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Food Security in the New Millennium-II. The Role of Agriculture Biotechnology

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Abstract: Plant breeding in its primitive form is being practiced since the transition of human being from hunter/gatherers to settled agriculturist, approximately 10,000 thousand years ago. Without knowing genetics and its principal, it was used genetics to modify crops and their products. The selection of plants with best characteristics as source of next year seeds quickly resulted into domestication of crops that were distinct from their wild relative. Genetic modification (GM) has emerged against this historic background of breeding and selection and is thus, the extension of existing techniques and not something, which is unprecedented. In present paper, efforts have been made to review situation (s) that are responsible for the origin of genetically modified (transgenic) approaches to be used for crop improvement. The outcome of these approaches and the credibility of the resultant products along with their impact and significance on crop productivity in particular have also been reviewed. Impact of GM technology on the poor farmers in the developing countries with special reference to their needs and resources has been discussed in detail. The current status of genetically modified crops in the developed countries and also in the developing countries willing to adopt this technology albeit slowly has also been described along with their fears and concerns in order to provide the readers the choice to select this technology or otherwise according to their own needs and resources. The paper also provides information on the genetically modified products that can have significant impact in improving nutritional status of food generally consumed by millions of people living in the hart land of poverty that is South Asia and Sub-Saharan Africa.

Key works: *Bt* crops, food security, GM technology, transgenic crops, genetic engineering

Introduction

During the past 3 decades, the situation has been significantly changed yet, an unacceptably high number (> 700 million) of people live with food insecurity. Improvement has been reported in 35 countries including East and Southeast Asia but, in 55 countries including South Asia and Sub-Saharan Africa, the situation of food insecurity has deteriorated (FAO, 2002). Malnutrition is another factor responsible for the deaths of 5 million children annually and affects 20-25% of economic growth due to childhood sickness in the developing countries (Smith and Haddad, 2000). Today, one third of preschool children in these countries and half of the children of south Asian region are malnourished. About 40 and 46% population of south Asia and Sub-Saharan Africa respectively, is living in absolute poverty. The demand for daily per capita calories is growing from 2100 to about 2700 in developing countries, while Sub-Saharan Africa and South Asia are still lagging behind the other regions in having per-capita calories availability below minimum requirement. To provide food security to these people, it has been pointed out that serious attention will have to be paid to re-evaluate and re-address the factors such as I) globalization and trade liberalization, ii) degradation of natural resources including water scarcity, iii) emerging and re-emerging health and nutrition crises, iv) rapid urbanization, v) rapidly changing structure of farming, vi) continued conflict between certain regions of the third world countries, vii) global climate change, viii) changing role and responsibility of those who matter and ix) technological changes (Anderson, 2001). In this article, the importance and significance of the last factor that is "technological changes" especially those affecting agricultural productivity and management will be discussed in detail with special reference to food security for the developing countries.

How to provide food security to the poor?: As once elaborated by Lipton (1999), the world's poor depends mainly on farm work to get access to the staple food and on higher yields of staples to escape poverty. World poverty fell fast in 1965-1985 because yield of staple food increased rapidly due to green revolution and agriculture research that created more work places for adults. The sharp rise in income per person and fall in poverty in East and Southeast Asia since 1965 was due to the fact that adults at that time were provided productive work place. The heart land of world poverty, South Asia and Sub-Saharan Africa will see a sharp rise in the proportion of people of working age during the 21st century. For example, from 1960-1980, on the average approximately 69 and 79% of the population of these two regions respectively, was dependent on farm income (FAO, 1999); the proportion will be 55 and 64%, respectively by the year 2010. To provide respectable work in the vicinity to this much population along with affordable, reliable and adequate food, concerted efforts are required to increase food which is only possible if new sciences boost yield potential of crops and subsequently the employment and output in the areas where poor live. Even if the food is available, the poor may not get it unless provided with extra labour income that can only be obtained through agriculture growth, rural development and trade, which rely on rising farm income and expenditure. Since 1987 however, growth trends have slowed down. The low productivity of resource poor farmers tend to perpetuate rural poverty to the extent that of more than 2.5 billion people in developing countries who lived in the rural areas, about 940 millions (633 million in Asia, 204 million in Africa, 27 million in Near East and 76 million in Latin America) used to live below poverty (Jazairy *et al.*, 1992). The situation has been aggravated over the years and affected poverty alleviation efforts (Rosegrant *et al.*, 2001). In addition, food farming is dogged by water shortage and diversion (Dick and Rosegrant, 2001), yield of staples in the developing countries is decreasing and crawling at half the rate of population growth (Flores and Gillespie, 2001), the demand for work is increasing more since 1995 and will be intensified till 2020, public funds for enhancing yields are diminishing and private research has exploded (Anonymous, 1998). All this would suggest that crop research is now less directed towards food staple of poor people.

Genetically modified (GM) plants can revive yield potential of major food staples and can thus address the problem of poverty and malnutrition. Nevertheless, it is possible only if the focus of the research shifts from traits like herbicide resistance to higher yield and drought tolerance, from crop that feed chicken to the crop that feed people and from huge, low employment farms to the small land holders and farm laborers (Lipton, 1999).

The origin of a need for improving crops through genetic modifications: Conventional plant breeding has so far been extremely successful but would require a significant increase in financial support for continued maintenance and improvement of agricultural yields. However, there are some limitations inherent in conventional plant breeding such as lack of practical access to useful germplasm due to sexual incompatibility barriers or un-

desirable linkage blocks and concomitant time lags in incorporating useful genes into existing varieties. Most of the gene pools lack some agronomically useful traits e.g. protein quality, abiotic stress tolerance, virus or viorid resistance that may be available in the gene pool of other crop species. For example, resistance to soft rot or blackleg (*Erwinia carotovara*) is lacking in the potato gene pool and causes crop losses estimated at US $ 100 million per year worldwide (Spillance, 1999). Indeed, many transgenic approaches to crop improvement did arise from lack or inefficiency of suitable conventional approaches to deal with an important agronomic problem. Examples of such instances include, rice sheath blight, cassava mosaic virus, potato leaf roll virus and black Sigatoga in plantain which seriously limit agricultural productivity. Transgenic approaches not only provide new options for such pests and pathogens but, it can also be of use for areas with limited options available through conventional plant breeding or a limited practicality for characters such as nuclear male sterility, improved heterosis breeding, reducing toxic compound, herbicide tolerance and generation of novel resistance genes. Through transgenic approaches, the range of a particular gene pool can be broadened and made accessible for crop improvement purposes (Flavell, 1999) like introduction of vaccine antigen genes in animals (Mason *et al.*, 1996; Arakawa *et al.*, 1998) and aluminum tolerance genes to food plants (Fuente *et al.*, 1997). Isolated plant genes conferring resistance to pests and pathogens can now be usefully transferred between sexually incompatible crops and plant species (Whitham *et al.*, 1996; Molvig *et al.*, 1997; Wilkinson *et al.*, 1997). In addition to that, biotechnological techniques such as plant tissue culture, molecular genetic mapping and marker assisted selection could have major impact on all those conventional crop improvement approaches that are dependent
upon genetic variation accessible only within he primary or secondary gene pool.

The prospects of biotechnology and genetic engineering for agriculture: The areas in which plant biotechnology and genetic engineering has been and will be employed successfully include I) disease resistance, ii) insect resistance, iii) labor saving approaches, iv) tolerance to abiotic stresses, v) improvement in product quality, vi) increasing yield potential, vii) and agricultural genomics.

I) Disease resistance: So far, genes for resistance to various plant diseases have been isolated from a wide range of plant species including mono- and di-cotyledonous plants and are being used as resistance source for improvement of crops through genetic engineering (Baker *et al.*, 1997). Many of these genes share structural characteristics and provide resistance to diseases caused by a wide variety of pathogens such as fungi, bacteria, viruses and nematodes. Quite a large number of these genes have already been tagged with molecular markers (Zhang and Yu, 1999). Closely linked markers flanking both sides of these genes have been identified and used as selection criteria in breeding programmes to monitor the transfer of genes via marker assisted selections. This is one of the most powerful components of plant biotechnology capable of revolutionizing crop improvement and production in the new millennium.

ii) Insect resistance: Powerful techniques have been developed for scanning crop genomes for identification of resistance genes and their subsequent cloning in plants for their improvement (Leister *et al.*, 1996; Chen *et al.*, 1998). The effective transfer of resistance genes from one crop species has been demonstrated. Through some transgenic approaches, higher levels of broad spectrum resistance can be obtained for a range of pathogens including viruses (Tacke *et al.*, 1996), bacteria (Cao *et al.*, 1998) and fungi (Shah, 1997), which is being considered as a new tool for resistance breeding. Although, a lot of genes possessing resistance to various insects have been identified, tagged and mapped with molecular markers (Zhang and Yu, 1999; Bent, 1996; Hammond-Kosack and Jones, 1997) nevertheless, the strategy for developing insect resistant crops has generally been based on utilization of *Bt* genes from bacterium *Bacillus thurengiensis* (Krattiger, 1997). Several of these genes have now been widely used in transformation studies especially for cotton, corn, rice, canola and soybean: the transgenic crop varieties, which have already been commercialized (James, 1998). Insect resistance based on *Bt* could have significant effect on the environment and substitution effects in the global insecticide market, which has been estimated to be approximately US$ 8100 million per annum (James, 1997). It is anticipated that US$ 2700 million of chemical insecticide application could be replaced with *Bt* either as improved sprays or through expression in the transgenic crops (Karttiger, 1997). The success of *Bt* has been demonstrated by an increase in global area from 2.5 million hectares in 1997 to 8.2 million hectares in 2001 that was planted by transgenic *Bt* crops (James, 2000). Utilization of the insect resistance genes at such a large-scale in crop production will not only reduce labour and costs of production but will also have long term beneficial effects on the environment and sustainability of agro-ecosystems.

iii) Labour saving approaches to weed management for resource-poor farmers: In the developing countries, dangerous pesticides have been over-used (Huang *et al.*, 2001) while the use of herbicide has been very low despite the fact that most of the herbicides are far less toxic than pesticide. Weed control is thus a major task for most of the farmers especially the poor farmers who have limited access to input resources (most of which are used for the purchase of pesticides) and has to control it manually. It is estimated that more than 60% of a farmer's time in the developing countries is spent on weeding. Women and children do most of this work, which is usually unpaid (Halos, 1992). Thus, herbicide resistant crops offer significant and economically accessible advantages to many poor farmers in the developing countries with limited resources and labour availability (Gressal *et al.*, 1996). Also, in these countries, farmers face many weed problems like parasitic broomrapes and witchweeds (*Striga hermonthica* and other spp.) for which no effective control measures have been developed. Areas infested with such weeds are vast and is expanding. For example, 72% of the fields in Nigeria (Hartman and Tanimonure, 1991) and about 100 million people in Sub-Saharan Africa and Asia are being affected by witchweeds infestation, which reduces crop productivity up to 50% especially in drought years (Akobundu, 1991). Witchweeds can be controlled by an acetolactate synthase inhibiting herbicide imadizoline (Abayo *et al.*, 1996). Seeds of transgenic maize treated with high levels of systemic imadizoline give excellent control on witchweed. Using US$ 5 for herbicide, an increase in yield worth US$ 100 per annum has been obtained in Kenya (Gressal *et al.*, 1996). Such strategies would do wonders in developing countries provided measures are adopted to ensure that resistance against herbicide will not be evolved (Gressal, 1997).

iv) Tolerance to abiotic stresses: One of the promising studies on abiotic stress tolerance has been the genetic engineering of sugar beets with a gene coding for citrate synthesis (Fuente *et al.*, 1997). The elevated expression of this gene in sugar beet exhibited enhanced tolerance against aluminum and increased uptake of phosphate in the acidic soils as a result of citrate excretion. This indicated that genetic engineering might be able to produce plants that can grow better in acidic soil even with reduced application of phosphate fertilizer. This work may have tremendous implications in crop improvement, especially for crops grown in tropical and subtropical regions.

v) Improvement in product quality: Biotechnology can significantly improve product quality especially poor cooking qualities of high yielding cultivars and hybrids of rice. Research conducted in China has established that these characters are dependent on three traits: that is amylose contents, gelatinization temperature and gel consistency, all the three are controlled by the waxy locus located on chromosome 6 (Tan *et al.*, 1999). Rice plants transformed with waxy locus have shown reduced amylose content, thus demonstrating the usefulness of transgenic approach.

Insufficient intake of dietary vitamin A is implicated in the death of approximately 5 million children annually in developing countries (Smith and Haddad, 2000) and in development of eye disease xerothalmia in another 5 million children in South Asia (Sommer, 1998). Many staple diet especially rice is deficient in vitamin A. Genetic engineering approaches have enabled the scientists to develop rice which can accumulate and provide increased dietary intake of vitamin A from rice (Burkhardt *et al.*, 1997). This technology can be applied to other crop species or varieties in locations where vitamin A deficiency is a medical problem. Similar approaches for combating micronutrient deficiencies by increasing both contents and availability of iron in transgenic rice are showing much promise (Goto *et al.*, 1999). Metabolic engineering of the pathways to increase seed oil contents in rapeseed (Voelker *et al.*, 1996) has also shown progress (Zou *et al.*, 1997) and is being grown commercially (Harlander and Roller, 1998) to meet the end user demands (Knauf, 1995). Hidden hunger, such as protein deficiencies, is a widespread and endemic problem for the world's poorest people especially women and children. Transgenic crops offer promise of transferring genes encoding more nutritious proteins from other species (Molvig *et al.*, 1997) into crops. For example, by manipulating crop biosynthetic pathways, the increase in nutritional profiles of endogenous proteins (Karchi *et al.*, 1993) has already been demonstrated in legumes such as peanut, beans and clover. These varieties were improved nutritionally through transferring methionine-rich genes from sunflower (Khan *et al.*, 1996). Transfer of key biochemical components of C4 photosynthesis to those crops which rely on less energy-efficient C3 photosynthesis (Ku *et al.*, 1999) system is also progressing significantly.

vi) Increase in yield potential: For the last 10-15 years, rate of yield increase has been declining in major food crops (Rosegrant *et al.*, 2001), which is a serious concern for most of the crop breeding programs. Two approaches have been utilized to solve this problem. First is to identify QTLs in the wild species (Xiao *et al.*, 1996) that can increase yield. The success of this has already generated considerable interest in identifying gene (s) for agronomic performance. The second approach is to modify certain physiological processes by genetic engineering. For example, delaying leaf senescence by auto-regulated production of cytokinin (Gan and Amasino, 1995). Biotechnology can thus, contribute significantly to sustainable food production by achieving higher yield, better quality and less dependence on chemicals, making crop production more environment friendly.

vii) Agricultural genomics: Genomics is a recently coined term that is used to describe development and application of large scale, high throughput and parallel processing approaches to the functional analysis of entire genomes or genetic system (Bouchez and Hofte, 1998). Agricultural genomics research is currently underway for a range of important agricultural species (Timberlake, 1998) including *Arabidopsis* and rice (Rounsley *et al.*, 1998). Genetic markers and genes are thus being identified that can be used either for marker assisted breeding or for the development of transgenic crops with improved agronomic properties. Express Sequence Tags (ESTs) are small fragments of genes that have been sequenced and which can act as unique 'bar-codes' for each particular gene in an organism and can uniquely identify more than 95% of the estimated 120,000 human genes that are available on public databases. Although, both public and private sectors have produced ESTs for different crops such as *Arabidopsis*, rice, maize and soybean nevertheless; most of this EST data is not publically accessible (Cohen, 1997).

The 'functional genomics' system to explore the function of genes through 'knockout' and 'monitoring' strategies has also been developed using transposon mutagenesis (Martienssen, 1998). The development of DNA 'chip' is revolutionizing the scale at which genetic experiments can be done. This technique can potentially allow simultaneous and rapid analysis of almost all the genes in any organism at any particular point in time or environment (Collins, 1999). If this technology becomes cost effective in the same manner that has led semiconductor technology to become widespread, it would have a very significant impact on how genetic improvement of crops and animals is conducted.

Current status of biotechnology and genetically modified crops: The total acreage of cultivated land in the world stands at over 1.4 billion hectares, which is predominantly under conventional crop varieties. However, for a few crops in few countries, (Argentina, Canada, China, USA) significant area has been planted to transgenic varieties which is further increasing swiftly along with the farmers who are adopting transgenic varieties (James, 1998). In 1997, global area under transgenic crops was 12.8 million hectares compared to 2.8 million hectares planted in 1996 and stands at 44.2 millions in 2000 (James, 2001).

The estimated global area for the year 2001 was 52.6 million hectares that was to be grown cumulatively by 5.5 million farmers. Of the total area, 68% was in USA, 22% in Argentina, 6% in Canada and 3 % in China. The largest yearly increase is recorded for China which is due mainly to the 3-fold increase in *Bt* cotton area i.e., from 0.5 million hectares in 2000 to 1.5 million hectares in 2001 (Pray *et al.*, 2000). Cropped area was also increased in South Africa and Australia in 2001 with a growth rate of 33 and 37%, respectively. Modest increases were also reported for Bulgaria, Germany, Indonesia, Mexico, Romania, Spain and Uruguay. Indonesia allowed commercial cultivation of *Bt* cotton in the country for the first time in 2001.

Like previous years, during 2001 also, genetically modified soybean dominated and remained at 33.3 million hectares (63% of global area) followed by corn (9.8 million hectares). Transgenic cotton occupied 6.8 million hectares (13% of the total) and canola was on 2.7 million hectares, which is only 5% of the total genetically modified cropped area.

The global adoption of genetically modified soybean, cotton, canola and corn also improved considerably during 2001. For example, soybean planting increased from 36% in 2000 to 46% during 2001, which is equal to 72 million hectares. Similarly, 20% of the 34 million hectares of cotton were genetically modified which is 4% higher compared to that in 2000. Transgenic canola and maize occupied 11% of the 25 million hectares and 7% of the 140 million hectares, respectively and remained unchanged. The aggregate global area planted with these (conventional and transgenic) crops was 271 million hectares of which approximately 19% (compared to 16% in 2000) was transgenic (James, 2001). Data obtained during 1996 to 2001 for 16 different countries indicated that genetically modified crops could meet the expectations of both large and small farmers in industrial as well as in developing countries. The beneficiaries in 2001 were resource-poor farmers who planted *Bt* cotton mainly in eight provinces in China (Pray *et al.*, 2000) and also in the Makathini Flats in KwaZulu Natal province of South Africa (James, 2001). An important finding made out of *Bt* cotton study in China (Pray *et al.*, 2001) was that the smallest farmers who planted less than 1 hectare, gained more than twice as much income per unit of land ($ 400 per hectare) from *Bt* cotton as the larger farmers ($ 185 per hectare).

Transfer of transgenic technology to the developing countries: There are many collaborative projects through which successful applications of biotechnology and knowledge developed in the private sector are being donated or shared on a royalty-free or humanitarian basis for the benefit of developing countries (James, 2001). Golden rice, which is a transgenic crop containing beta-carotene and other carotenoide precursors of vitamin A, is one of such examples (Al-Babili *et al.*, 1999). The golden rice technology was developed with funding from the Rockefeller Foundation

(1991-2002), the Swiss Federal Institute of Technology (1993-1996), the European Union under a European Community Biotech Programme (1996-2000) and the Swiss Federal Office for Education and Science (1996-2000). In 2002, the inventors explored ways in which golden rice could be donated for humanitarian purposes. This appeared possible only through granting intellectual property licenses from Bayer, Monsanto, Orynova, Syngenta and Zeneca Mogen. Each company licensed free-of-charge technology used in the research, which led to the Golden Rice invention.

"Golden Mustard" is another collaborative project initiated between Tata Energy Research Institute (TERI) India, Monsanto and Michigan State University (MSU), USA, to develop a rape seed variety that will yield cooking oil high in beta-carotene (pro-vitamin A). Monsanto has announced (Monsanto, 2000) that it would share this technology at no cost with African countries. It is hoped that one day the technology used to develop golden rice and golden mustard oil might be extended to other crops such as maize, a staple food in many African countries where vitamin A deficiency is also prevalent.

Positech: a new marker system based on mannos: Marker systems currently used in transgenic research includes antibiotic or herbicide resistance genes or chemicals. Although antibiotic markers do not create a risk for farmer or consumers, but such systems are often confused with antibiotic use in health care. In May 2000, Novartis (now Syngeneta) announced "Positech" a new markers system based on a simple sugar (mannose) to grow and form new plants. Positech is an alternative to antibiotic resistance markers that has been successfully used in cassava and will be used in future transgenic research. Novartis (Syngenta, 2001) has indicated that Positech will be provided free for use in subsistence farming provided that appropriate regulations are in place to confirm user and consumer's safety and to protect local environments for modified crops.

Transgenic crops in developing countries: China is one of those countries that have swiftly adopted cultivation of insect-resistance transgenic *Bt* cotton. During 2001, the area under *Bt* cotton increased up to 1.5 million hectares compared with just 0.5 million hectares in 1999-2000. This increase in the area has resulted into increase in cotton yield up to 23 million bales, which are the highest cotton yield obtained during the last 10 years and 2.7 million bales higher compared to the yield obtained during the year 2000. United States Department of Agriculture (USDA) claims that cotton yields in China have been increasing due to widespread adoption of transgenic *Bt* cotton varieties.

South Africa currently grows *Bt* cotton (which is of particular importance to small farmers in the Makhatini Flats of KwaZulu Natal Province), yellow *Bt* corn for feed and plans to add white *Bt* corn for food to its selection of transgenic crops in 2001 (AfricaBio2, 2001). In 1999-2000, small farmers who planted *Bt* cotton in the Makhatini Flats reported increase in yield up to 40% across the marginal advantage of 35%. This is equal to 249 Rand/ha (US$ 25) and a decrease in pesticide cost of 46 Rand/ha. Together this is equivalent to 36% less than the cost estimates of the farmers planting conventional cotton varieties (Ismael *et al.*, 2001).

Mahyco, the developer of *Bt* cotton in India, are conducting large-scale field trials on *Bt* cotton. The data and information thus gathered is being prepared for presentation before a committee and it is hoped that commercialization of *Bt* cotton in India will be approved by early 2002.

Philippines developed its own transgenic rice by incorporating into IR-72 rice variety, the Xa-21 gene that is resistant to bacterial-blight. The resistance has been checked in green house and the crop is ready for field-testing. This way, Philippines has joined the group of developing countries that include Argentina, China, Cuba, Malaysia, Mexico, South Africa and Thailand that develop their own transgenic crops to the stage where they are ready for field testing. Philippine has already successfully tested *Bt* corn varieties in the field.

Indonesia has successfully commercialized *Bt* cotton as its first transgenic crop. The introductory crop occupied 4,000 hectares in Sulawesi and resulted in superior yields that produced 2.2 tons per hectare in contrast to only 1.4 tons per hectare for the Kanesia cotton (James, 2000).

Kenya conducted its first field trials of virus resistant transgenic sweet potato in 2000. This variety was developed through a collaborative project between Kenyan Agricultural Research Institute (KARI) and Monsanto of the United States. A royalty-free license from Monsanto provided the technology free of charge to KARI.

Future of biotechnology and genetic engineering: The well-documented experience of China with *Bt* cotton presents a case study where 5 million small resource poor farmers benefited from genetically modified crop. This provides a good example of how biotechnology can impact on poverty alleviation (UNDP, 2001). Resource poor farmers in Asia, Latin America and other developing countries can learn from the rich experience of China as maximum hectarage of global cotton is being grown in these developing countries. Following a successful launch of *Bt* cotton in 2001, Indonesia is also expected to expand its *Bt* cotton in 2002. India, the largest cotton growing country in the world, is progressing towards approval of *Bt* cotton, which could occur in early 2002. Thus, global area planted to transgenic crops is expected to grow further by 10% or more. Nevertheless, the issue that will modulate adoption of specific products in some countries will again be (as in previous years) public acceptance, which drives market demand, regulation and commodity prices. These issues will have impact on commercial planting of transgenic crops and consumption of genetically modified foods in countries of the European Union. However, modest progress is expected in the countries of Eastern Europe where field trials are being advanced.

The facts and figures of five years (1995-2001) on biotechnology and the genetically modified crops confirmed (per se), what was once pointed out by Conway (2000) that "crop biotechnology does have a crucial role to play in feeding the hungry of the world and the potential benefits of genetically modified crops to the developing countries are significantly increasing the likely risks, however, if new information causes this to be reversed, the component of food security would require re-thinking".

Despite this, the big question is will the genetically modified crops increase the amount of food in the world and make more food accessible to the hungry? To answer this, it is imperative that the genetically modified crops should not be seen in isolation as technical achievement but in the context in which they are developed and deployed.

The current status of biotechnology and genetically modified crops indicates that this research is so far focused mostly on single gene manipulations for two characters. This includes i) transferring to corn and cotton, the genetic material from the bacterium *Bacillus thuringiensis* (*Bt*) which produces an insecticidal toxin and ii) transferring to soybean, corn, cotton, sugar beet and canola, a gene with resistance to herbicides such as glyphosate. Application of biotechnology to help raise yield ceiling to produce crops resistant to drought, salinity, pests and diseases and to produce new crop products with greater nutritional value (Conway and Toenniessen, 1999) that can help the poor and hungry of the world are yet to appear in the market. Currently, about 200 crops are under field trials in the developing countries (Fresco, 2001) mostly of Latin America (152), Africa (33) and Asia (19). It is anticipated that the number of genetically modified crops ready for commercial release in these countries will expand considerably in the next few years. However, perception mentioned above would only be changed if at least three things inappropriate for poverty reduction within the genetically modified priorities were addressed. These include crops, traits and the target users.

i) The crops: Only seven developing countries commercially cultivate genetically modified crops on area less than 100,000 hectares except Argentina and China. Among these, China is the only exception that developed and commercialized genetically modified cotton produced locally. Rest of the countries obtained genetic constructs and varieties from the industrialized countries mostly for maize and soybean. Unfortunately, the genetically modified yellow maize varieties and the soybean varieties are almost all fed to the animals rather than being used as staples for poor people. Does this mean that suppliers of genetically modified seed companies will show little (if any) interest in self-pollinating crops like wheat, rice, millet and sorghum (the later being poor people's staple) unless they can protect their intellectual property rights (IRPs)?

Rice has become the massive exception to this rule. This is due to the combined efforts of Chinese researchers and the Rockefeller Foundation. "La Fen Rockefeller" is a rice variety that was developed through collaboration between China and the Rockefeller Foundation, USA. This variety is providing the farmers of the Shanghai region with 15-25% increase in yield (Conway, 2000). Scientists in West Africa have crossed high yielding Asian rice (*Oryza sativa*) with traditional African rice (*Oryza glebrrima*). The varieties thus developed are high yielding and require very low inputs. It is hopped that through such collaborations, developing countries can be provided access to patented biotechnology that can provide more nutritious food to alleviate life-threatening diseases that afflict the poor and their children in the third world countries. However, it remains to be seen whether these public efforts (small compared to the big budgets that GM companies allocates for animal feed) suffice to achieve major breakthroughs applicable over large areas or to rice with currently low or unreliable yields?

ii) The trait: The trait that is most widely spread by the private-sector agri-biotech companies is herbicide resistance. For example, during 2001, herbicide tolerance remained the focus of genetically modified crops with insect resistance a second priority. Herbicide tolerant soybean, corn and cotton occupied 77% of the total cropped area (40.6 million hectares) of which 7.8 million hectares (15%) was occupied by *Bt* crops, while the stacked genes for herbicide tolerance and insect resistance deployed in cotton and corn occupied only 8% (4.2 million hectares). Compared to the higher yield or greater robustness under moisture stress, this is a very low priority area for the poor because it displaces labor, especially under no till farming (Naylor, 1994) and adds little to yield. Insect resistance via *Bt* toxin has raised yield on small farms (Pray *et al.*, 2001) and created productive employment. However, it is a single gene resistance which if broken will put the poor farmers in big trouble because they may not be able to respond swiftly to tackle newly developed pest biotypes.

Shelf life and other high end quality features (like flavor saver tomatoes) also suit the well off instead of poor farmers. What the poor farmers want is genetic modification to rise yields or to permit good plant types to grow in formerly recalcitrant environments.

The examples of genetically modified plants carrying the yield enhancing traits do exist like Fan Shen yield-enhancing rice hybrids in China (Dalrymple, 1999), insertion of citric acid secreting genes against aluminum toxicity into Mexican wheat and of virus-resistant genes into Colombian potatoes and Kenyan sweet potatoes (Lipton, 1999). However, most of these are collaborative efforts of public sector institutions and the Rockefeller Foundation. The future investment of big Agri-biotech. companies on such pro-poor traits can still not be ascertained at this moment.

iii) The targets: Commercial researchers and suppliers of genetically modified crops aim at meeting market demand and therefore, select the farmers who can transport and pay for inputs, preferably with scale economies and avoiding dealer's costs. This would strongly select large farmers who are not labor-intensive. The small farmers would largely be bypassed. Thus, in the biotechnology revolution, the access advantages that a big farmer has in obtaining genetically modified seeds from private sector are much likely to be long lasting and sustainable compared to the advantages that a small farmer of the developing country used to enjoy in the first green revolution.

Exceptions to this are Argentina and Brazil, the two developing countries where genetically modified crops are also being adopted by the large farmer particularly the herbicide tolerant crop to displace human and/or weeders. Contrary to this, China is still keeping a large proportion of family farms intact irrespective of the distribution of genetically modified crops. Therefore, if golden rice were fed via CGIAR and NARSs, to the systems like in China, it would be equally welcome on small as well on the big farms.

Scientific and technical constraints in adoption of genetically modified crops: Biotechnological research can be accelerated and adopted in the developing countries to help attain food security and alleviate poverty provided certain technical and scientific constraints are removed or taken care off.

One of the major constraints is lack of understanding of mechanisms governing the traits that are very important for crop improvement. For example, drought causes severe losses of crop yield worldwide and it will continue to be among the most damaging stresses in crop production. Tolerance of crop to drought has not been well defined and it is still not clear what type of morphological and physiological traits are most important for drought tolerance. Research is therefore, needed to define a clear target in this respect (Zhang, 1999). Also, there is a dire need for germplasm, which is not available for certain traits such as resistance to fungal disease and number of pests in crop species such as sheath blight of rice, scab disease of wheat and yellow wilt of cotton. These are some of the most devastating diseases, the world over, as have borer insects of number of crops that cause heavy damage. It is widely acknowledged (Farooq, 1994) that exotic germplasm such as wild relative is infrequently used by breeders (Farooq and Azam, 2002; Duvick, 1996). The international collaboration coordinated by CGIAR may have a crucial role to play in germplasm identification, exchange and utilization.

Lack of delivery and extension system that can take the product to the farmers are other major constraints that may hinder the development and adoption of genetically modified crops in the developing countries. With the development of market economy, the old system of dispensing agricultural technologies, seeds and other material is being evolved into profit orientated seed companies. The system itself is good but will take several years to take root in the farming communities relying for ages on extension services that are now in the process of reform and transition the world over (Riveria, 1996). Pressures towards cost-recovery and privatization have led to a rapid slimming of public sector extension services in Europe, the USA and Australia over the last decade (Riveria and Gustafson, 1991), while in the developing countries, these services are facing un-sustainably high recurrent cost. The distribution channels through which, biotechnology products can reach the farmer fields are now undergoing major structural changes. Instead of old extension service providers, a wide range of public, private and non-governmental organizations (NGOs) are attempting to deliver appropriate products to different groups of farmers (Farrington *et al.*, 1993). The most efficient public sector extension services of the future are likely to focus on spheres such as geographical, thematic and social that have previously been inadequately provided by private commercial sector (Antholt, 1994). Subsequently, novel extension approaches are emerging which are farmer participatory, institutionally pluralistic and geared towards cost sharing, which may also have potential for poverty alleviation (Scarborough, 1996). It is unclear, how agricultural biotechnology research could interface with such changes especially in relation to NGOs or farmer led approaches to agricultural research and extension and how technologydisseminating organizations will meet this challenge? For the success of biotechnology, it is imperative for the agricultural biotechnologists to interact with the farmers in order to identify and prioritize i) the technologies that they need, ii) the type of farmers who could be the resultant client of the product that an agricultural biotechnologist of a particular organization is expected to produce and iii) what types of farmers and consumers will ultimately reap the benefits of that particular product? A key feature of such approaches have been farmers participatory needs through which research priorities can be determined prior to initiation of research and development (Bunders and Broerse, 1991). Since presently, most of the biotechnology research is being conducted in the developed/industrialized countries while most of structural changes in the agricultural extension and marketing sectors are taking place in the poor developing countries therefore, its likely that a large scale impact of biotechnology in the developing countries will remain skeptical especially with reference to poverty alleviation.

There is also a lack of biotechnology research that may enable a key agricultural ‘process’ at the on-farm level to improve or empower poorer farmers’ livelihood. This is possible only if there is a link between farmer participation and plant biotechnology researchers. Giving membership to the farmers’ groups who are truly representative of the needs of resource-poor farmers, agricultural biotechnology could be re-oriented towards meeting the needs of often-neglected poorer farming groups. This approach may help generate a much greater impact for poverty alleviation (Bebbington *et al.*, 1994). However, a number of important issues must be addressed if client-driven research is to actually meet the needs of resource-poor rather than richer farmers (Ashby and Sperling, 1994). For example biotechnology could become more effective and demand-driven if farmers organizations could exert their demand on research services by funding research activities that they consider are of immediate and strategic importance (Collin and Rondot, 1998).

Although the development of genetically modified crops appears to be the most promising route to increase the staples yield, the potential of this approach is locked into a system where it is not used for such purposes and where a few large firms are competitively bound to protect their investments by means that threaten the public research. Current privatizing and lock in trends range from patenting the F1 hybrids that rapidly lose vigor if kept by farmers for re-use, to Genetic Use Restriction Technology (GURT), traitor technologies or chemical activators. Where there is a competitive public and private supply, these methods need not threaten small farmers or poor consumer. Long before the genetically modified crops, patenting did very well in distributing the maize hybrids produced by private firms in the USA. There has been no single persuasive evidence to suggest the threat to framer or environment of patented technologies. But the increasing monopolization and the impending protection by a wide range of technologies of specific elite traits does appear to pave the way (albeit gradually) for the demise of public sector research and of competition from other private seed suppliers. The question arises that “are the losses due to reduction in competitive public and private research in the wake of protection of genetically modified plants via IPRs, outweighed by the large volume of research induced by such protection?”

The most compelling case for biotechnology and more specifically for transgenic crops is its potential and vital contribution to global food security as well as alleviation of hunger and poverty in the Third World. While the techniques such as IPRs and GURTs have also been developed particularly for the developing countries because it is in these countries that the seed companies are least able to enforce patents. Thus these techniques will disproportionately increase R and D expenditures for varieties suitable for developing countries. Subsequently, the big, rich and low employment farmers in the developing countries like S. Brazil and N. Argentina would perhaps use such a product. However, they would neither be encouraged to grow food staples nor they would address the mass of farmers in the developing countries. This is because developing transgenic crops implies massive investment (being further increase several folds due to regulations) and thus, need for massive returns. For example bringing a pharmaceutical to the market now costs about $ 500 million; bringing a pesticide to the market can cost about $ 200 million and it has recently been reported (Fresco, 2001) that genetically modified crops can cost about $ 30 million to produce plus regulation costs of about $ 5-6 millions. What crop can bear such high costs in the commercial market? How are we going to serve the local needs, poor consumers and small farmers in the developing countries who are unattractive targets for big, private seed supplies because most of these farmers are not just illiterate but they are also out of reach, hard to deliver the goods and to recover the investment? Such situations and other like small number of genetically modified technologies currently in use indicates a real danger that the scale of the investment may lead to selective concentration on species and problems of global importance and not on the problems of small farmers in developing countries who are in grate majority.

The UPOV legislation demonstrated that incentives from IPRs (legal or technical) raises the amount of private research (Pray and Knudsen, 1994), but technical IPRs such as GURTs, create property rights that accrue to and encourage research by, only final developers. Incentives do not reach originators whether they are farmers or researchers who selected and developed seeds over generations, or researchers belonging to National Agriculture Research Stations or CG centers. Giving all the rights to the final developer through GURTs and giving nothing to the breeder or the original farmer will be uneconomical and will not take us anywhere. The selective development and use of increasingly enforceable IPRs along with their technicalities will not only encompass one’s own but also the other’s intellectual property ands will have even more serious effect. For example an elite line that may serve poor and dispersed farmers living in remote areas in many countries, if locked in private research will gradually squeeze out despite its high returns (Alston *et al.*, 1998) and despite the unique incentives to work on its various aspects. This would only delay the access of biotechnology to the developing countries that seek new knowledge in their quest for food security.

Scenario after September 11th 2002: It is anticipated that following the terrorist attacks in the USA on September 11th 2001, global poverty will increase by 10 million more people in 2002 (Anonymous, 2001). Growth rate of developing countries could be as low as 2.9% in 2001 compared with 5.5% in 2000. For 2002, lowered growth rates for developing countries in the range of 3.5-3.8% are projected as compared to 4.3% predicted before 11 September. Africa is expected to suffer most of the economic damage from the continued economic slowdown and there will be an addition of 2 million more Africans surviving on less than $1 a day. Africa was judged to be the most vulnerable because many African nations do not have the means to stabilize their economies when prices of the agricultural commodities on which they are dependent will fall. Consequently, farmers, rural laborers and others tied to agriculture will bear a major portion of the burden. Almost similar rather than worst situation is prevailing in Pakistan where growth rate of the country remained lower (2.6%: FAO, 2002) than the lowest forecasted (2.9%) for the developing countries The World Bank (Anonymous, 2001) recommended that donor countries should increase aid, reduce trade barriers for developing countries and urged the donor community to coordinate its economic reform policies. Under such situations, not only that the agri-biotech companies but the WTO will also have to play extraordinary role by facilitating cultivation of genetically modified crops in the developing countries to attain food security and to alleviate poverty. Liberalization of trade, overseeing the implementation of Agreement on Trade Related Aspects of Intellectual Property rights (TRIPs) and establishing an advisory body to provide direction in the implementation of science-based decisions may also help improving the situation.

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