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Biotechnology: Promethean Science or Obsession?

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Introduction

According to Rick Weiss (science writer), science is an elegant way of getting the truth. Molecular biology and other tools of modern biotechnology add elegance and precision to the pursuit of science. However, everyone cannot appreciate this elegance in the pursuit of truth, which is finding solutions to thwart poverty, malnutrition and food insecurity in many developing countries. Instead this elegance is being used for a debate focused on its initial use in the industrialized countries and its potential risks to human health and environment. The debate about the potential utility of modern biotechnology for food and agriculture presents a challenge for modern sciences to contribute to the solution of human problem. Those who accepted the challenge believe that biotechnology is a Promethean science [In Greek mythology, Prometheus was a Titan who introduced to the human being "Fire": an innovation with enormous benefits and risks depending upon its use; since then Promethean means daringly original and creative], while those who are skeptical view this as a scientist's obsession. In the present attempt, biotechnology is being presented as a continuum of biological sciences, which has evolved with the passage of time depending upon its needs. The risk and benefits associated with this technology has also been explained along with the possible reference to the context. The readers are the best judge to decide whether biotechnology is a Promethean" science or a scientist's obsession.

The history of scientific progress and concerns

Mendel's laws of genetics based on inheritance patterns in pea were originally published in 1865 but it took 35 years for others to grasp their significance when they were re-discovered in 1900 and another 20 years to take control over genetic traits when Muller Stadler discovered (in 1920) that radiation could induce mutations in animals and plants. Since then, science has witnessed steady progress in understanding the genetic makeup of living organisms including microbes, humans and plants.

Between 1930s and 1940s, several new methods of manipulating chromosomes and genes were discovered, such as the colchicine-induced doubling of chromosome number, commercial exploitation of hybrid vigor in maize and other crops, use of chemicals (such as nitrogen mustard and ethyl methane sulphonate) to induce mutations and tissue culture/embryo rescue techniques to make viable hybrids from distantly related species. The discovery of double helix structure of DNA by James Watson and Francis Crick in 1953 triggered an explosive progress in every field of genetics the "Green Revolution" being an outcome of that.

The last decade of 20th century witnessed a rapid transition from Mendelian to molecular genetic applications in agriculture, medicine and industry. The progress in genetics from 1900 to date has, therefore, stressed that knowledge and discovery represent a continuum, with each generation taking our understanding of the complex web of life to a higher level. It would, therefore, be a mistake to worship or discard experimental tools or scientific innovations because they are either old or new. Just as it took 35 years for biologists to understand fully the significance of Mendel's work and another 6 decades to see its miracles, it may take a couple of decades more to understand fully the benefits and risks associated with new genetically improved organisms: a process that has been accelerated by Human Genome Project that involved investment of substantial public and private resources into the development of new technologies to work with human genes. The same technologies are directly applicable to other animals and plants thus giving rise to a new scientific discipline known as genomics, which has contributed to powerful new approaches for identification of genes and their application in agricultures and medicine. We must now think how to use biotechnology effectively in our scientific endeavourers. However, before this we must take a stock of the Green Revolution and the reason(s) forcing us to use new technologies.

The Green Revolution:

The term "Green Revolution" coined in 1968 by the late William Gaad was stimulated by the first good harvest of wheat in India and Pakistan in 1968. This was largely caused by widespread introduction of semi-dwarf varieties of wheat supplied by Dr. Norman Borlaug. At that time, both India and Pakistan had a fairly large quantum jump in terms of wheat production, which instigated "Gaad" to coin the term "Green Revolution". At the same time, the high yielding rice variety IR-8 from the International Rice Research Institute (IRRI), Philippines, had become available. Thus, in the next few years, both rice and wheat production started moving forward in many parts of Asia and Latin America and in some pockets of Africa as well.

Green revolution technologies provided fine examples of genetic manipulation using complex set of breeding and selection procedures through which the "Norin-10" and the "Dee-gee-woo-gen" dwarfing gene were introduced into commercially acceptable varieties of wheat and rice, respectively. The real magic of the revolution was evidenced through rice for which per capita production went up and the per capita area went down. Between 1968 and 1988, it was widely accepted and proved that Green Revolution technologies are aimed at yield enhancement and land saving approaches. As a result farmers of the developing countries irrespective of their holding were enormously benefited. The global cereal production doubled, per capita food availability increased by 37%, per capita calories available per day increased by 35% and real food prices declined by 50%. Global poverty fell fast between 1965 and 1985 mainly due to agriculture research that increased cereal yield and created more work places for the adults.

After almost thirty-two years of Green Revolution, a new thrust is needed because 800 million people still have too little to eat. Many live with agriculture almost untouched by the Green Revolution. Food farming is increasingly dogged by water shortage and diversion. Most worryingly, since mid 1980, progress against poverty has slowed down sharply and so has progress in yields of main food staples in the developing countries. Malnutrition is still responsible for the deaths of 5 million children annually in the developing countries and affects 20-25% of their economic growth due to childhood sickness. Today, one third of pre-school 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 is still lagging behind the region in having their per capita calories below minimum requirement (Farooq and Azam 2002).

The critics of the technology say that it was not resource friendly because the inputs (fertilizer, pesticide and irrigation) were required according to the estimated outputs (yield) and were beyond the capacity of resource-poor farmers who were unable to achieve the true potential of the technology. Some other concerns were also raised such as economics (the ability of the very poor farmers to adopt such technology), equity (in terms of inter and intra-generational equity particularly the impact on women), employment (whether the technologies are labor-displacing or labor-diversifying), ecology (such as genetic homogeneity arising from the replacement of a large number of local varieties by one or two high-yielding, high-tech cultivars over large areas and the problems arising from pesticide residues, excessive use of fertilizer and emergence of new pests and pathogens) and energy (in terms of increasing dependence on fossil fuel-based sources). The failure to make such distinctions in the early days led to a considerable degree of criticism, that Green Revolution technologies had "in-built" seeds of social discrimination. This criticism was mainly due to inadequate interaction with social scientists right from the early planning of such work. The role of the whole set of services, including credit and government policies for input/output pricing, agrarian reform and rural infrastructure development were never planned at initial stages.

Green Revolution disproportionately benefited the rich in the early years (McCalla and Brown, 2000) by giving them the necessity for complementary increases in fertilizers, pesticides and irrigation. Therefore, despite its massive performance, hundreds and millions of people are still food-insecure. This insecurity is not due to lack of overall production but more to the location of production and the access to food by countries, household and individuals living on the edge of subsistence. It also contributed to environmental degradation to the extent that millions of acres of arable land went barren due to water logging and salinity: an outcome of extensive irrigation. The next agricultural revolution must learn some lessons from the past. It must benefit the poor, improve the existing state of environment and do no harm in terms of further degradation. The next technology-driven revolution must be doubly green, increase food production at a faster rate than observed in recent years and in a sustainable manner without significantly damaging the environment. It should also improve rural income and increase accessibility to food by the poor.

Contrary to all these concerns, the miracle of the past four decades is that today's farmers are feeding almost twice as many people far better from virtually the same cropland base. The world used about 1.4 billion hectares of land for crops in 1961 and only 1.5 billion hectares in 1998 to get twice the amount of grain and oilseeds. Producing today's food supply with 1960 crop yield would probably have required at least an additional 300 million hectares of land; an area equal to the entire landmass of Western Europe. However, ***it must not be taken for granted that the current balance between overall food supply and demand will persist***. It has been the result of successful interaction among farmers, input supplies and an overwhelmingly supported public research and extension system that furnished innovations and relevant knowledge free of any cost. Little land remains now for agriculture expansion. Water and other natural resources needed for agriculture are being degraded and diverted to other uses. Therefore, in order to increase food production and maintain it at the higher levels for foreseeable future, continued strong performance in research and innovation is needed if we are to feed 3 billion more people over the next half century in addition to the 6 billion we already have. With the dawn of 21^{st} century, whole new vistas in agricultural R&D were opened up and "Biotechnology" is just one of them, which has the potential to contribute substantially to this objective.

What is biotechnology and its components?

Biotechnology is any technique that uses a living organism or substances from organisms to make or modify a product, improve plants or animals or develop microorganisms for specific uses. The key components of modern biotechnology are:

- Genomics: the molecular characterization of all species
- Bio-informatics: the assembly of data from genomic analysis into accessible forms
- Transformations: the introduction of one or more genes conferring potentially useful traits into plants, livestock, fish and tree species
- Molecular breeding, the identification and evaluation of desirable traits in breeding programmes by the use of marker-assisted selection, for plant, trees, animals and fish
- Diagnostics: the use of molecular characterization to provide more accurate and rapid identification of pathogens and other organisms and
- Vaccine technology: the use of modern immunology to develop recombinant DNA vaccines for improving control against lethal diseases

To use this technology effectively in our scientific endeavors we must know the risks and the benefits associated with it. Also, before its application, we must ask:

- What are the challenges of the future agriculture?
- What are the opportunities for deploying biotechnological approaches to meet these challenges?
- What are the potential constraints that the developing countries may face in using these approaches?

The risks

Ever since its inception, biotechnology has become a lightning rod for an increasingly impassioned debate with opposing factions making strong claims of promise and of peril.

Opposition to biotechnology and specifically to genetic engineering is derived from several viewpoints. These include fears of high-tech farming destroying the livelihood of small holders, concerns about artificially created products competing with and destroying the marketability of "natural" products and the presumption of environmental threat. However, the major concerns are ethical, bio-safety and patents and Intellectual Property Rights (IPR).

Ethical concerns

Many critics fear that biotechnology is a scientist's obsession, which is being exploited to bring quick profits to the few even though it can do great harm to the majority. Those who hold such views are profoundly concerned that the increased application of biotechnology will harm not only us, but our future generations as well. These concerns are genuine and cannot be ignored.

Transforming a particular variety of plant through transferring genetic material from another variety of the same species should not pose any sort of problem because this would be nothing but an accelerated way of achieving through biotechnological means an objective that could also be achieved through conventional breeding. Bioengineering of plants through genetic transfers involving related but different species of plants such as wheat and barley may also not be problematic. This way, we may already be tinkering with nature, but the boundaries of conventional or "natural" breeding system are so overlapping that this would also be acceptable because the likely result of such a gene transfer is unlikely to significantly modify or denature the plant. ***Triticale*** is one such example.

Beyond this, improvement of plants or creation/evolution of new varieties depends upon the collection and assemblage of desirable traits from individual plant species or even form other organisms. Critics of biotechnology say, that this way, scientists are "tinkering" with the natural order of things. However, one can argue (and rightly so) about our very own presence on this planet earth. Are we not changing the natural order of things by increasing in number, using more powerful technology and insatiable appetites for consumption and pollution? Indeed all these are affecting nature mostly in negative and potentially dangerous way. Global warming and biodiversity losses are two examples to illustrate this situation. Yet all these are as per general proposition of doing something for the welfare of human beings.

Had we encouraged societies of hunter and gatherer to live constantly in harmony with nature then today's people would have been living in squalor, want, disease and premature death. A human treatment required improved diet, education and health and resultant reduction in infant mortality (thereby increasing the number) and increase in consumption, which collectively assert a pressure on the natural system. The question is how to handle this pressure and to ensure that the patterns of development adopted are sustainable. It does not make sense to undermine the ecosystems on which our long-term survival depends. Therefore, this matter has become a calculus of potential benefits and potential risks associated with change, including the adoption of new technology.

Bio-safety concerns

The major risk associated with biotechnology, which could create potential export trade problems for developing countries, is difference of opinion regarding food safety and bio-safety in industrial countries. Development of new transgenic varieties [The term "transgenic" is used for genetically modified organisms or GMOs and refers to organisms that have been modified by the application of recombinant DNA technology, where DNA is transferred from one to another organism] of developing country's food crops is likely to fall outside present food and environment safety testing in industrial countries. Consumption patterns may render developed county's bio-safety systems less relevant. The lack of an export market for many of these food crops may also leave food safety testing outside the Codex. Since many of these food crops are not consumed in industrial countries, they would not have been tested for human consumption there. This difference may lead to the development of non-tariff barriers to trade, which developing countries have less ability and resources to address in the international arena. Biotechnology is therefore, a solution not without problems, but it is the one we cannot afford to ignore. For example, in pharmaceutical sector, new drugs are being introduced every other day and none of them is 100% risk free. Nevertheless, careful evaluation through extensive clinical trials indicates that the benefits outweigh the risks when taken under prescribed conditions. Likewise, there is no such thing as 100% safe food in today's world. There were 6.5 million cases of food poisoning in the United State of America in 1992, resulting in 9000 fatalities. But, if the benefits of the technology outweigh such risk one should move forward with both good science and effective public education. Incentives are needed for research on developing country's foods crops without which poor farmers and consumers in these countries will not have access to and benefits of technologies that would allow them to increase their productivity. It is therefore, imperative that the risks and benefits are carefully evaluated both at global and national open fora, ensuring that the risks and benefits to all potential beneficiaries are recognized and considered.

Patent and Intellectual property right (IPR)

Another most crucial issue related with biotechnology is that of patenting to which there is no direct answer. The ownership of animals and plants is recognized and so is the right of owning and sale of a particular breed. Varieties of flowers and livestock are also owned and sold; breeding of horses and other show animals is recognized. Therefore, patenting of a gene or gene sequence should not have been offensive. The offense, however, lies in the idea of owning a "building block of life" rather than the actual living creature itself because building block in question can be a part of many other living things. This is an issue, which cannot be easily defined to the satisfaction of the majority.

Intellectual property right (IPR) is another hot issue. Supporters of patenting point out that if the private sector is to mobilize and invest large sums of money in R&D of agricultural biotechnology, it has a powerful claim to protecting and recouping what it has put into the exercise. The other side of the argument is the fear that patenting and exercise of IPR will lead to monopolization of knowledge, restricted access to germplasm, controls over the research process, a selectivity in the focus of research and thereby, increasing marginalization of the majority of the world's populations. Apparently, any legislation on these issues will not function unless it has the support of the majority, which can best be achieved through education and scientific evidence and not through the assertive preemptive action by a vocal minority.

It is worth mentioning here that green revolution took place mainly in public sector research establishments, in an era of free-of-charge and an open access to genetic resources. Today's biotechnology revolution is taking place largely in the private sector with associated intellectual property protection. This is being done to the benefits of the companies and allows them to recoup in the marketplace the often-high R&D costs involved. For example, bringing a pharmaceutical to the market now costs about US$ 500 million; bringing a pesticide to the market can cost about US$ 200 million and bringing a genetically modified crop in the market can cost about US$ 30 million to produce plus regulation cost of about US$ 5-6 million. What crop can bear such high costs in the commercial market? The private sector therefore, has to protect their investment through the so-called discriminatory laws such as patenting and IPR.

The benefits

In the 21st century, the world of science has grown and changed beyond most of the expectations. Today, a revolution is taking place due to huge investments in biotechnology, enormous advances in computing and informatics and ground breaking work in modern molecular biology. This progress has helped decoding the very blue print of life and learning to manage the deployment and expression of gene. Those who have excelled in these techniques are enjoying the benefits of high yielding and environment friendly plants and new remedies for killer diseases that many others can dream of.

Enhanced productivity and improving quality

Modern biotechnology has been used successfully in agricultural research institutes. The un-controversial techniques such as tissue culture, gene mapping and molecular markers have been and are being used since long to improve efficiency of plant breeding system and improving developing county's food crop. A recent advance using these techniques by the West African Rice Development Association (WARDA), has resulted in a successful cross of traditional African rice with high-yielding Asian variety. An exciting development from this work is the creation of new plant type that can, during its early stages of growth, shade out weeds, similar to the African variety, but has the high yield capacity of Asian rice. In essence the best characteristics of both rice types have been combined, including drought tolerance, disease and pest resistance and high yields.

The potential of biotechnology can further be evidenced from the production of a) "Golden Rice" containing the gene that enhances Vitamin A and was transferred from "Daffodils" and b) bioavailability of iron in rice, a gene that was inserted from "French bean". The potential of these advances are enormous as more than two billion people are anemic due to iron deficiency. In developing countries, 180 million children die annually from diseases linked to vitamin A deficiency, especially in Asia where poor children are weaned on rice gruel.

Reduction in pesticide use

One of most significant impacts of the biotechnology being observed consistently during the period 1996-2000 (when first transgenic crops were adopted) is consistent reduction in the amount of pesticides used in the production of transgenic crops. Both Bt and herbicide tolerant crop varieties of soybean, corn, cotton and canola, have contributed to this reduction in different countries (Table 1). Studies have shown that during 1998-2000 a total of 23,100 tons of active ingredient of pesticide have been reduced in different countries (Table 1).

Table 1: Pesticide reduction for selected transgenic crops in different countries during 1998-2000

Country/Year	Crop	Quantity of active ingredient reduced
USA/1998	Bt. cotton	900 metric tons of insecticide
USA/1999	Bt. cotton	1200 metric tons of insecticide
China/1999	Bt. Cotton	15,000 metric tons, (formulated)
Canada/2000	Herbicide Canola	6000 tons herbicide

Source: Clive James, 2001.

By reducing massive amount of active ingredient, not only the environment is being gradually improved but efficiency of pest control has also enhanced by reduced cost and the number of sprays some of which damaged the soybeans and resulted in residues harmful for the following crops such as corn.

Improved pest control and productivity

One of the most significant benefits of transgenic crops is that they provide with improved methods of insect pest control. Effective deployment of Bt crops eliminated the yield loss that results from less than optimal pest control by insecticides and provides the farmer with more flexibility and time for other farm duties. This effective control results in higher yields. For example, by growing corn varieties resistant to European Corn Borer (ECB), US corn grower produced 1.5 and 1.7 million tons of more corn in 1998 and 1999, respectively compared to the quantity that they produced with non-transgenic crop.

Food safety and health hazards

Approximately 59% of corn grain samples collected globally are contaminated with fumosins: a secondary toxin produced by ECB. These toxins are detected in corn grown in the warm and subtropical conditions with highest contamination occurring in Oceana (82%), Africa (77%) and North and South America (63%). The incidence of contamination in commercially available corn products made for human consumption varied from 47% to 82%. Fumosins can produce fatal brain damage in horses when fed at the level =10 mg Kg^{-1} or higher, liver and kidney damage in many species and liver and kidney cancer in rodents. The highest level of fumonisins contamination in corn has been reported in Africa and China, which is the major cause of esophageal and liver cancer reported in subsistence farmer who consume corn as a major dietary staple. Genetically modified corn plant with Cry 1Ab insect control protein from ***Bacillus thuringiensis*** (Bt) are protected against damage from corn bores and reduce fumonisins levels up to 90 % compared to conventional corn plants. Thus, protection of corn against insect damage may have important health implications for farmers and farm animals that are routinely exposed to fumonisins.

Decreases in pesticide poisoning

There are roughly 50,000 pesticide poisoning cases per year reported in China of which 50 result in death. Farmers using Bt cotton suffer less pesticide poisoning than farmers growing conventional cotton. Bt. cotton farmers used 80% less insecticide than the 48 kg ha^{-1} of formulated insecticide used by farmers growing conventional cotton varieties. This is of tremendous significance for developing countries where small farmers are at particular risk to pesticide poisoning when applying insecticide with hand sprayers under difficult and often unsafe conditions.

The benefits outlined above are only some of the realities of modern sciences while one can dream of new scientific brake-through and new products such as edible vaccines, single cell proteins to feed cattle and clean wastes, hyper-accumulating plants to take toxins out of the soil, expanding forests and habitats where more species can thrive, sustainable development where human thrives in harmony with each other and with the environment and much more that can help humanity as never before. These opportunities are necessary focus of interest among all of us who believe that the full potential of science has yet to be realized in our continuing efforts to fight poverty and hunger, increase agriculture productivity and protect the environment.

The relevance of biotechnology to such objectives is now at the forefront of international interest. The perceived promise and perils of biotechnology are under intense public scrutiny. Firstly, despite the great advances made in the last decade of the 20^{th} century, development challenges have grown more complex. In the new millennium, the demographic pressure is unprecedented. The world's population is expected to exceed 8 billion by 2025 i.e. an increase of 2.0 billion in the next 25 years. Much of these increases will occur in cities of the developing countries where urban populations will be more than triple as per calculations made by Norman Borlaug, to meet projected food demands by 2025, the average yield of all cereals must be 80% higher than the average yield in 1990, which should primarily come from increasing biological yield and not from area expansion and irrigation, because both these commodities are becoming increasingly scarce. Poverty and hunger will remain pervasive in the world. Despite massive burst of output and productivity, dazzling changes wrought by science and technology and the amazing achievements recorded on the planet, the 47 least developed countries (LCDs) of the world (10% of world's population) still subsists on less than 0.5% of the world income. Some 40,000 people die from hunger related causes every day. A sixth or more of human family has been marginalized. The challenges are therefore:

a) Comprehending and preparing for unprecedented increase in global population
b) To ensure that this population has access to food in adequate quantities at adequate prices, everywhere, at all times
c) To produce this much food in a way that does not destroy the natural resources on which we all depend.

These challenge are both technological (requiring the development of new, high-productivity, environmentally sustainable production systems) and political (requiring policies that do not discriminate against rural areas in general and agriculture in particular) and will have to be accomplished at a time when attention to agricultural development and rural well being is diminishing. An essential aspect of the response to this challenge is to harness all instruments of sustainable agricultural growth. Agricultural biotechnology is one such instrument. It has moved to the center of the development debate fairly recently and that marks it out for particular interest and indeed concern.

Another reason for the current scrutiny is that in recent years, agro-biotechnology has exploded into a major private sector activity, mainly in the industrial countries, with possibilities of even greater expansion in the future. The global area planted with transgenic crops was 2.8, 12.8, 27.8, 39.9, 42.2 and 52.6 million hectares in 1996, 1997, 1998, 1999, 2000 and 2001, respectively (James, 2001). Data obtained during 1996-2001 from 16 different countries indicated that genetically modified crops could meet the expectations of both large and small farmers in developed as well in developing countries. The beneficiaries in 2001 were resource-poor farmers who planted ***Bt***. cotton. An important finding of the study made on ***Bt***. cotton in China was that the smallest farmers who planted less than I hectare, gained more than twice as much income per unit of land (US$ 400 per hectare) from ***Bt***. cotton as the larger farmers (US$ 185 per hectare). Global market for transgenic crop has grown from US$ 75 million in 1995 to US$ 3 billion in 2000 and is projected to reach US$ 8 and 25 billion in 2008 and 2010, respectively. So, the biotechnology revolution is there but it has so far been very much the preserve of the richer countries, a fact that has distorted the debate on what biotechnology can do for the poor.

The situation in the developing countries

As pointed by Miguel Altieri (2002), an estimated 1.4 billion people live and work in the vast, diverse and risk prone rain-fed areas in the developing word. These people will not benefit in the foreseeable future by any of the current biotechnological techniques because their systems are usually located in heterogeneous environments and are too marginal for intensive agriculture. They are mostly located far from the markets/institutions and tackling simultaneously, the objectives like poverty alleviation, food security and self-reliance, ecological management of productive resources, empowerment of rural communities and establishment of supportive policies. To achieve these objectives, the scientific strategy must be applicable under highly heterogeneous and diverse conditions in which small holders live. These strategies must be environmentally sustainable, based on the use of local resources and indigenous knowledge and should emphasize on improving whole farming system rather than the yield of specific commodities. The technologies generation process should be demand driven i.e. according to the socio-economic needs and environmental circumstance of resource poor farmers. ***Modern biotechnology does not meet any of these requirements***. Thus, a debate based on the best available empirical evidence on the relevance of modern science for poor people in the developing countries with a purpose to identify the most appropriate ways that molecular biology-based research might contribute to the solution of poor people's problems is lacking.

The problems of the poor countries are very different from those of the developed countries problems and context of the countries where most of the biotechnology debate currently takes place. Therefore, the position and conclusions from the current debate would largely be irrelevant for poor farmers and poor consumers in the developing countries. A more focused debate on the role of agricultural biotechnology in developing countries led by their own people would help identify and solve the problems. Because agriculture resources are diminishing, there is no option but to produce more food and other agricultural commodities from less arable land and irrigation water. It is needed therefore, to examine how science can be mobilized to raise further the biological productivity ceiling without associated ecological harm. Scientific progress on the farms as an evergreen revolution must emphasize that productivity advances are sustainable over time since it is rooted in the principle of ecology, economics, gender equity and employment generation.

Global challenges vis-vis biotechnology

The most important global challenges are:

i) Alleviating poverty, improving food security and reducing malnutrition of the rural poor and
ii) Providing sufficient income for the rapidly increasing numbers of urban poor

To meet these challenges it is imperative to address the associated problems such as:

i) increasing population
ii) increased demand for food
iii) reduced per capita availability of arable land and irrigation water

In global terms, increases in world food production kept pace with the increases in the global population to date. According to the latest projections, world food supply will continue to outpace population growth world wide, at least up to 2020 because per cap capita availability of food has increased since 1993 and also is projected to increase around 7 percent up to 2020. Despite this, approximately 0.8 billion of the global population of the 6 billion are food insecure. This is because there is an intrinsic linkage between poverty and food security. The access to food depends on income and in the developing countries, more than 1.3 billion people are absolutely poor, with incomes of a dollar a day or less per person, while another 2 billion people are only marginally better off. These poor people are living mostly in the remote rural areas and under diverse environmental conditions in different part of the world (Fig. 1). The maximum number (≃= 48% to its total population) of these people are living in Sub-Saharan Africa, followed by South Asia (≃= 39% of its total population), while the minimum (≃= 5%) lives in Latin America and are mainly dependent on agriculture for their livelyhood (Fig. 2). Rural poverty thus, represents a very high percentage of the overall poverty, which will increase further and will certainly affect many more people globally. However, with increasing urbanization, an increasing proportion of poor people will be living in the cities of the developing countries in the next century thus, the number of people dependent on agriculture will decrease further as is evidenced in Fig. 2. Nevertheless, they will still be in a very high proportion (between 15-55%) and will demand help from modern biotechnology to provide them with the food security for the years to come. They will need biotechnology that can increase rural instead of urban income because this will be designed to help the poor both in rural and urban areas by reducing rural-urban migration and thus, competition for urban workplaces. However, any increase in income is only possible by increasing the agriculture employment. The question is: how biotechnological research can help increasing this employment?

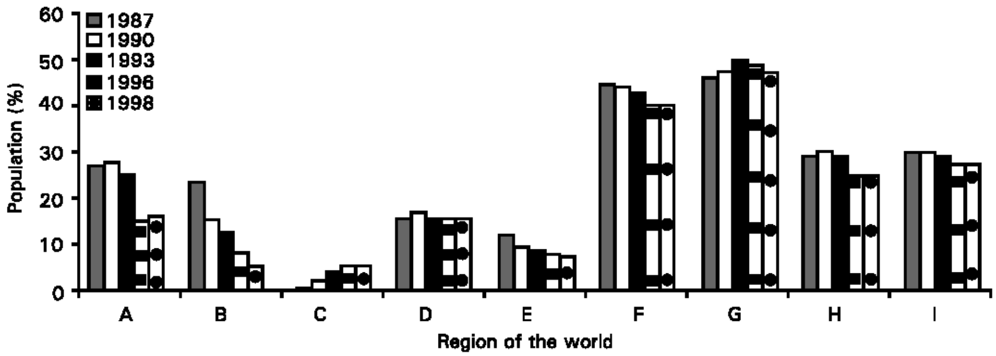

Fig.1: Detail of population (% of total) living below US$ 1 per day as estimated during 1987-1998 in East Asia and Pacific (A), China (B), Eastern Europe & Central Asia (C), Latin America and Caribbean (D), Middle East and North Africa (E), South Asia (F), Sub-Saharan Africa (G), Average total (H), Average total, excluding China (I). Source: World Bank Report, 1999.

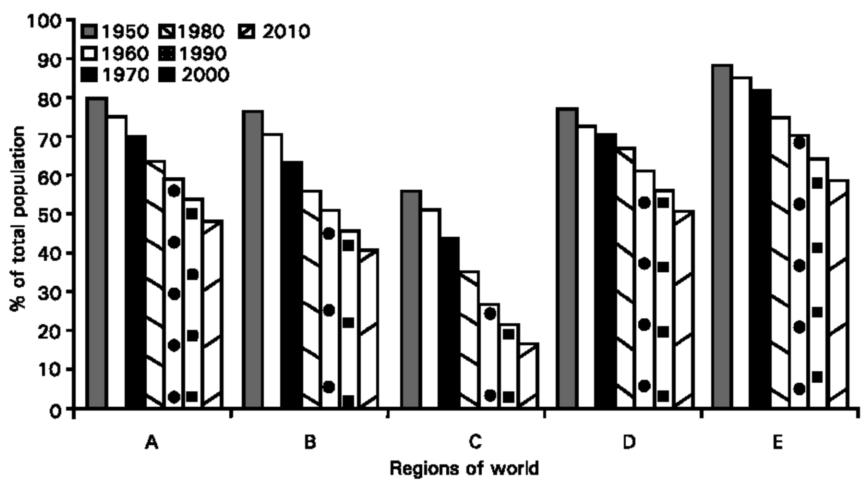

Fig. 2: Number of people (% of total population), mainly dependent on agriculture in Developing countries (A), East and Southeast Asia (B), Latin America & Caribbean (C), South Asia (D) and Sub-Saharan Africa (E). Source FAOSTAT, 1999.

This question becomes increasingly important while keeping in view that environmental and social implications of the new technologies, especially the biotechnology, are yet to be fully understood. Also, there is much to learn from the past in terms of ecological and social sustainability of technologies, including traditional and those that are under pinned the Green Revolution technologies if the emerging problems are to be solved and the new challenges are to be met amicably. Since enormous new development in science have opened up new opportunities to develop technologies, it is possible to have high productivity without adverse impact on natural resources base. A strong component of "Agricultural Research" would be required to blend traditional and frontier technologies, which may eventually lead to the birth of eco-technologies with combined strength in economics, ecology, equity, employment and energy.

Significance of research in Agricultural Biotechnology

Pardey and Beintema (2001) provided an overview of the status and key trends in global agricultural research. They estimated that investments in public agricultural research rose from US$11.8 to US$21.7 billion from 1976 to 1995 (Table 2).

Considering the latest figures (1995), a total of 47% of investments were made in developed countries while 53% went to developing countries, specifically to China (10%), Asia and Pacific, excluding China (21%), Latin America and the Caribbean (9%), the Middle East and North Africa (7%) and Sub-Saharan Africa (6%). The influence of individual countries was quite significant. Four countries (France, Germany, Japan and the United States) accounted for two-thirds of the spending in developed countries while three countries (Brazil, China and India) accounted for 44% of spending in developing countries. This means that only 8.9% of the total investment made in developing countries were used in the remaining countries. This amount is quite small when expressed as percentages of the agricultural Gross Domestic Product (GDP) particularly in the developing countries (Table 3) and represented just 0.6 % i.e. for every US$100 of agricultural outputs, developing countries are investing only US$0.61 in public agricultural research and development. The developed countries on the other hand are investing 2.31% of the agricultural GDP in the public sector. In addition to that some US$11.5 billion (only during 1990's) were invested in the private sector, which is roughly one-third of the global agriculture research investments. Consequently there was an enormous progress in the developed countries. In developing countries, research was almost totally funded by the public sector and this is one of the reasons that progress similar to that achieved in the developed countries could not be achieved in the developing countries.

How should developing countries do this research?

Biotechnology clearly offers tremendous promise for addressing key problems in food and agriculture. However, as mentioned in table 3, resources for agricultural research is very limited in developing countries consequently, their policy makers are faced with a series of very difficult choices. How much importance should they give to biotechnology research? How should they allocate the biotechnology research resources with respect to the different agricultural

Table 2: Public research expenditure (million dollars) and annual growth rate (percent per year) estimated globally during 1976-1996

Countries	Nos.	Expenditure 1976	1985	1995	% of total
Developing countries	119	4738	7676	11469	52.9
Sub-Saharan Africa	44	993	1181	1270	5.8
China		709	1396	2063	9.5
Asia and Pacifica*	23	1321	2453	4619	21.3
Latin America and the Caribbean	35	1087	1583	1947	8.97
Middle East and North Africa	15	582	981	1521	7.01
Developed Countries	34	7099	8748	10215	47.1
Total	153	11837	16424	21692	

Source: Pardey and Beintema, 2001, * excluding China

Table 3: Worldwide investments made in the field of science and technology up to 1995.

	Science expenditures Share of GNP*	Share of GDP**
Developing countries (109)[a]	14.7	0.61
Africa (24)	0.6	0.34
Asia (43)	9.9	0.70
Latin America (28)	2.5	0.50
Middle East and North Africa (12)	1.5	0.57
Developed countries (30)	85.3	2.31
Total (139)	100	1.64

*Gross National Product; ** Gross Domestic Products,
Figures in parenthesis are number of countries in each region,
Source: Pardey and Bientema (2001).

sectors or to the different kinds of biotechnologies available? How should they prioritize different kinds of problems (and specifically those affecting poor farmers) that might be addressed by the research? [It should be kept in mind that the exaggerated importance being given to biotechnology in terms of funds and scientific talent and its preoccupation is for goals that are not always the priority in the short-term fight against hunger and poverty. Much of what is happening today is because of the hype and the charm of a new and fashionable science, whetted by the interest shown by huge biotechnology companies].

To be of benefit to the rural poor, agricultural research and development should operate on the basis of "using and building upon" the resources available already through local people, their knowledge and their autochthonous natural resource keeping in mind the aspiration and circumstance of small holders. The research agenda must include:

Crops with improved agricultural performance (yield) and reduced usage of agricultural chemicals (we must weigh biotechnological vs cheaper conventional technologies to achieve this), Improved food quality (is this the priority for the short term need of poor nations?)

Ability to grow plants in previously inhospitable environments via increased ability of plants to grow in conditions of drought, salinity, extremes of temperature: a expected consequence of global warming. [we have to decide which is easier, deployment of stress-tolerant crop varieties through biotechnology and sold for a price all over the world, or work towards rehabilitation of the land and preventing the worsening of situation]. We should therefore:

I) Think how to improve understanding of marginal agro-ecosystems,
ii) Select varieties that can give stable yields under any of the environmental stress,
iii) Adopt cheaper and easily adoptable technologies of water saving and drought management
iv) Choose synergetic, diversified and less risky cropping and crop-livestock systems providing more stable yield
v) Select productive and sustainable agro-forestry alternatives for shifting cultivation and
vi) Adopt sustainable income and employment generating exploitation of forest, fisheries and natural resources as well as research reforms and access to local market etc.

How should developing countries carry out research to work on this agenda?

- By focusing on their National Agricultural Research System (NARS)?
- In collaboration with other countries in their region?
- With the private sector? Or with the universities in the developed world?
- With what objectives (e.g. increased production, better animal health etc.) and at what level (Federal or Provincial level, in public or private sector) should the objectives of research in agricultural biotechnology be prioritized?
- Should some (or all) of the biotechnology research in developing countries preferably be carried out within the NARS or through collaborative regional efforts?
- Should developing countries focus on developing the biotechnology products themselves or should they focus on adapting biotechnologies that have been developed elsewhere
- Individual developing countries differ greatly in their capacities to do biotechnology research and in the resources they have available for such activities. How important are these differences for the role and focus of biotechnology in the agricultural research agenda?

- The needs of small farmers are generally being ignored in the so-called "biotechnology revolution". How can the biotechnology research agenda in developing countries be focused towards their needs? What concrete actions can be taken?

These are the kinds of issues that should be thoroughly raised and discussed if biotechnology is to be deployed for the benefits of the poor in the developing countries. More specifically, it should be discussed, how much of the limited resources (human and financial) dedicated to agricultural research in developing countries, how much should be devoted to biotechnology?

What are the opportunities for deploying biotechnological approaches in the developing countries?

Some of the biotechnologies particularly, offer tremendous potential to address real problems facing farmers in developing countries. For example, the area of genomics, allowing the identification and characterization of individual genes influencing traits such as disease or stress resistance, growth rate or yield and are of great value. The genetic material (genomes) of several hundred species, including mammals, plants, fish, bacteria and viruses, has already been sequenced or sequencing is in progress and the information generated from genomics studies in other fields, such as human medicine or basic science, may also be useful for the application of genomics to food and agriculture.

Most of this research (≈65-80%) is carried out by the private sector in developed countries. For example, Byerlee and Fischer (2000) from the World Bank compiled some rough figures, which give a general idea of the relative investments being made by the different players. The figures indicate that, annually, the private sector probably invests more than US$1.5 billion, mostly in developed countries; the public research organizations and universities in developed countries invest up to US$1.0 billion; the public sector national agricultural research systems (NARS) in developing countries invest US$100-150 million from their own resources (excluding donor funding); the 16 international agricultural research centres (IARCs) of the Consultative Group on International Agricultural Research (CGIAR) together invest roughly US$25 million (about 8% of their total budget) and, finally the donors, such as the Rockefeller Foundation or non-profit technology transfer organizations, invest US$ 40-50 million in developing countries. The biggest single source of investment is therefore the private sector and the majority (about 90%) of biotechnology research is carried out in developed countries.

Not only that the investments made in the developing world are relatively small in this area, there are also major differences between the individual developing countries. Byerlee and Fischer (2000) classify the NARS into three main groups based on their capacity in plant breeding and biotechnology research (Table 4). The first group ("very strong") includes the NARS in Brazil, China, India, Mexico and South Africa, which have strong capacity in molecular biology, including the capacity to develop new tools for their own specific needs. The second group ("medium to strong") has considerable capacity in applied plant breeding research, as well as capacity to apply molecular tools (markers and transformation protocols), but they depend on tools developed elsewhere (a couple of NARS in Pakistan come under this category). The third group ("fragile or weak") has weak capacity in plant breeding and virtually no capacity in molecular biology (most of the NARSs in Pakistan come under this category). It is estimated that the NARS invest on average 5-10% of their research expenditures on biotechnology, which comes primarily from the NARS in the first group and a few in the second group. From the first group, recent trends in China are worth specific mention. Here, the government (which funds almost all plant biotechnology research) has increasingly priotrised biotechnology in recent years to the extent that the resources allocated to plant biotechnology in the crop research budget have risen to 9% in 1999: an amount which is half of the developing world's expenditures on plant biotechnology.

The large differences between developing countries with respect to biotechnology capacity and financial/human investments (and to the focus of their biotechnology research) is also clear from the data in FAO-BioDec, a database developed by FAO containing information on the development, adoption and application of crop biotechnologies in Africa, Asia, Eastern Europe, Latin America and the Near East. Information is organized in two sections: the first covering production of genetically modified (GM) crops and the second covering other technologies grouped into four classes i.e. plant propagation (e.g. anther culture, micro-propagation, embryo rescue, protoplast fusion and culture), microbial (e.g. development of bio-pesticides or bio-fertilizers), molecular markers and, finally, diagnostics (e.g. enzyme linked immuno-sorbent assays (ELISA)). The database publicly available since December 2002 on the FAO Biotechnology website.

Analysis of the data on the website shows that the majority of countries in Latin America and Asia are either carrying out research on or field testing GM crops, while few countries in the other regions have reached that stage. The countries like Argentina, Brazil, China, Cuba, Egypt, India, Mexico and South Africa have well-developed biotechnology programmes, with a wide range of initiatives. In addition, countries like Bangladesh, Indonesia, Malaysia, The Philippines and Thailand in Asia; Cameroon, Morocco, Kenya, Nigeria, Tunisia and Zimbabwe in Africa; and Chile, Colombia and Venezuela in Latin America have medium-sized biotechnology programmes, making use of a wide range of technologies, including molecular markers and diagnostics, although the number of initiatives underway is not substantial.

Table 4: Capabilities wise rating of National Agriculture Research Centers involved in plant breeding and biotechnology research

Parameters used for rating	Very strong centers	Medium to strong centers	Fragile or week centers
Market size in terms of potential R&D impacts	Large or very large	Medium to large	Small to medium
Plant breeding	Comprehensive National Commodity breeding program including some pre-breeding	National commodity programmes that are generally strong in applied breeding	Small and fragile programmes with success dependent on one or two individuals. Can conduct local crosses but value addition to the product is low due to small Market size.
Use of International material in breeding programmers	Used as parents to obtain specific traits for breeding and prebreeding and some time released directly. Also use early generation material.	Very important as parents and also as direct release	Mostly direct releases after local screening and testing
Biotechnology research	Capacity in molecular biology as great or greater than most of the International centers. Marker assisted selections being incorporated into breeding programmes Considerable research on transgenic Growing capacity in genomics and participants In international genomics networks	Usually develop capacity in molecular biology but with support from donors and international centers, potential to participate in genomics in screening of germplasm	Very little to no capacity in molecular biology although many have capacity in tissue culture
Basic and strategic research	Often considerable capacity that can match in many industrialized countries	May have capacity areas	No capacity
Private sector	Private sector active for hybrid crops and increasingly for non hybrid commercial crops	Private sector activity increasing and usually involved in hybrid crops	Little private sector activity for food crops.
Regularity farm work for bio-safety and IPR	Framework in place capacity to implement is modest and untired	Most countries have, or soon will have framework, but weak capacity to implement	Most countries do not have regulatory framework

Table 5: Biotechnology indicators

	Field Trials							Area under transgenics				
	No. of		Share of		Number of Approved Events/Crops			Number of			Share of **	
Region of the world	C	Trials	G. Tot.	Pri. In C Tot.	C.	Events	Cr.	C.	Cr.	Area	Cr. With C/R	G. Tot
Developed	20	9701	84.2	na	19	160	14	7	na	77.5	na	74.2
United States	1	6337	55.0	83.4	1	49	14	1	3	69.6	41.0	66.6
Canada	1	1233	10.7	63.9	1	49	4	1	4	7.4	17.6	7.1
All others	18	2131	18.5	na	17	62	5	5	na	0.5	na	0.5
Developing Countries	19	1822	15.8	na	8	23	4	8	na	26.9	na	25.8
Argentina	1	393	3.4	90.1	1	7	3	1	3	24.7	84.1	23.7
China	1	45	0.4	na	1	5	4	1	1	1.2	12.4	1.2
All others	17	1384	12.0	na	6	11	3	6	na	1.0	na	0.9
Total	39	11523	100.0	na	27	183	14	15	na	104.0	na	100.0

C=Countries; Cr= Crops; G. Tot= Global total; Pri.In.C Tot= private in country total; C/R= country /region
*million acres; ** Percentages. (Source: Pardey and Zambrano, 2001)

The needs of the developing countries:

Because agricultural biotechnology research is primarily being carried out in the developed countries and by the private sector in these countries therefore, most of the research and the biotechnology products being developed or released are directed primarily towards the needs of farmers in the developed (and not for the developing) countries. Also, the rich (and not poor) farmers can afford these products. According to the latest analysis presented in Table 5, private sector conducted maximum number of above 11,000 field trials on GM crops in the United States and the Europe (Table 5) and that only a small number involve tropical crops and traits for stress resistance.

Abiotic stress (e.g. drought, frost, heat or salt) is a major limitation to agricultural production in parts of the developing world. A vast area of soils contains an excess of heavy metals in Brazil and Africa. Steadily increasing acreage of agricultural land in Asia and elsewhere is becoming non-productive because of salinity from poorly managed irrigation practices. In many environments, crop performance is severely limited by drought. Research investments in these areas could have major impacts on food security and hunger. However, preliminary analysis of the data in FAO-BioDec indicates that no GM crops resistant to abiotic stress have been released so far in developing countries and that only six GM varieties are currently under field testing - in Bolivia (frost tolerant potato), China (cold tolerant tomato), Egypt (salt tolerant wheat), India (moisture tolerant Brassica) and Thailand (salt tolerant rice and drought tolerant rice). Contrary to this, 3 GM crop varieties with herbicide resistance are already available for commercial cultivation and 50 more are under field trials in the developing countries. The database shows that 28 research initiatives are underway for abiotic stress resistance in developing countries. In most of the research activities being carried out in five Asian countries, very little research is being done on drought resistance. Work on aluminum-resistant varieties is underway for wheat in Mexico and sugar beet in China. Little research is being done on cold tolerance, although Bolivia and China have progressed to field trials in potato and tomato, respectively. The amount of research and testing devoted to abiotic stress resistance is highly insufficient compared to the real needs of developing countries and should increased substantially along with increase in research investments. This is not possible without the participation of the private sector who will not undertake high cost R&D without either functioning market place or intellectual property protection. This is one of the major reasons why negligible research is done in private sector on the developing country food crops such as sorghum, millet and cassava and the developing country problems such as drought, salinity and other abiotic stresses. The need of the day is to encourage such research by lowering the relative costs of R&D.

How the relative cots of R&D be lowered to make it suitable for developing countries?

According to McCalla and Brown (2000), as first option the active public-private sector partnerships in research would have to be developed for improving and/or evolving developing country's own food crops. This would benefit both parties through increasing the availability of crop germplasm to the private sector and ensuring attention to the crops most important to the poor farmers in developing countries. Intellectual property right protection needs to be carefully explored in such partnerships in a way similar to what has been adopted in USA by Donald Danforth Plant Science Center, which is jointly funded by Monsanto, the State of Missouri, the Missouri Botanical Garden, the University of Missouri, the University of Illinois and the Purdue University. State of Missouri supported the work of the center in the form of tax credits. Such tax credits can further be explored from the host governments for the R&D specific to developing country crops associated with some form of non-exclusive intellectual property protections.

Another approach could be like the one that is adopted by the medical sector where WHO, the World Bank and other development agencies are collaborating with pharmaceutical companies in the development of new vaccines against major tropical diseases. Establishment of global competitive grants research facility for R&D on developing country crops with non-exclusive intellectual property protection can also be initiated. The companies can be convinced to undertake research for which their intellectual property was nonexclusive, arguing that this R&D could lead to development of new enabling technologies, which they can apply on the crops other than the developing crops and which could have intellectual property protection on the final product. Increasing agriculture productivity of developing country will reduce poverty, which will automatically lead to agricultural commercialization, thus creating future competitive market for other commercial products.

Conclusion

The challenges that the developing countries in general and the least developing countries (LDCs) in particular are facing are daunting. Their rapidly increasing population needs food and economic security in the times to come. Biotechnology can provide answer to this dilemma only if it is integrated fully into the breeding programmes and becomes an important component of increasing yields and adding nutritional values to their staples. The first generation transgenic crops such as herbicide resistant and ***Bt***. transgenics will never address the developing countries requirements nevertheless, a combination of technologies such as mapping, genetic transformation and micro-propagation can be appropriate. These techniques can provide germplasm, which can eventually be incorporated into breeding programmes or as direct use by the farmers. The performance of this germplasm will not be input intensive because traits for biotic and abiotic stresses can be incorporated into plants through marker assisted breeding. Achieving this objective however, will require willingness of the public and private sectors in the developed countries to work with policy makers, scientists, breeders and the extension workers in the developing countries. Intellectual property rights would certainly become concerns for the multinational willing to work in the developing countries, which can be resolved through international agreements. The multinationals have the technologies within their portfolios for use in the improvement of developing country food crops. These companies should come forward and use them even if these crops do not constitute a market for the foreseeable future. After all, it a question of feeding 80% population of the world that is depending on such crop and un-hoppitable production systems. Thus, all the available technologies irrespective of their being "Promethean" or "Obsessive" should be used to tackle this challenges.

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