent and severe, more intense precipitation events will lead to increased flooding, some soils will degrade and climactic extremes will be more likely to occur.[10] Climate change will have an impact on land degradation, leading to water logging, soil salinity and development of sodicity in vulnerable areas of the world. Inter-seasonal climactic variability (mainly temperature and rainfall) may influence crop production and food security.[11]

In the past decade climate change and environmental degradation have led to increased desertification, soil contamination and depletion. This kind of environmental degradation and the exhaustion of natural resources, such as forests and fertile agricultural land, constitute critical obstacles affecting sustainability of agriculture production systems and the accomplishment of the MDGs.[6] Drought ranks among the most serious problems—61% of the globe has precipitation lower than 500 mm annually.[12] For agricultural systems, water is supplied through irrigation to 17% of global cropland, contributing 40% of global food production.[13] Most of global irrigation water is used in Asia, and therefore it is in this region that urgent consideration of change in water resources is most needed. For example, much of the irrigation water in India and Pakistan originates from Himalayan glaciers. These glaciers are rapidly melting and their summer streamflow may be significantly reduced within a few decades.[14-16] Generally speaking, the most drought-vulnerable parts of our planet are the regions between 15° and 30° of the northern and southern latitudes, the localities on the lee side of mountains and areas situated deep inland— where up to one-sixth of the world's population can be adversely affected by an acute shortage of water.[17] The annual average temperatures show an upward trend and evapotranspiration requirements for water are growing. Periods without water are becoming longer; thus, plants often suffer from water shortage.[18]

"Green biotechnology" offers environment-friendly solutions for agriculture, horticulture and plant breeding processes.[19] Over the past ten years, research investment in plants' response to drought and heat increased significantly, and much of this investment is driven by the private sector in high value crops such as maize.[20] Since rice is a staple food in Asia and is cultivated under irrigated conditions, the International Rice Research Institute (IRRI) launched important and visionary research for developing drought tolerance in rice. A project to scale-up the detection, analysis and delivery of genes for use in marker-aided breeding is under progress.[21] This comprehensive rice research and breeding program aims at making rice more tolerant of submergence, drought, heat and salinity—all conditions predicted to increase in frequency and severity with climate change.

Rise in temperature is likely to increase the water requirement of crops due to high evaporative demand. In India an analysis of data for 47 stations across the country for more than 50 y revealed that 75, 60 and 54% of the stations in south, east and central India, respectively, showed an increasing trend in maximum temperature, while 80, 78 and 75% of the stations in east, north and south, respectively, showed increasing trends in the minimum temperature, as well.[22] The European Commission's Directorate General for Agriculture published a working document in April, 2009 on "Adaption to Climate Change: the Challenge for European Agriculture and Rural Areas," outlines that high water-stress areas are expected to increase from 19% to 35% by 2070, implying "significant changes in the quality and availability of water resources" (http://ec.europa.eu/agriculture/index_en.htm). This could have a damaging impact on food security and in developing countries would contribute to a downward spiral of poverty and poor nutrition. Water deficit/drought usually causes inhibition of transpiration, because of which plants fail to dissipate heat and heat stress can thus ensue.[23] Rising temperatures and desertification are likely to reduce the land area available for farming.

Biotech Crops: Contributing to Food, Nutrition and Livelihood Security

Biotech crops offer an opportunity to increase yields, ensuring food security and improving the micronutrient content of foods, therefore contributing to the achievement of nutrition security, as well. These crops have made a modest contribution, and have the potential to continue to contribute to some of the major challenges facing global society, including: food self-sufficiency and security, more affordable and nutritious food, sustainability, alleviation of poverty and hunger. Additionally, biotech crops can mitigate some of the challenges associated with climate change and global warming. The foremost example is the incorporation of semi-dwarf genes, creating the modern high-yielding varieties that began with the release of IR8 40 y ago, spurring the green revolution in rice.[21]

In the past decade, the advent of 'Golden Rice' created through the use of modern genetic engineering, was a major advance. It involved the transfer of genes necessary for the accumulation of carotenoids (vitamin A precursors) in the rice endosperm. The endosperm of rice does not contain any provitamin A and the genes coding it are not available in the rice gene pool.[24,25] The best provitamin A line had 85% of its carotenoids as β-carotene, while other lines had less β-carotene and high lutein and zeaxanthin, both substances of nutritional importance.[24] The first generation of Golden Rice drew considerable criticism, with opponents arguing that Golden Rice would encourage people to rely on a single food rather than promote dietary diversification. Critics also pointed out that a normal serving of Golden Rice contained only a small fraction of the recommended daily allowance (RDA) of β-carotene. However, the development of Golden Rice 2, replacing the daffodil gene with an equivalent gene from maize (*Zea mays*), increased the amount of β-carotene by about 20-fold. As a result, about 140 g of the rice provide a child's RDA for β-carotene.[26] It has also been demonstrated that β-carotene from Golden Rice is efficiently converted to vitamin A in humans.[27] It is well recognized that vitamin A deficiency indirectly interferes with iron (Fe) resorption, and an effort to increase the availability of Fe in the rice endosperm by expressing a ferritin gene from *Phaseolus* resulted in a 2.5-fold increase in Fe content of the endosperm.[28] New transgenic plants aimed at combining the genes for Fe availability and absorption with the provitamin A genes by crossing are under development.[29,30]

Another notable example of biotech crops genetically-engineered for increased productivity by controlling major insect pests and imparting herbicide tolerance, is maize. Traits such as high lysine content, amylase enzyme, phytase enzyme (nutritional enhancement) are explored and incorporated in maize to make it commercial.[31] Recently, the genetically-modified maize, "SmartStax™," received registration from the United States Environmental Protection Agency (EPA) and regulatory authorization from the Canadian Food Inspection Agency (CFIA).[32] SmartStax™ is a multiple-trait product based on a total of 8 genes (cry2Ab, cry1A.105, cry1F, cry3Bb1, cry34, cry35Ab1, cp4 and bar), and is the most advanced stacked biotech crop currently approved. It is designed to provide the most comprehensive insect pest control in maize (both above and below ground), in addition to herbicide tolerance for weed control. Doubled haploid (DH) techniques to rapidly develop inbred lines is another area of widespread commercial interest in maize.[33-35] DHs are increasingly attractive to develop better inducer lines, more efficient chromosome doubling and efficient introgression of transgenes, especially stacked transgenes.

Transgenic technology helps reduce the amount of ploughing required before planting crops and therefore helps retain soil moisture. Under drought conditions this can mean the difference between having a crop to harvest and crop failure. With the entry of its drought-tolerant maize in the regulatory phase of development, the United States has taken the lead in this direction, demonstrating that a GM solution to this important issue is well beyond the theoretical stage. The Water Efficient Maize for Africa (WEMA) partnership, led by the African Agriculture Technology Foundation (AATF) is another example where the main aim is to develop new African drought-tolerant maize varieties with the best technology available internationally (*www.aatf-africa.org/wema*). China faces the onerous task of feeding a fifth of the world's population with less than a tenth of global farmland. Confronted with land degradation, chronic water shortages and a growing population that already numbers 1.3 billion, China announced investment of $3.5 billion in research and development of GM plants.[36] Recently, China completed approval of three key biotech crops:

(1) Bt cotton (Fiber), (2) Phytase maize (Feed) and (3) Bt rice (Food). China has successfully grown Bt cotton since 1997, increasing the income of over 7 million small farmers by approximately US$220 per hectare (annually equivalent to US$1 billion nationally), with a 10% increase in yield and a 60% reduction in insecticides, both of which contribute to more sustainable agriculture and prosperity.[32] After the United States, China is the second largest grower of maize in the world (30 million hectares grown by 100 million households). It is principally used to feed China's swine herd of over 500 million (the largest in the world), and 13 billion poultry birds. Phytase maize allows pigs to digest more phosphorus, resulting in faster growth and meat production, and reduces phosphate pollution from animal waste into soil and bodies of water. With economic progress in China, more meat is consumed, which in turn requires significantly more animal feed, of which maize is a principal source. Similarly, Bt rice offers the potential to generate benefits of around US$4 billion annually from an average yield increase of up to 8%, and an 80% decrease in insecticides. China is the biggest producer of rice in the world (178 million tons of paddy) with 110 million rice households (440 million people, assuming 4 per family) who could benefit directly as farmers.

Following these consistent, and substantial, economic, environmental and welfare benefits generated from biotech crops over the past 16 y (1996 to 2011), millions of large, small and resource-poor farmers in both industrial and developing countries continue to plant more hectares of biotech crops than ever before. The economic gains at the farm level were approximately US$78 billion generated globally by biotech crops between 1996 and 2010, of which 40% is due to reduced production costs (less ploughing, less pesticide spray, less labor) and 60% is due to a yield gain of about 276 million tons.[37] A total of 16.7 million farmers grew biotech crops in 2011, of which 15 million or 90% were small resource-poor farmers from developing countries. In 2011 more than 82% of the 30 million hectares of cotton grown globally were biotech; for soybean almost 75% of the 100 million hectares were biotech; for maize 32% of the 159 million hectares grown globally were biotech; and finally, for canola, 26% of the 31 million hectares were biotech.[38] For the period 1996–2010, the total crop production gain globally for these four principal biotech crops is 276 million tons. This would have required 91 million additional hectares had biotech crops not been used. Additionally, there is a reduction in pesticide usage of about 9.1% for the period, amounting to 443 million kilograms of active ingredient.[37]

Biotech Crops to Moderate Some Adverse Effects of Climate Change

International treaties and national policies seek to enhance global efforts to mitigate and adapt to climate change. From the middle of the 19th century to the present, the concentration of CO_2 in the atmosphere increased from 270 $\mu l\ CO_2\ l^{-1}$ to the present 400 $\mu l\ CO_2\ l^{-1}$. This is expected to further rise to 500 $\mu l\ CO_2\ l^{-1}$ in the following decades.[18,39-41] With respect to CO_2 emissions, the rate of growth of CO_2-equivalent emissions was much higher during the period of 1995–2004 than during the previous period of 1970–1994. The global trend has not changed thus far.[22] The IPCC reported that 11 of the 12 y between 1995 and 2006 rank among the 12 warmest years of recorded global surface temperature (since 1850).[9]

It has long been recognized that agriculture is a significant contributor to global greenhouse gas emissions, in terms of CO_2 and, especially, methane and nitrous oxide.[42] Implementing sustainable agricultural practices is therefore now more important than ever before. Various initiatives under the umbrella of "green biotechnology" offer to decrease greenhouse gases and reduce some of the adverse effects of climate change by giving farmers opportunities to use less (and environment-friendly) energy, increase carbon sequestration and reduce fertilizer usage.[19] These involve mitigation measures like (1) decreased fuel consumption by developing herbicide resistant crops for reduced tillage[43-45] and insect resistant crops for reduced spraying;[46-48] (2) reduced artificial fertilizer use by engineering crops with high nitrogen use efficiency;[49-52] and (3) carbon sequestration by biotech crops suitable for no-till farming.[43,45]

Modern biotechnology can help develop plant varieties that are better adapted to farm management practices such as "reduced tillage" or "no tillage," which are beneficial for growing crops in water-limited environments. Weed control becomes a problem with dry sowing/reduced tillage, but GM crops tolerant to broad spectrum herbicides have enabled farmers to adopt these practices and to meet new weed management issues in a changing climate. Adoption of "zero tillage," GM herbicide tolerant crops and GM insect resistant crops directly reduces on-farm operations, in turn reducing fuel use and lowers CO_2 emissions.[43] Brookes and Barfoot[53] indicate that each liter of tractor diesel consumed adds 2.75 kg of CO_2 into the atmosphere. Therefore, the fuel savings associated with making fewer spray runs (relative to conventional crops) resulted in permanent cuts in CO_2 emissions. From 1996 to 2008, the cumulative permanent reduction in fuel use was estimated at 8,632 million kg of CO_2 (arising from a reduction of 3,139 million liters of fuel). A reduction of 1,205 million kg of CO_2 (arising from a reduction of 534 million liters of fuel) was recorded in 2008 alone.

In addition to reducing carbon emissions by reducing fuel consumption, GM technology can aid in carbon sequestration too. Increasing carbon sequestration in agricultural soils can be achieved by maximizing the amount of carbon delivered to the soil and increasing the time during which carbon stays in the soil. Strategies include developing plant varieties through biotechnology that have increased photosynthetic efficiency, increased lignin content, improved pest and disease resistance, deeper roots and improved water use and nutrient efficiency.[54] The adoption of no-till farming practices also helps increase carbon sequestration.[55,56] According to Brookes and Barfoot,[53] the additional amount of soil carbon sequestered since 1996 due to the adoption of GM crops is equivalent to 101,613 million tons of CO_2 which would otherwise have been released into the atmosphere. These soil carbon savings arise from the rapid adoption of new farming systems in North and South America, for which the availability of GM herbicide tolerant technology is cited by many farmers as an important facilitator. Genetically-modified Roundup Ready™ (herbicide resistant) soybean technology has accounted for up to 95% of no-till area in the United States and Argentina.[43-45]

Reduced fertilizer use and N_2O emissions are an additional result of GM technology. Nitrogen fertilizer accounts for one-third of the greenhouse gases produced by agriculture. Nitrous oxide (N_2O) has 296 times greater global warming potential (GWP) than CO_2 and stays in the atmosphere for more than 100 y.[57] GM rice and canola that use nitrogen more efficiently are developed to need less fertilizer and thus reduce the amount of nitrogen fertilizer lost into the air, soil and waterways (http://www.arcadiabio.com/nitrogen.php). In addition to the environmental impact, farmer's input costs are reduced and profit increased.[19]

Designing Biotech Crops with Resilience to Some Adverse Effects of Climate Change

While it is important to continue striving for reducing greenhouse gas emissions, reduction alone is not enough. It is equally important to design evolving, resilient, holistic and secure food systems that can adapt to climate change and other stress factors. Plants require carbon dioxide, sunlight, water, a given temperature range, and nutrients to germinate, grow and reproduce. Of these five primary environmental factors that are critical for plants, four are related to climate: carbon dioxide, light, temperature and water. They vary spatially, diurnally and seasonally but also, in the climate change context, over longer time periods. It is therefore important to keep these four factors in mind while designing plants resilient to climate change. Broadly, the traits important for plants adapting to climate change, include heat tolerance, drought tolerance, water-use efficiency, nitrogen-use efficiency, early vigor, water-logging tolerance, salinity tolerance, frost resistance, pest and disease resistance and reduced dependence on low temperatures to trigger flowering or seed germination.[56,58-66] Genetic modification techniques provide access to a greatly increased diversity of genes for developing plant varieties with these traits. A recent major advance has been the release of IRRI's submergence-tolerant rice with *SUB 1A* gene that can produce good yields even after two weeks under water, conditions that would devastate most other types of rice. Progress is also underway to develop "C4" rice that could yield up to 50% more grain than currently possible from existing rice varieties. It would be vastly more water- and nutrient-efficient (IRRI 2009 Annual Report; www.irri.org). A "thermometer gene" that not only helps plants feel the temperature rise, but also coordinates an appropriate response has recently been discovered in Arabidopsis.[67] The researchers showed that the key ingredient for plants' temperature-sensing ability is a specialized histone protein (H2A.Z) that binds the plant's DNA tightly at lower temperatures, thus preventing gene expression; when the temperature rises it loses its grip and drops off the DNA.

As discussed with climate change conditions crop plants would often experience more than one biotic and abiotic stress.[68] Our long-term strategy should be to develop technologies for creating "weather-proof" biotech crops. Transgenes that enhance product quality or promote various forms of abiotic stress tolerance (e.g., drought, cold, salinity, submergence and heat stress) predominate among the new traits being developed by the large multinational companies (http://www.isb.vt.edu/cfdocs/fieldtests1.cfm). However, at present we have a limited choice of genes that can be employed to develop biotech crops resilient to high or low temperatures, water scarcity and salinity.

There are several categories of stress-induced genes/proteins with known functions that can be exploited for generating transgenic plants resilient to climate change. These genes can be classified into the following six groups: (1) transgenes involved in osmolyte biosynthesis; (2) transgenes encoding factors for protection of cellular machinery; (3) transgenes encoding membrane proteins; (4) transgenes encoding ROS scavenger proteins; (5) transgenes encoding transcription factors; and (6) transgenes encoding protein kinases.

Transgenes encoding ROS scavenger proteins, transcription factors and those encoding protein kinases are the most suitable as these confer an adaptive advantage to transgenics with respect to multiple stresses.[69] For example, overexpression of genes leading to increased amounts and activities of mitochondrial Mn-SOD, Fe-SOD, chloroplastic Cu/Zn-SOD, bacterial catalase and glutathione-S-transferase (GST)/glutathione peroxidise (GPX) increase the performance of plants under stress.[70-75] Transgenic plants overexpressing ROS-scavenging enzymes such as SOD,[76] ascorbate peroxidase (APX),[77] and glutathione S-transferase/glutathione peroxidase (GST/GPX)[75,78] show increased tolerance to osmotic, temperature and oxidative stress. The overexpression of the tobacco *NtGST/GPX* gene in transgenic tobacco plants improves salt and chilling stress tolerance because of enhanced ROS scavenging and prevention of membrane damage.[75,78] Transgenic tobacco plants overexpressing *AtAPX* targeted to the chloroplasts show enhanced tolerance to salinity and oxidative stress.[79]

Dozens of transcription factors are involved in the plant response to drought stress.[80,81] Stress tolerance is a complex trait and unlikely to be under a single-gene control. There are some major families of transcription factors that act under the influence of ethylene, jasmonic acid, salicylic acid and other phytohormones conferring abiotic stress tolerance. One important way of achieving tolerance to multiple stress conditions is to overexpress transcription factor genes that control multiple genes from various pathways, viz., ethylene responsive element binding proteins (EREBP) and dehydration-responsive-element binding proteins (*DREB*s) or CBFs (C-repeat binding proteins). Similarly, transgenes encoding protein kinases like Mitogen Activated Protein Kinases (MAPKs) can also be used for developing climate resilient plants as salt stress triggers the activation and enhances gene expression of MAPK signaling cascades, common for both salt and ROS.[82,83]

The Regulatory Regime for Biotech Crops

Despite the availability of promising research results, many applications of biotechnology have not met their full potential to deliver practical solutions to end users in developing countries.[84] These applications have remained confined to the research laboratories and have not translated into technologies at the farm. For example, genetically-modified beneficial crops with agronomic traits like enhanced drought tolerance, salt tolerance and insect resistance, developed by publicly funded research, have not reached end users because of the extremely high cost of regulatory compliance. It is estimated that it costs up to US$20 million to gain commercial certification of a single GM crop.[85] As a result, these biotech crops which would help the poor are not commercialized. Even Golden Rice, the most acclaimed consumer-oriented biotech crop, has suffered from the bio-politics of GM crops, with unnecessary delay in its release to farmers. Besides political, socioeconomic, cultural and ethical concerns about modern biotech crops related to the fear of technological "neo-colonialism" in developing countries, intellectual property rights, land ownership, customer choices, negative cultural and religious perceptions, and fear of the unknown have impeded the spread of these crops.[86] Such public concerns fueled and supported by vested interests have led to the over-regulation of this technology, threatening to retard its applications in agriculture as discussed above.[87] Although North America has largely adopted biotech crops, Europe is still sceptical. It is not the difference of "scientific" opinion that has hindered large scale acceptance of biotech crops in Europe,[88] but the prejudiced campaign by vested interests and NGO's. For example, a statement made to the British House of Lords by Lord Melchett, then head of Greenpeace, made it clear that Greenpeace remains opposed to GM crops "regardless of any scientific safety evaluations."[89,90] However, in a report in 2001, the European Commission confirmed the safety of GM crops and food, after painstaking "research spanning 15 y and involving 81 projects with 400 scientists." The report concluded: "GM plants [...] have not shown any new risks to human health or the environment, beyond the usual uncertainties of conventional plant breeding. Indeed, the use of more precise technology and greater regulatory scrutiny probably make them safer than conventional plants and food."[91] The International Council for Science in France, probably the world's largest scientific group representing most National Academies of Science and about 150 scientific organizations, published an extensive report on the health and environmental risks of GM crops and food.[92] According to the report "there is no evidence of any ill effects from the consumption of foods containing genetically modified ingredients. […] There are also benefits [for example, vitamin content of rice] to human health coming from GM foods; […] Pest tolerant crops can be grown with lower levels of chemical pesticides, resulting in reduced chemical residues in food and less exposure to pesticides." This report further notes that, "there is no evidence of any deleterious environmental effects having occurred from the trait/species combinations currently available."[92]

Genetically Modified Organisms (GMOs), as defined by the European Union Directive 2001/18/EC, are organisms "in which the genetic material has been altered in a way that does not occur naturally by mating and/or natural recombination" while the non-GM "Upgraded Crops" are those created without the use of genetic modification as defined by Directive 2001/18/EC but do permit the use of induced mutagenesis or embryo rescue to facilitate intraspecific crossing that would not occur naturally. In the former, strict environmental risk assessment is a pre-requisite for release while for equivalent trait in the non-GM upgraded crop no such clause is applicable. To illustrate, one example of currently available upgraded non-GM varieties with similar characteristics to GM crops are the herbicide-resistant (HR) CLEARFIELD™ crops developed by BASF. This trait is heritable and potentially transmissible through pollen to adjacent crops, but since these HR crops have been developed using mutagenesis and/or traditional breeding methods and contain no introduced genetic material these are not covered by Directive 2001/18/EC (http://www.agriculturalproducts.basf.com). However considering that risk can be measured by Hazard × Outrage,[93] since the European public has not developed a sense of outrage toward "upgraded HR" crops (rice, maize, oilseed rape and sunflower) these crops are considered "safe."

Conclusion and Future Perspectives

Agriculture is central to human welfare and the accomplishment of the Millennium Development Goals. However, the negative effect of climate change on agriculture is a constraint to achieving the MDGs, while agricultural activity, in itself, contributes to climate change directly through emission of greenhouse gases (25% emissions are contributed by agriculture) and indirectly through on-farm operations involving use of fossil fuels. A heavy dependence on chemical pesticides and fertilizers leads to toxification of water bodies, sometimes with a direct negative impact on human health and other serious environmental issues, both of which are connected to the MDGs. As such, major reductions in emissions of these gases from agricultural activities could contribute to climate change mitigation and biotech crops show promising potential in this area. Using biotech crops, agronomic practices that increase carbon sequestration can be easily adopted to render additional benefits, such as increased root biomass, soil organic matter, water and nutrient retention capacity and, overall, increased land productivity. Enhancing carbon sequestration in degraded drylands and mountain slopes by planting such transgenic plants could have direct environmental, economic and social benefits for local people, with consequent improvement in their livelihood and food security status. Cultivation of biotech crops with "engineered disease tolerance," adoption of resource conservation technology like 'zero tillage' could reduce fuel consumption for on-farm operations and reducing the cost of crop production. Planting biotech crops tolerant to pests, and with increased nitrogen use efficiency, could reduce the input of chemical pesticides and fertilizers, thus "tending towards" organic farming which may not be practical on a large scale due to a limited supply of organic inputs for agriculture. Many supporters of the "organic movement" scoff at transgenic culture and recommend that synthetic fertilizer be replaced entirely with manure and legumes. This option, however, is problematic since livestock animals are a major contributor of greenhouse gases, more so than the transportation sector.[94] Moreover, this would require multiplying the global cattle population many times, raising the question of where such a gigantic global cattle herd would graze.[32] Nobel Laureate Norman Borlaug, the father of the Green Revolution, has commented that organic agriculture can only feed four billion people.[95] According to Borlaug, "The so called GMOs can play a very vital role in peoples' lives. However, this must be accompanied by political goodwill because technology alone cannot survive without decisive support." As organic agriculture produces only 70% of the yield of conventional agriculture,[96] we will have to divert massive land from forests, etc. toward agriculture which is violative of the "Borlaug hypothesis": increasing the productivity of agriculture on the best farmland can help control deforestation by reducing the demand for new farmland. Thus, a massive increase in organic agriculture at the expense of existing agricultural production systems would not only threaten global biodiversity but may also increase greenhouse emission. Therefore to suggest that organic agriculture is the "only" best way for on-farm production is not logical.

The second important aspect in which biotech crops can help is in overcoming the stresses imposed by climate change. Such crops can be created with both trans- and cis-genic approaches, employing genes that can confer tolerance to multiple stresses. These crops will be able to withstand water scarcity, flooding, high temperature, cold weather, salinity, etc., and thus help stabilize food prices by avoiding fluctuations in assured food supply. Food security and assured food supply at an affordable price is of direct significance to meeting the MDGs. The first step in the development of such crops is the identification of candidate genes that can impart tolerance to multiple stresses per se or through modulation of regulatory pathways; and if necessary pyramiding such genes for developing complex traits.

To sum up, the most promising technological strategy at this time for increasing global food, feed and fiber productivity is by integrating the best of conventional crop breeding and the best of crop biotechnology, including novel traits. The improved crop products resulting from this strategy need to play a major role in an integrated global food, feed and fiber security strategy while taking due note of biosafety aspects in an unbiased and practicable manner, even if additional initiatives like Co-Extra, SIGMEA, Transcontainer, PETER, etc. are undertaken to build confidence among the stakeholders, owing to the so-called "precautionary principle" as applied specifically to biotech crops. But can we afford to prolong this process endlessly?

Disclosure of Potential Conflicts of Interest

No potential conflicts of interest were disclosed.

Acknowledgments

This paper is an offshoot of an invited lecture delivered by the lead author A.M. Husaini on January 6, 2012 during the plenary session "Moving forward with agricultural biotechnology in India: Scientific regulatory and societal challenges" of the 99th Indian Science Congress, Bubneshwar, Orissa. The lead author expresses his appreciation for the helping hand extended by Ms Souliha Rasool; heartfelt gratitude to Professor C.S. Prakash, Chairman of the Session and Professor Geetha Bali, President of the Congress, for inviting and financially sponsoring him as invited speaker for the grand scientific event; and The Indian Science Congress Association, Kalinga Institute of Industrial Technology University and National Institute of Science Education and Research for the best possible arrangement and hospitality during the science congress. For more information, visit http://kiit.tv/archiveinner.asp?id=415.

References

1. Evans A. The feeding of the nine billion: Global food security for the 21st Century (Chatham House Report). London: Chatham House, The Royal Institute of International Affairs, 2009.
2. Fischer R, Byerlee D, Edmeades G. Can technology deliver on the yield challenge to 2050? Expert Meeting on How to feed the World in 2050. Rome, Italy: Food and Agriculture Organization of the United Nations, 2009.
3. Msangi S, Rosegrant M. World agriculture in a dynamically-changing environment: IFPRI's long term outlook for food and agriculture under additional demand and constraints. High Level Expert Forum on How to Feed the World in 2050. Rome, Italy, 2009.
4. van der Mensbrugghe D, Osorio-Rodarte I, Burns A, Baffes J. Macroeconomic environment, markets: A longer term outlook. High Level Expert Forum on How to Feed the World in 2050. Rome, Italy: Food and Agriculture Organization of the United Nations, 2009.
5. Ivanic M, Martin W. Implications of higher global food prices for poverty in low-income countries. Agric Econ 2008; 39:405-16; http://dx.doi.org/10.1111/j.1574-0862.2008.00347.x.
6. UNDG. Thematic papers on the Millennium Development Goals. New York: United Nations Development Group, 2010.
7. UNDP. The path to achieving the Millennium Development Goals: A synthesis of MDG evidence from around the world. New York: United Nations Development Programme, 2010.
8. Christiaensen L, Demery L, Kuhl J. The (evolving) role of agriculture in poverty reduction—An empirical perspective. J Dev Econ 2011; 96:239-54; http://dx.doi.org/10.1016/j.jdeveco.2010.10.006.
9. FAO. Climate change and food security: A framework document. Rome: Food and Agricultural Organisation, 2008.
10. Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, et al. Climate change 2007: The physical science basis: Contribution of working group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge, UK: Cambridge University Press, 2007.
11. Nagarajan S, Nagarajan S. Abiotic tolerance and crop improvement. In: Pareek A, Sopory SK, Bohnert HJ, Govindjee, eds. Abiotic stress adaptation in plants: physiological, molecular and genomic foundation. Dordrecht: Springer Netherlands, 2010:1-11.
12. Deng XP, Shan L, Inanaga S, Inoue M. Water-saving approaches for improving wheat production. J Sci Food Agric 2005; 85:1379-88; http://dx.doi.org/10.1002/jsfa.2101.
13. FAO. Crops and drops: Making the best use of water for agriculture. Rome, 2002.
14. Singh P, Bengtsson L. Hydrological sensitivity of a large Himalayan basin to climate change. Hydrol Processes 2004; 18:2363-85; http://dx.doi.org/10.1002/hyp.1468.
15. Barnett TP, Adam JC, Lettenmaier DP. Potential impacts of a warming climate on water availability in snow-dominated regions. Nature 2005; 438:303-9; PMID:16292301; http://dx.doi.org/10.1038/nature04141.
16. Rees HG, Collins DN. Regional differences in response of flow in glacier-fed Himalayan rivers to climatic warming. Hydrol Processes 2006; 20:2157-69; http://dx.doi.org/10.1002/hyp.6209.
17. Larcher W. Physiological plant ecology: ecophysiology and stress physiology of functional groups. Berlin: Springer-Verlag, 2003.
18. Rizza F, Badeck FW, Cattivelli L, Lidestri O, Di Fonzo N, Stanca AM. Use of a water stress index to identify barley genotypes adapted to rainfed and irrigated conditions. Crop Sci 2004; 44:2127-37; http://dx.doi.org/10.2135/cropsci2004.2127.

19. Treasury HM. Green biotechnology and climate change. EuropaBio, 2009.
20. Braun HJ, Brettell R. The role of international centers in enhancing cooperation in wheat improvement. Borlaug Global Rust Initiative - Technical Workshop. Ciudad Obregon, 2009.
21. Zeigler R. Rice and the Millennium Development Goals: the international rice research institute's strategic plan 2007–2015. Paddy Water Environ 2007; 5:67-71; http://dx.doi.org/10.1007/s10333-007-0067-9.
22. ICAR. Climate Change. Department of Agricultural Research and Education - ICAR, Annual Report 2008-09. Indian Council of Agricultural Research, 2009:16.
23. Buchanan BB, Gruissem W, Jones RL. Biochemistry and molecular biology of plants. Rockville, Maryland: American Society of Plant Physiologists, 2000.
24. Ye X, Al-Babili S, Klöti A, Zhang J, Lucca P, Beyer P, et al. Engineering the provitamin A (β-carotene) biosynthetic pathway into (carotenoid-free) rice endosperm. Science 2000; 287:303-5; PMID:10634784; http://dx.doi.org/10.1126/science.287.5451.303.
25. Potrykus I. Nutritionally enhanced rice to combat malnutrition disorders of the poor. Nutr Rev 2003; 61:S101-4; PMID:12908739; http://dx.doi.org/10.1301/nr.2003.jun.S101-S104.
26. Raney T, Pingali P. Sowing a gene revolution. Sci Am 2007; 297:104-11; PMID:17784631; http://dx.doi.org/10.1038/scientificamerican0907-104.
27. Tang G, Qin J, Dolnikowski GG, Russell RM, Grusak MA. Golden Rice is an effective source of vitamin A. Am J Clin Nutr 2009; 89:1776-83; PMID:19369372; http://dx.doi.org/10.3945/ajcn.2008.27119.
28. Goto F, Yoshihara T, Shigemoto N, Toki S, Takaiwa F. Iron fortification of rice seed by the soybean ferritin gene. Nat Biotechnol 1999; 17:282-6; PMID:10096297; http://dx.doi.org/10.1038/7029.
29. Lucca P, Hurrell R, Potrykus I. Fighting iron deficiency anemia with iron-rich rice. J Am Coll Nutr 2002; 21(Suppl):184S-90S; PMID:12071303.
30. Shetty P. Incorporating nutritional considerations when addressing food insecurity. Food Secur 2009; 1:431-40; http://dx.doi.org/10.1007/s12571-009-0039-6.
31. Stein AJ, Rodríguez-Cerezo E. International trade and the global pipeline of new GM crops. Nat Biotechnol 2010; 28:23-5; PMID:20062032; http://dx.doi.org/10.1038/nbt0110-23b.
32. James C. Global Status of Commercialized Biotech/GM Crops, 2009: Brief 41. ISAAA South Asia Office, 2009.
33. Chen S, Song T. Identification of haploids with high oil xenia effect in maize. Acta Agron Sin 2003; 29:587-90.
34. Cuong BM, Kha LQ, Tam NTM. Genetic diversity of maize doubled haploid line nurseries in Vietnam and their potential for utilization in hybrid breeding. In: Pixley K, Zhang SH, eds. Proceedings of 9th Asian regional maize workshop. Beijing: China Agricultural Science and Technology Press, 2007:67-71.
35. Zhang S, Liu Z, Li D. Analysis of quantitative trait loci for grain quality of maize doubled haploid population. J Agric Univ Hebei 2008; 31:1-5.
36. Stone R. Plant science. China plans $3.5 billion GM crops initiative. Science 2008; 321:1279; PMID:18772402; http://dx.doi.org/10.1126/science.321.5894.1279.
37. Brookes G, Barfoot P. Global impact of biotech crops: environmental effects, 1996-2010. GM Crops Food 2012; 3:129-37; PMID:22534352.
38. James C. Global Status of Commercialized Biotech/GM Crops: 2011. ISAAA South Asia Office, 2012.
39. Kimball BA, Kobayashi K, Bindi M. Responses of agricultural crops to free-air CO_2 enrichment. Adv Agron 2002; 77:293-368; http://dx.doi.org/10.1016/S0065-2113(02)77017-X.
40. Ainsworth EA, Long SP. What have we learned from 15 years of free-air CO_2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. New Phytol 2005; 165:351-71; PMID:15720649; http://dx.doi.org/10.1111/j.1469-8137.2004.01224.x.
41. Long SP, Ainsworth EA, Leakey ADB, Nösberger J, Ort DR. Food for thought: lower-than-expected crop yield stimulation with rising CO_2 concentrations. Science 2006; 312:1918-21; PMID:16809532; http://dx.doi.org/10.1126/science.1114722.
42. Rosenzweig C, Hillel D. Climate change and the global harvest. New York, USA: Oxford University Press, 1998.
43. Fawcett R, Towery D. Conservation tillage and plant biotechnology: How new technologies can improve the environment by reducing the need to plow. West Lafayette, IN, USA: Conservation Technology Information Center, 2002.
44. Brimner TA, Gallivan GJ, Stephenson GR. Influence of herbicide-resistant canola on the environmental impact of weed management. Pest Manag Sci 2005; 61:47-52; PMID:15593073; http://dx.doi.org/10.1002/ps.967.
45. Kleter GA, Harris C, Stephenson G, Unsworth J. Comparison of herbicide regimes and the associated potential environmental effects of glyphosate-resistant crops versus what they replace in Europe. Pest Manag Sci 2008; 64:479-88; PMID:18078305; http://dx.doi.org/10.1002/ps.1513.
46. May MJ, Champion GT, Dewar AM, Qi A, Pidgeon JD. Management of genetically modified herbicide-tolerant sugar beet for spring and autumn environmental benefit. Proc Biol Sci 2005; 272:111-9; PMID:15695200; http://dx.doi.org/10.1098/rspb.2004.2948.
47. Bonny S. Genetically modified glyphosate-tolerant soybean in the USA: adoption factors, impacts and prospects. A review. Agronomy for Sustainable Development 2008; 28:21-32; http://dx.doi.org/10.1051/agro:2007044.
48. Dun Z, Mitchell PD. Can conventional crop producers also benefit from Bt Technology?: Agricultural and Applied Economics Association, 2011.
49. Zahran HH. Rhizobia from wild legumes: diversity, taxonomy, ecology, nitrogen fixation and biotechnology. J Biotechnol 2001; 91:143-53; PMID:11566386; http://dx.doi.org/10.1016/S0168-1656(01)00342-X.
50. Saikia S, Jain V. Biological nitrogen fixation with non-legumes: An achievable target or a dogma? Curr Sci India 2007; 92:317-22.
51. Yan Y, Yang J, Dou Y, Chen M, Ping S, Peng J, et al. Nitrogen fixation island and rhizosphere competence traits in the genome of root-associated *Pseudomonas stutzeri* A1501. Proc Natl Acad Sci U S A 2008; 105:7564-9; PMID:18495935; http://dx.doi.org/10.1073/pnas.0801093105.
52. Johnson JMF, Franzluebbers AJ, Weyers SL, Reicosky DC. Agricultural opportunities to mitigate greenhouse gas emissions. Environ Pollut 2007; 150:107-24; PMID:17706849; http://dx.doi.org/10.1016/j.envpol.2007.06.030.
53. Brookes G, Barfoot P. GM crops: global socio-economic and environmental impacts 1996-2008. Dorchester, UK: PG Economics Ltd, 2010.
54. Ruan C-J, Shao H-B, Teixeira da Silva JA. A critical review on the improvement of photosynthetic carbon assimilation in C_3 plants using genetic engineering. Crit Rev Biotechnol 2012; 32:1-21; PMID:21699437; http://dx.doi.org/10.3109/07388551.2010.533119.
55. Aalde H, Gonzalez P, Gytarsky M, Krug T, Kurz WA, Lasco RD, et al. Generic methodologies applicable to multiple land-use categories. Agriculture, forestry and other land use: Intergovernmental Panel on Climate Change, 2006.
56. Glover J, Johnson H, Lizzio J, Wesley V, Hattersley P, Knight C. Australia's crops and pastures in a changing climate–can biotechnology help? Canberra, Australian: Australian Government Bureau of Rural Sciences, 2008:67.
57. Nicholas S. Stern review on the economics of climate change. Stern Review on the Economics of Climate Change, UK Treasury, 2006.
58. Wang W, Vinocur B, Altman A. Plant responses to drought, salinity and extreme temperatures: towards genetic engineering for stress tolerance. Planta 2003; 218:1-14; PMID:14513379; http://dx.doi.org/10.1007/s00425-003-1105-5.
59. Hong Z, Lakkineni K, Zhang Z, Verma DPS. Removal of feedback inhibition of delta(1)-pyrroline-5-carboxylate synthetase results in increased proline accumulation and protection of plants from osmotic stress. Plant Physiol 2000; 122:1129-36; PMID:10759508; http://dx.doi.org/10.1104/pp.122.4.1129.
60. Jaglo KR, Kleff S, Amundsen KL, Zhang X, Haake V, Zhang JZ, et al. Components of the Arabidopsis C-repeat/dehydration-responsive element binding factor cold-response pathway are conserved in *Brassica napus* and other plant species. Plant Physiol 2001; 127:910-7; PMID:11706173; http://dx.doi.org/10.1104/pp.010548.
61. Manavalan LP, Guttikonda SK, Tran LS, Nguyen HT. Physiological and molecular approaches to improve drought resistance in soybean. Plant Cell Physiol 2009; 50:1260-76; PMID:19546148; http://dx.doi.org/10.1093/pcp/pcp082.
62. Hsieh T-H, Lee JT, Charng YY, Chan M-T. Tomato plants ectopically expressing *Arabidopsis* CBF1 show enhanced resistance to water deficit stress. Plant Physiol 2002; 130:618-26; PMID:12376629; http://dx.doi.org/10.1104/pp.006783.
63. Zhang HH, He XL. Effect of AM fungi on the protective system in leaves of *Artemisia ordosica* under drought stress. Biotechnol Bull 2007; 3:129-33.
64. Yamanouchi U, Yano M, Lin H, Ashikari M, Yamada K. A rice spotted leaf gene, *Spl7*, encodes a heat stress transcription factor protein. Proc Natl Acad Sci U S A 2002; 99:7530-5; PMID:12032317; http://dx.doi.org/10.1073/pnas.112209199.
65. Van Camp W. Yield enhancement genes: seeds for growth. Curr Opin Biotechnol 2005; 16:147-53; PMID:15831379; http://dx.doi.org/10.1016/j.copbio.2005.03.002.
66. Gómez-Barbero M, Berbel J, Rodríguez-Cerezo E. *Bt* corn in Spain--the performance of the EU's first GM crop. Nat Biotechnol 2008; 26:384-6; PMID:18392015; http://dx.doi.org/10.1038/nbt0408-384.
67. Kumar SV, Wigge PA. H2A.Z-containing nucleosomes mediate the thermosensory response in *Arabidopsis*. Cell 2010; 140:136-47; PMID:20079334; http://dx.doi.org/10.1016/j.cell.2009.11.006.
68. Hasanuzzaman M, Hossain MA, Silva JAT, Fujita M. Plant response and tolerance to abiotic oxidative stress: antioxidant defense is a key factor. In: Venkateswarlu B, Shanker AK, Shanker C, Maheswari M, eds. Crop Stress and its Management: Perspectives and Strategies. Netherlands: Springer Netherlands, 2012:261-315.
69. Husaini AM. Pre- and post-agroinfection strategies for efficient leaf disk transformation and regeneration of transgenic strawberry plants. Plant Cell Rep 2010; 29:97-110; PMID:19956955; http://dx.doi.org/10.1007/s00299-009-0801-4.

70. Bowler C, Montagu MV, Inze D. Superoxide dismutase and stress tolerance. Annu Rev Plant Physiol 1992; 43:83-116; http://dx.doi.org/10.1146/annurev.pp.43.060192.000503.
71. Gupta AS, Heinen JL, Holaday AS, Burke JJ, Allen RD. Increased resistance to oxidative stress in transgenic plants that overexpress chloroplastic Cu/Zn superoxide dismutase. Proc Natl Acad Sci U S A 1993; 90:1629-33; PMID:8434026; http://dx.doi.org/10.1073/pnas.90.4.1629.
72. Gupta AS, Webb RP, Holaday AS, Allen RD. Overexpression of superoxide dismutase protects plants from oxidative stress (induction of ascorbate peroxidase in superoxide dismutase-overexpressing plants). Plant Physiol 1993; 103:1067-73; PMID:12232001.
73. Van Camp W, Capiau K, Van Montagu M, Inzé D, Slooten L. Enhancement of oxidative stress tolerance in transgenic tobacco plants overproducing Fe-superoxide dismutase in chloroplasts. Plant Physiol 1996; 112:1703-14; PMID:8972606; http://dx.doi.org/10.1104/pp.112.4.1703.
74. Shikanai T, Takeda T, Yamauchi H, Sano S, Tomizawa K-I, Yokota A, et al. Inhibition of ascorbate peroxidase under oxidative stress in tobacco having bacterial catalase in chloroplasts. FEBS Lett 1998; 428:47-51; PMID:9645472; http://dx.doi.org/10.1016/S0014-5793(98)00483-9.
75. Roxas VP, Lodhi SA, Garrett DK, Mahan JR, Allen RD. Stress tolerance in transgenic tobacco seedlings that overexpress glutathione S-transferase/glutathione peroxidase. Plant Cell Physiol 2000; 41:1229-34; PMID:11092907; http://dx.doi.org/10.1093/pcp/pcd051.
76. Alscher RG, Erturk N, Heath LS. Role of superoxide dismutases (SODs) in controlling oxidative stress in plants. J Exp Bot 2002; 53:1331-41; PMID:11997379; http://dx.doi.org/10.1093/jexbot/53.372.1331.
77. Wang J, Zhang H, Allen RD. Overexpression of an *Arabidopsis* peroxisomal ascorbate peroxidase gene in tobacco increases protection against oxidative stress. Plant Cell Physiol 1999; 40:725-32; PMID:10501032; http://dx.doi.org/10.1093/oxfordjournals.pcp.a029599.
78. Roxas VP, Smith RK Jr., Allen ER, Allen RD. Overexpression of glutathione S-transferase/glutathione peroxidase enhances the growth of transgenic tobacco seedlings during stress. Nat Biotechnol 1997; 15:988-91; PMID:9335051; http://dx.doi.org/10.1038/nbt1097-988.
79. Badawi GH, Kawano N, Yamauchi Y, Shimada E, Sasaki R, Kubo A, et al. Over-expression of ascorbate peroxidase in tobacco chloroplasts enhances the tolerance to salt stress and water deficit. Physiol Plant 2004; 121:231-8; PMID:15153190; http://dx.doi.org/10.1111/j.0031-9317.2004.00308.x.
80. Bartels D, Sunkar R. Drought and salt tolerance in plants. Crit Rev Plant Sci 2005; 24:23-58; http://dx.doi.org/10.1080/07352680590910410.
81. Vinocur B, Altman A. Recent advances in engineering plant tolerance to abiotic stress: achievements and limitations. Curr Opin Biotechnol 2005; 16:123-32; PMID:15831376; http://dx.doi.org/10.1016/j.copbio.2005.02.001.
82. Chinnusamy V, Zhu JK. Plant salt tolerance. Top Curr Genet 2003; 4:241-70; http://dx.doi.org/10.1007/978-3-540-39402-0_10.
83. Chinnusamy V, Schumaker K, Zhu JK. Molecular genetic perspectives on cross-talk and specificity in abiotic stress signalling in plants. J Exp Bot 2004; 55:225-36; PMID:14673035; http://dx.doi.org/10.1093/jxb/erh005.
84. Ruane J, Sonnino F, Steduro R, Deane C. Coping with water scarcity in developing countries: What role for agricultural biotechnologies. Land and water Discussion: Food and Agricultural organization (FAO), 2007:33.
85. CropGen. Regulated to Blindness and Death. London, UK: CropGen 2007; http://cropgen.org
86. Makinde D, Mumba L, Ambali A. Status of Biotechnology in Africa: Challenges and opportunities. Asian Biotechnol Dev Rev 2009; 11:1-10.
87. Qaim M. The economics of genetically modified crops. Annu Rev Resour Econ 2009; 1:665-94; http://dx.doi.org/10.1146/annurev.resource.050708.144203.
88. EFSA GMO Panel Working Group on Animal Feeding Trials. Safety and nutritional assessment of GM plants and derived food and feed: the role of animal feeding trials. Food Chem Toxicol 2008; 46(Suppl 1):S2-70; PMID:18328408; http://dx.doi.org/10.1016/j.fct.2008.02.008.
89. Taverne D. Thunderer: when crops burn, the truth goes up in smoke. Times (Lond) 2003.
90. Taverne D. The March of Unreason: Science, Democracy and the New Fundamentalism. Oxford, UK: Oxford University Press, 2005.
91. Europeon Commission Sponsored Research on Safety of Genetically Modified Organisms. Brussels, Belgium: European Commission, 2001.
92. ICSU. New Genetics, Food and Agriculture: Scientific Discoveries—Societal Dilemmas. Paris, France: International Council for Science, 2003. www.icsu.org
93. Morris SH. EU biotech crop regulations and environmental risk: a case of the emperor's new clothes? Trends Biotechnol 2007; 25:2-6; PMID:17113665; http://dx.doi.org/10.1016/j.tibtech.2006.11.004.
94. Steinfeld H, Gerber P, Wassenaar T, Castel V, de Haan C. Livestock's long shadow: environmental issues and options. FAO, 2006.
95. Pollock J. Green revolutionary. Technol Rev January/February 2008 http://technologyreview.com/biomedicine/19871
96. Avery A. The Truth About Organic Foods, pp 157–168. Chesterfield, MO, USA: Henderson Communications LLC, 2006.