Biotechnology Foresight: Recommendations for the Future Biotechnology Policy of Pakistan

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Pakistan Council for Science and Technology
Ministry of Science and Technology
Government of Pakistan
(2014)

Preface

All living organisms on this planet Earth survive through manipulation of natural resources. The more efficient and sustainable is this manipulation; the better is overall adaptation and evolution of the species. Since its earlier appearance on the planet Earth, human beings utilized natural resources for its survival, ranging from preying animals to domestication of animals and plants for food, feed, shelter and health care. This could be considered as the earliest preliminary phase of all forms of biotechnology, i.e., the technology to manipulate living systems for the betterment of humanity. These technologies were improved with the passage of time, resulting in traditional medicine, farming, fishery and animal rearing. However, the population size of human species increased gradually till the modern era, where the population is getting increased dramatically. This population expansion was associated with other dramatic "un-natural" changes on the planet like industrialization, climate change, environmental hazards and the increased disease invasion in human, plants and animals due to increased trade and travel. To cope with these challenges, a more efficient and better manipulation of these natural surroundings is required in a more appropriate direction.

The efficient manipulation, however, requires a more insight and comprehensive understanding of the living systems and its surrounding, modern tools for their manipulation, and understanding of subsequent consequences. Advancements in life sciences in the last century have increased our understanding of living systems. New tools were made available to characterize organisms, understand the biochemical pathways of organisms and understand the inheritance mechanisms. These understanding enabled a more efficient exploitation of living systems, creating the "modern" *Biotechnology*. Biotechnology can be defined in various ways but it is simply the skilful manipulation of living system for an efficient exploitation in the interest of humanity. The technology aims in the improvement of crop and animal production, health care and environment. Since the advent of biotechnology, a number of application of biotechnology has proved its utility in the form of molecular applications to biology, recombinant DNA technology, gene therapy, pharmaco-genomics, forensic DNA technology, bioremediation and cloning, to name a few.

Considering the enormous potential of biotechnology, it is our national duty to devise the most efficient biotechnology policy, not only for short term but also for long term. Considering the limitations and potential of the technology, its intellectual and justified use with a pre-planned, objective oriented research is thus indispensable. The current report provides the recommendations for the future biotechnology policy for Pakistan, compiled after a series of biotechnology foresight meetings, involving expert views from nationwide biotech scientists. Although the report is compiled by the undersigned, it accumulates the input from all the experts who participated in these meetings or have sent their inputs.

In compilation of this report we tried to put forward the context, vision & mission, opportunities & challenges and a final section of recommendations of different sub-divisions of biotechnology. We attempted to avoid the technical details, which could be found elsewhere, but only mentioned the main issues, opportunities and challenges. We attempted to give an overall idea of the potentials of biotechnology and we do not claim that the issues raised here are exhaustive and inclusive. In this essence, the present report could be a precursor for further thoughts and discussions.

We would like to acknowledge Pakistan Council for Science and Technology for arranging these meetings and providing all possible support, as well as to all the participant experts, which made this foresight exercise successful.

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List of chapters

Chapter 1. Biotechnology Foresight: Planning for the Future Biotechnology

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A series of meetings were arranged at Pakistan Council for Science and Technology (PCST) to provide recommendations for formulation of a long-term national policy regarding the growth and development of biotechnology in Pakistan (Annex 1). Considering the importance and potential of biotechnology, the technology foresight approach was adopted by the expert panel to identify the future challenges and potentials in the area of biotechnology. The overall goal was to enable the adoption of an efficient and effective biotechnology policy to enable the nation benefit from this technology not only in short run, but also in the long run.

Technology foresight; to anticipate future

The "technology foresight" technique was selected as a holistic approach to anticipate the future challenges and opportunities related to biotechnology in Pakistan, placing it in the international context. The technology foresight neither predicts the future nor the impact of future technology on the current day life, but it provides an overall view of future risks and potentials of the technology and enables a better preparedness.

To forecast the future risks and potential, some strategy is required to foresee the future challenges and opportunities. The biotechnology foresight expert panel selected the STEEPV approach to carry out this biotechnology foresight practice.

Selection of STEEPV issues

The selection of STEEPV approach enabled to foresee the future biotechnology in Pakistan. STEEPV approach identifies the Social, Technical, Economic, Environmental, Political and Value related issues/aspects of any technology; both the challenges and opportunities. The expert panel identified a number of issues related to biotechnology, ranging from Food, Feed and Fibre Security and Health Care to public awareness and international obligations/treaties. These issues are listed in Table S1 (Annex 2). All experts discussed and voted for various issues raised during the first brainstorming session to select the three most important issues. The selected three issues from each category are presented in Table 1.

These three issues from each category of STEEPV were used to identify the main drivers related to the future challenges and opportunities of biotechnology.

Table 1. The list of three issues selected in each STEEPV category by the Biotechnology Foresight expert panel for identification of scenario drivers.

Social	Technological	Economics	Environmental	Political	Value
Food, Feed and Fibre Security and Health Care	Development and application of Biotechnology in Agriculture, Health, Industry, and Environment	Socioeconomic benefit via. Bio-economy	Use of biotech to solve environmental Problems	Policy formulation for development and deployment	Development and Deployment of Bio-Tech product in line with Bio-Ethics
Collaborative efforts among stakeholders for Tech development & deployment according to industries and end-users	Adoption, Innovation, Dissemination and utilization with emphasis on PPP	Self sufficiency and self reliance	Enforcement and implementation of bio-safety guidelines	Strict implementation of protocol conforming to int. standard	Protection of public rights of ownership
Capacity building for job opportunity and Social Stability	Support for result oriented and mandated activities by avoiding overlapping	Integration of biotechnology research/application into national economic planning and production processes	Environmental and health risk assessment	Mobilizing political will and support	Awareness

Selection of drivers

The most important two drivers were selected based on the selected STEEPV issues. These were:

- **1st driver (D1):** Increasing demand for sustainable development through food, feed, livestock, environment and health security with increased employment.

- **2nd driver (D2):** Increasing pressure for product/result oriented patentable cost effective research according to international laws/standards that equally satisfies public concern about new technologies/products and public rights.

The expert panel made a consensus about the importance of these two drivers.

Contrasting scenarios

A set of four contrasting scenarios were identified based on these drivers (Fig. 1a). The profiles and probability of these scenarios were also discussed by the experts (Fig. 1b). These scenarios were considered to address various Actors and Actions. The actors and actions were put forward to provide a basic trigger for further discussion and recommendations.

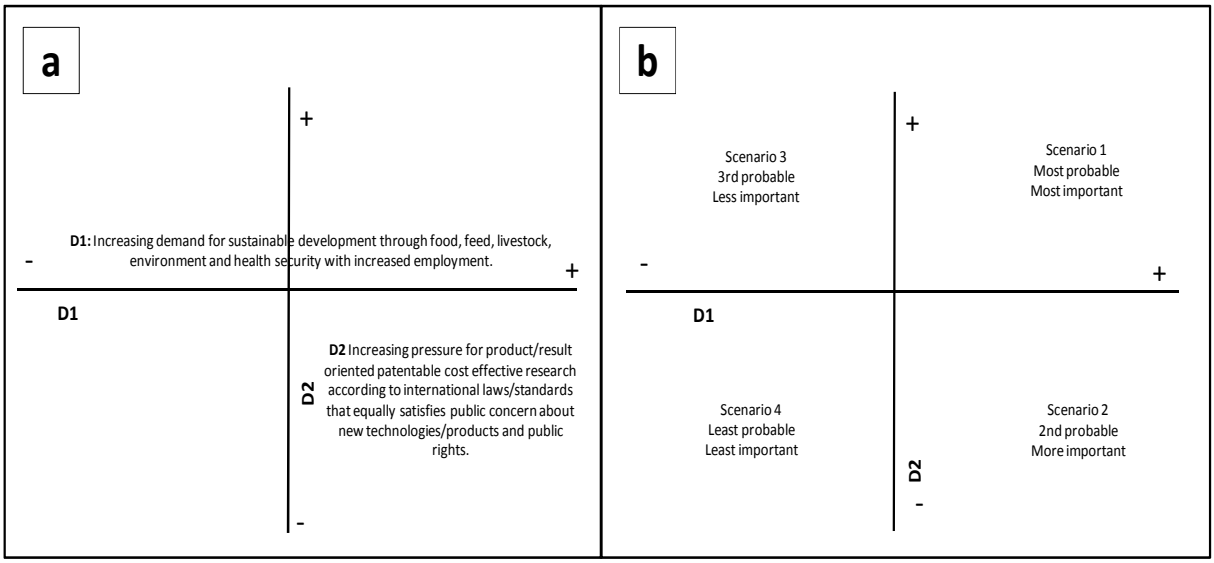

Fig. 1. The contrasting four scenarios identified considering the two drivers (a) and their probabilities (b) used to identify actions and actors for biotechnology foresight.

Actions and actors

Considering the importance and probabilities of the above described scenarios, a number of actor and actions were identified. The expert panel identified at least five sub-divisions of Biotechnology to provide recommendations. Along with some general overall actions and actors (detailed in Chapter 2), the expert panel provided recommendations on further actions and actors specific to each of these subdivisions (detailed in Chapter 3-7).

- **Agricultural Biotechnology** (Detailed in Chapter 3)
- **Industrial, Microbial and Environmental Biotechnology** (Detailed in Chapter 4)
- **Health and Medical Biotechnology** (Detailed in Chapter 5)
- **Veterinary and Animal biotechnology** (Detailed in Chapter 6)
- **Application to Biology and Bioinformatics** (Detailed in Chapter 7)

The actions and actors are detailed in "Recommendations" section of each chapter. We have compiled the report in different chapters to provide an easy access to readers according to their area of interest. The chapter 2 on general biotechnology could be consulted by non-specialist readers to have an overall idea of importance and challenges linked with biotechnology and recommendations for devising the policy. The onward chapters would provide more detailed information on each of these divisions of biotechnology.

Chapter 2. General Recommendations on Biotechnology

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CONTEXT

Increasing demand of food, feed, fibre, livestock, environment, energy and health security is the main driving force for all life science research. Like any other field of applied life sciences, biotechnology aims to skilfully manipulate the living systems for human interest in a more sustainable way. The sustainability and environment friendliness is one of the important objectives of this skilful manipulation. A number of biotechnological applications do exist to attain the improvement of crop and animal production, health care and environment.

The development of any nation is dependent on technological exploitation of its natural resources, including human resources. Biotechnology provides a promising way to skilfully exploit the natural resources. It also enables to preserve the national resources through their characterisation and conservation.

There is an increasing interest worldwide to invest in biotechnology industry. A number of national and multinational firms have been involved in biotechnology worldwide, with some dedicated to biotechnology (Fig. 2). The developed countries like USA and Spain are the leading nation (Fig. 2). Pakistan, however, is not among these countries due to the negligible involvement in biotechnology industry. No such data is available for Pakistan to compare its status of biotechnology industry. However, for sustainable development, it is indispensible to invest in biotechnology.

VISION & MISSION

The vision and overall mission for biotechnology is to fulfil the increasing demand of food, feed, fibre, energy, livestock, environment and health security through skilful and sustainable exploitation of living systems.

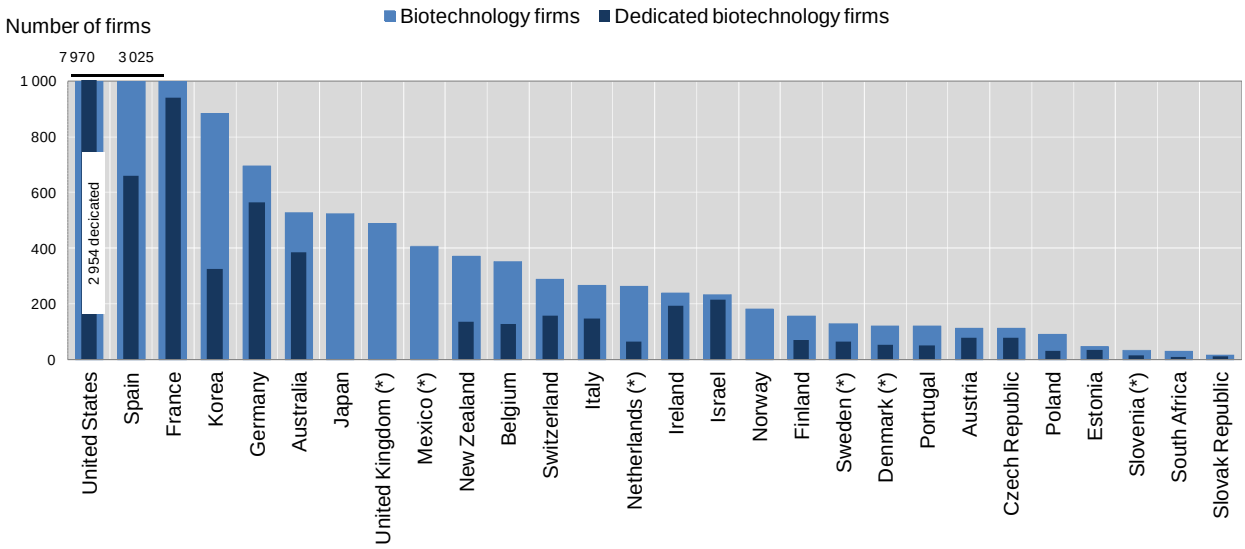

Fig. 2. Worldwide pattern of involvement in biotechnology by different countries during 2011.

Source: Key Biotechnology indicators, OECD, last updated 2013.

(http://www.oecd.org/innovation/inno/keybiotechnologyindicators.htm)

OPPORTUNITIES AND CHALLENGES

Biotechnology could intervene in various disciplines to cope with future challenges and benefit from the opportunities. Each of these applications is detailed in relation to various practical problems in their respective chapters; however, a few of the biotechnological tools are mentioned below, which could be exploited to attain food, feed, fibre and health care security.

Molecular applications to biology: The utilization of molecular techniques enables a better understanding of different biochemical and molecular aspects of living processes. This is the only way to the skilful and sustainable exploitation of these living processes.

Tissue culture: Tissue culture tools are used for *in vitro* multiplication of any organism, without genetic changes. It is widely used in the context of conservation genetics, multiplication of disease free and true to type propagation. Through soma-clonal variation, it could create new heritable variations, to be exploited in genetic improvement.

Molecular Markers: The molecular markers enable a better crop and animal genetic improvement through marker assisted selection. These are also extensively used in genetic conservation, invasion biology and overall population biology.

Forensic DNA technology: Considering the fact that each individual has its own genetic make-up, the forensic DNA technology enables the exact identity of individuals. This is intensively used today in criminal and parentage identification.

Sequencing and Genomics: The advancements in sequencing technologies have resulted in accumulation of sequencing data for a number of species, which can be exploited for a number of purposes to understand the underlying genetic mechanism of different life process.

Recombinant DNA technology: The field of recombinant DNA technology, genetic engineering or transformation has expanded the possibilities of genetic improvement enabling the introduction of transgenes (foreign genes) into an organism for its expression. Genes could thus be incorporated from genetically distant organisms e.g. from an insect into a plants. Numerous research projects are ongoing in plant, microbial and animal transformation, with the ultimate aim of commercial exploitation.

Reproductive biotechnology: The assisted reproductive biotechnology provides a large number of tools for animal production improvement ranging from artificial insemination, embryo transplantation etc.

Gene therapy: In medical biotechnology, gene therapy enables the introduction of disease curing or preventing genes to the cells lacking the gene or having its inactive form.

Pharmacogenomics: The pharmacogenomics investigates the association of individuals' genetic make-up and his reaction to medical therapy. This knowledge will help develop individual oriented therapy, according to patient's genetic make-up.

Bio-Pharming: The idea of production of pharmaceutical products through plants and animals is under intense research in some countries. The idea is to express the genes for production of these compounds in plants or animals for subsequent exploitation.

Tissue and organ transplantation: The transfer of tissues and organs from one individual to another individual or from one site to another site of patient body provides a promising opportunity to cure several anomalies.

Energy: agriculture and domestic waste has a great potential to complement energy needs by conversion in biogas (methane), ethanol and butanol. The biological source of energy has been exploited in China, Brazil and India. The technology can be adopted both in villages where livestock waste and agricultural waste can be converted into energy. The waste from sugar industry and urban waste dumps can also be exploited for energy production.

Biotechnology, thus, possesses an enormous potential for the sustainable development of the country. The limitations and potential of the technology should thus be considered to enable a more objective oriented research and application of biotechnology.

RECOMMENDATIONS

Considering the opportunities and challenges identified in a series of biotechnology foresight meetings by expert panel, following recommendations were made to devise the future national biotechnology foresight policy.

- The first and the most important recommendation was regarding the strengthening of institutions for capacity building in biotechnology (both infrastructure and man power). This should be done on a priority basis throughout the country.

- Research innovation in the field of biotechnology must be encouraged to minimize dependency on foreign imports. This must also be oriented to human resource development and generation of employment.
- The sector-wise flagship status in different areas of biotechnology must be given to the institutions, with each of these institutions having a clear mandate.
- Support should be given only to the target oriented research to fulfil the increasing demand of food, feed, fibre, livestock, environment and health security.
- The balance between the basic and applied research needs to be made; only very highly competitive basic research must be supported, where lesser cost pressure would be applied.
- A small number of projects under scenario 3 could be supported considering lesser pressure for the drivers on food, feed, livestock and health and employment, but considering cost efficiency.
- The scientists must be encouraged/stressed upon to develop cost effective and product oriented patentable and deliverable outputs.
- Some national biotechnology forums like Pakistan Council for Biotechnology (PCB) should be re-activated with more active role. It must provide the latest information, probably through a website and through the monthly news letter.
- Repetition of same research at different institutions should be avoided and a more complementary nature of research collaboration must be ensured with the help of these national biotechnology forums.
- The scientists must be encouraged to adopt measures to protect the national interest and public rights.
- The private sector should be encouraged to invest in biotechnology related ventures, with support from their sides to biotechnology research in public/private institutions. The government should provide attractive incentives to have an early involvement of these firms in biotechnology.
- Scientists must be encouraged to develop international collaborations. The bureaucratic formalities should be reduced to enable them focus on search and use of international funding for their research in Pakistan.
- Measures should be taken to avoid brain drain of newly returning PhD scientists from abroad. They should be encouraged in all measures to establish their own laboratories through both national and international funding.
- The national bio-safety agency should be strengthened and a national bio-safety policy should be developed. This should be circulated among all biotechnology related institutions and industries, who should devise their respective bio-safety measures, considering the national policy.
- Considering the worldwide propaganda against the technology, efforts should be made to increase public awareness about the real limitations and potential of this technology.

Chapter 3. Recommendations on Agricultural Biotechnology

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CONTEXT

"Grow more food" is cry of the day. Agriculture is crucial for attaining food, feed and fibre security. After its creation, Pakistan faced a major food security threat in 1950's. The intervention of modern agricultural practices and adoption of high yielding fertilizer and pesticide responsive varieties enabled to cope with the risk. This resulted in self sufficiency in food, often termed as "Green Revolution". However, this was only possible for cereal crops like wheat and rice. Pakistan has still a huge import of food items that include edible oil, pulses, tea and other commodities, posing a continuous threat to the nations' food security. The population has also increased, thus threatening even the sufficiency in cereal crops.

With the current population of around 200 million, Pakistan is the sixth largest country and our population is expected to rise to 250 million by the year 2022. About half of the Pakistani population has been estimated to be food insecure due to deficiency of calories, proteins, vitamins and minerals. This food insecurity is associated with health insecurity and mal-nutrition. As there is limited scope to bring new land under cultivation, the major increase in production must be attained through application of technologies that increase production per unit land, decrease cost of production by enhanced efficiency of input utilization and increase the nutritive value of food being produced in the country.

The increasing cost of fertilizers, new pest and diseases and environment challenges such as sudden temperature variations, unpredictable rainfalls and uncertain flow of water in our rivers are the major limitations for agricultural production. Several crop production technologies have been deployed to cope with these major limitations, based on agronomy, crop protection and chemical intervention. Exploitation of the genetic potential of crop plants, however, has resulted in impressive success to overcome these limitations. Such genetic potential exploitation was made through the application of genetic principals to classical plant breeding.

The classical plant breeding has, however, its own limitations, mainly the requirement of successful crossing with fertile progeny and the time required to develop the desired genetic variant. Biotechnological intervention to the classical plant breeding had overcome these limitations, thus providing overwhelming opportunities to develop crop genetic variants with better qualitative and quantitative yields. This has revolutionized the classical plant breeding in to "Modern Plant Breeding".

The modern plant breeding exploits the knowledge of molecular biology coupled with the tools of biotechnology to improve crop production. The knowledge on genetic composition of crop plants is used to characterize the relevant gene sequences, identify the desirable allele types, develop markers to detect those alleles in a segregating population and use the transformation techniques to insert the genes in a

more targeted and efficient way. The crop production enhancement expected through the biotechnological intervention is often termed as “Gene Revolution”.

VISION & MISSION

The vision and overall mission of agricultural biotechnology is to improve food, feed and fibre production through skilful and sustainable exploitation of crop genetics in the context of improved agricultural system.

OPPORTUNITIES AND CHALLENGES

The agricultural biotechnology could have a number of interventions to cope with the agriculture related challenges and benefit from the related opportunities. Some of these are described below:

Yield enhancement: The enhancement of per acre yield still remains the most important desirable goal of crop improvement program. Yield enhancement has been achieved by adopting technologies such use of hybrids and development of crop varieties with higher partition of nutrients towards grain production. Biotechnology can also intervene in various areas of this improvement to better understand crop physiology and its contribution to overall yield.

Abiotic stress resistance: The major abiotic stresses in Pakistan include drought, salinity, less rainfall, unexpected rain, hailstorms and floods and the fluctuations in temperature. The existing biodiversity of a species to response to such stresses have widely been exploited through classical breeding. The genes residing outside of the species, either in the wild relatives or unrelated species, could only be incorporated into crop plants through the intervention of biotechnology. For example, a desired gene could be transferred from a microbe to a crop plant through transgenics, while the genes from the same or related species could be transferred efficiently and rapidly through cisgenics.

Biotic stress resistance: The outbreak of crop pests, insects and diseases and the prevalence of weeds are the major biotic stresses to reduce crop production. As for abiotic stresses, the biotic stress resistance has also been achieved previously through classical breeding. However, the biotic stresses, caused by other organisms, evolve against the resistance achieved. Thus a continuous effort is required to develop innovative approaches for such resistance. Biotechnological interventions have been shown to be quite effective in controlling these biotic stresses. The use of molecular markers would also enable a more efficient and rapid selection for the desirable genotypes in modern plant breeding.

Increased input responsiveness: The low soil nutrition status requires intensive application of fertilizers and nutrients. Similarly, other inputs like water, insecticides, weedicides etc. are also applied to attain high yields. However, only an efficient utilization of these inputs could ensure higher production. The exploitation of genetic mechanisms for such an efficient exploitation would enable a better yield with less input applications. Biotechnology could provide a more efficient method to develop such input responsive genotypes.

Environment friendly agriculture: A major challenge to agricultural biotechnology is the environment and ecosystem safety. The biotechnological research and products must be carefully tested for bio-safety before their widespread applications. Similarly, the un-justified propaganda against biotechnologically developed agricultural crops must be well replied and their concerns should wisely be answered.

Improved nutritional quality: The food security could only be attained if the nutritional requirements of the population are achieved. Previously most of the efforts were targeted toward more quantitative yields. However, the current improvements in modern plant breeding, resulting after biotechnological intervention, could develop crop genotypes with higher nutritional quality.

Thus agricultural biotechnology presents an enormous potential for crop improvement, both qualitatively and quantitatively.

RECOMMENDATIONS

Considering the overall challenges and opportunities related to agricultural biotechnology, the expert panel suggested the following recommendations, along with the general recommendations, to be considered in the future biotechnology policy.

- Empowerment of agricultural biotechnology in all agricultural universities and colleges through human resource development and provision of infrastructure.

- New posts for young biotechnologists should be created in research and extension system, to enable them strengthen the research and extension system with the modern tools of biotechnology.

- Both the agricultural universities and research stations should be provided with basic infrastructure for biotechnology related research.

- Research in agricultural biotechnology should be encouraged to solve the major agricultural problems, mainly in improving biotic and abiotic stress resistance, improved input responsiveness and better nutrition qualities.

- Greater emphasis on crop genomics, crop physiology and crop molecular interactions is essential to enhance capacity for their exploitation in crop genetic improvement. Human resource development in these areas would be essential for development of molecular information-based breeding program and selection of desirable plants.

- The agricultural biotechnologists should be encouraged to interact with scientist from other fields of agriculture and farmers to work together for solving the major agriculture related problems.

- The public institutions should actively contribute to the development of transgenic crops and biotechnological crops along with national industry to avoid the public perception against the multinational companies as the only owner of biotechnological products.

- All agricultural biotechnology projects must strongly consider the sustainability and environmental safety aspects of their research and products. The protection of environment and ecosystem should be on top priority.

  The bio-safety aspects of all agriculture related biotechnology products should be thoroughly tested before their release. A strong and neutral bio-safety body should be devised for the purpose, which should be compatible with the international regulations.

- There is an urgent need to enhance our capacity for characterization of transgenic events to safeguard national interests and bio-safety evaluation of transgenic plants for feed and feed as well as their environmental safety.

Chapter 4. Recommendations on Industrial, Microbial & Environmental Biotechnology

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CONTEXT

The industrial biotechnology deals with the skilful manipulation of living systems for industrial exploitation through processing chemicals, materials and energy. One of the important components of industrial biotechnology is based on the utilization of microorganisms and enzymes in chemical, food & feed, paper & pulp, textiles and energy industries. Although our economy is mainly based on agriculture, the country has a potential for growth in industrial sector. Industrial biotechnology would be a very useful component of this industrial development, reducing our dependence on foreign import.

The microbial biotechnology exploits the increased knowledge about various microbial organisms for commercial purposes. It may involve various exploitations of microorganisms, their products and eve, their genes for commercial exploitation.

Environmental Biotechnology involves the use of a combination of biological and other processes to protect, maintain & restore the quality of environment. The Environmental biotechnology also provides an enormous potential to restore the environmental through bioremediation and better waste management.

As these three subdivisions have related domains, we will describe them together in this chapter.

VISION & MISSION

The vision and overall mission for industrial, microbial and environmental biotechnology is to exploit the living systems, especially microbes for industrial processes and environmental management, considering the environmental safety.

OPPORTUNITIES AND CHALLENGES

Industrial and microbial biotechnology has a number of applications which could be exploited at commercial level. Some of these are described below:

Enzymes in industries: Enzymes are widely used in various industries. For example, the cloth manufacturing industry, with almost 1000 units in Pakistan, has a massive demand of desizer α-amylases and bio-scouring cellulases and pectinases. Similarly, animal feed industry, 1200 units working in Pakistan, also employs a cocktail of enzymes including the fibre degrading enzymes, proteases, lipases, α-amylases and phytases and this industry can also be boosted by the aid of these indigenously prepared

enzymes. These could be efficiently and rapidly developed, modified and produced at commercial scale through biotechnological intervention.

Production of biomolecules: The microbial biotechnology could also produce a number of biomolecules. The development of prebiotics and probiotics, as functional food, can address health issues by protection from gastroenteritis, immune regulation, improved digestion and gut function. Moreover, prebiotic inulin biosynthesis from molasses represents more than 100 times value addition in the product, as the market price of insulin ranges from US $ 15,000-20,000/ton compared to molasses, which is exported at the rate of ~US $ 62/ton.

Nano-biotechnology: In recent years, the merger of biotechnology and nanotechnology has appeared as a new frontier with important applications by expediting the synthesis, assembly and targeted functionalization of nanoparticles. Nanoparticles have applications in developing ultra-sensitive disease diagnostic protocols, potential scaffold material for bone implants and drug/gene delivery. In addition, the nanoparticles have potential to be used as building blocks to make new materials such as composites, nanowires, nanochains, and porous materials for applications in nano-electronics, nano-optics, catalysis and forensics.

Contribution to energy: In view of rapidly growing energy demand in Pakistan, it is indispensable to exploit all indigenous resources by increasing the supply of traditional fuel. The generation of methane gas from animal, agricultural and industrial wastes through anaerobic digestion has significant potential for increasing indigenous supply of fuel. Though Pakistan have huge coal reserves (> 185 billion tonnes), they are not being fully exploited, as most of our coal is lignite in nature and simple burning of this raw material is highly inefficient. Biological beneficiation of our coal resources involving biodesulfurization of high sulfur coals or biodegradation/biogasifiaction of low rank coals can be used for tapping this huge natural resource for progressive, efficient and cost-effective fuel and non-fuel applications of brown coal including as source of hamates and waxes production.

Microbial diversity conservation: The microbial biodiversity is one of the important and precious components of the natural biodiversity reserve of any nation. The conservation of microbial biodiversity must be an important component of national policy.

Bio-mining: Bio-mining has been described as one of ten “World changing ideas”. Pakistan is also blessed with a vast array of other minerals; however the contribution of mineral sector to the GDP of Pakistan is less than 1% that can be increased to 3% by exploiting only 25% mineral resources of Pakistan. Bio-mining can be an economical and environmental friendly alternate to the mining industry for extraction and purification of metals from large quantities of low grade ores.

Bioremediation and waste management**:** The environmental intervention could enable the transformation of waste to useful products, the rapid detection of microorganisms, creation of new natural products and fast low-energy consumption bioprocesses, which must promote sustainability. It would improve our understanding regarding the influence of human health by environmental exposures and how this knowledge can be used to reduce morbidity, improve quality of life, and extend longevity.

The biodegradation of organic and inorganic materials, phytoremediation, mycoremediation, biomonitoring and bioremediation of emerging pollutants should enable a better waste management strategy.

Another challenge would be to generate new knowledge on the sources, fate, exposure, and effects of environmental contaminants and natural toxins in our environment. This knowledge would be useful to develop and apply improved tools and methodologies for assessing the risk caused to humans and the environment, and for minimization of potential risk.

RECOMMENDATIONS

Following recommendations were made regarding the industrial, microbial and environmental biotechnology by the concerned expert panel of biotechnology foresight.

- Efforts should be made to increase awareness about the importance of industrial, microbial and environmental biotechnology.

- Provision of education and training in environmental toxicology and risk assessment must be kept on the top priority.

- Research innovation should be encouraged in the areas of *in-situ* and *ex-situ* biotreatments and on aquifer, sediment, seawater and wastewater bioremediation and the reuse.

- Research should be encouraged in biotransformation and impacts of nanomaterials and biopolymers in the environment.

- The potential of biofixation of nitrogen and CO_2 in soils, along with plant microbe interaction & phytoremediation for treatment of polluted areas should be exploited.

- Microbial potential should be exploited from non-conventional, stressed or contaminated environments.

- Research should be carried out to enable the use of constructed wetland for waste water treatments.

- Further efforts are needed to empower research in environmental toxicology & toxicogenomics.

- The exploitation of biosensors for environmental applications should be encouraged.

- Efforts should be made to conserve the microbial biodiversity of Pakistan and make the living culture available for various purposes.

- Posts should be created for industrial, microbial and environmental biotechnologists in concerned departments and institutions like environment protection agency etc.

Chapter 5. Recommendations on Health & Medical Biotechnology

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CONTEXT

Pakistan is the 6th most populous country of the world with a population, with an annual population growth rate is 1.8% which is highest in the region and more than India, Bangladesh and Sri Lanka. Due to poor socioeconomic conditions, inadequate health facilities, low literacy rate and unique social and cultural practices the incidence of various infectious, metabolic and genetic diseases are higher than other countries. Unfortunately, there are few diseases having high prevalence and specificity in this region, which are not being actively pursued by the multinational global health sector due to shallow market. There is a very strong need to address the major health issues in Pakistan. Biotechnology has the great potential for discovery and development of specific and targeted drugs for a healthy Pakistan and to improve the socioeconomic condition of the country.

Health and Medicinal biotechnology could include the modern diagnostic tools for various diseases, medicines and vaccines developed through recombinant DNA technology and a wide range of modern therapy techniques like gene therapy and transplantation.

VISION & MISSION

The vision and mission of health and medical biotechnology is to attain the health security through the biotechnological exploitation to health and medical sciences.

OPPORTUNITIES AND CHALLENGES

The health and medical biotechnology has a huge potential along with numerous challenges to attain health security for Pakistan.

Vaccines production: The health and medical biotechnology possess a huge potential to enable large scale, cost effective, efficient and rapid development and production of vaccines. The technology is used already in the developed world; however, countries like Pakistan are mostly dependent as consumer on these countries.

Improved diagnosis: The latest molecular diagnostic tools enable a rapid and efficient diagnosis of various diseases. A number of diagnostic tools are available for different diseases like HIV, HCV etc. However, their efficient application is scarce in Pakistan. Similarly, diagnostic tools specific to other pathogens and their strains specific to Pakistan are lacking.

Gene therapy: In medical biotechnology, gene therapy enables the introduction of disease curing or preventing genes to the cells lacking the gene or having its inactive form. The potential of this technology for health care is still scarce for a large number of diseases.

Medical counselling considering genetics and Pharmacogenomics: The pharmacogenomics investigates the association of individuals' genetic make-up and its interaction with the medical therapy. This knowledge will help develop individual oriented therapy, according to his genetic make-up. Although this area needs intensive research, the general genetic information should be considered during any medical counselling.

Bio-pharming and biofactories: The use of animals to produce medicinal compounds and, potentially organs in future. Although the former has been achieved in various cases, for example, the production of vaccines, the latter is under intensive research.

Tissue and organ transplantation: Tissue and organ transplantation involves the replacement of a defective or damaged tissues and organs through its transfer from another individual. It may also include the replacement from one site to another site of patient body. Depending on the complexities, the transplantation is effectively used in some cases, while in other cases, intensive research is still required.

RECOMMENDATIONS

In addition to the general recommendations suggested for biotechnology, some specific recommendations were made for health and medical biotechnology, which are listed below.

- The first and the most important recommendation is the human resource and infrastructure development in health and medical biotechnology.

- Research & development efforts should be encouraged for the production of vaccines and drugs for infectious and vector borne diseases.

- The universities, hospitals and research institutes should be directed to develop new DNA / protein based techniques for specific diagnosis and improved treatment.

- Development of molecular strategies for gene mapping of genetic and metabolic diseases for prevention/control through carrier screening, prenatal diagnosis and DNA based treatment planning.

- Posts should be created for health and medical biotechnologists in various health related organizations and hospitals to fully benefit from this technology in health and medical sector.

Chapter 6. Recommendations on Veterinary & Animal Biotechnology

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CONTEXT

Biotechnology has a huge potential in veterinary and animal sector to attain long term sustainability in a number of domains like conservation, animal improvement, healthcare (diagnosis and control of diseases) and augmentation of feed resources. Adopting biotechnology has resulted in the animals' genetic improvement and economic returns to the livestock entrepreneurs and small producers. However, developing countries has to address issues related to political commitment, trained manpower, infrastructure and funding in research, development and industries. In a nutshell, investing in animal production and biotechnologies is crucial for social sustainability, economic prosperity, food security and safety, rural wealth creation and health improvements especially to poor populations in the developing countries.

Currently, livestock production in the country is based on conventional technologies. However, the complete potential of livestock resources in Pakistan can be exploited using biotechnological tools. The research aimed at improving animal production and health would not only generate new opportunities for knowledge creation but also new options for solving established and emerging problems. Livestock health and production in Pakistan can be improved, through the use of biotechnology.

VISION & MISSION

The vision and mission of veterinary and animal biotechnology is to attain the animal health and animal production security through the biotechnological exploitation. The vision of veterinary and animal biotechnology policy for Pakistan should be to harness the vast potential of biotechnology as a key contributor to the development of the country.

OPPORTUNITIES AND CHALLENGES

The veterinary and animal biotechnology possesses a number of opportunities and challenges, which should be considered to suggest recommendations to for biotechnology policy. Animal biotechnology strategies, which have been proposed under several focus areas, if implemented in its true sense, could usher a new era in the development of the country.

Animal health and feed products: Biotechnological intervention could enable to develop new products for better animal health and feed. These methods are more target-oriented, efficient and rapid. New drugs and vaccines could be developed through biotechnology. Similarly, new feed products could be produced at commercial level to ensure the fulfilment of animal nutrition requirements.

Biotechnology in dairy Industry: Over the past ten years, the rise in milk production in Pakistan is largely a result of increases in animal population rather than in animal productivity. Similarly, milk quality is also low in most of the animal breeds. The genetic improvement of animals, provision of improved feed and health care to animals would enable a higher per animal production.

Animal reproductive biotechnologies: The classical use of reproductive biotechnology in animal breeding has been to increase the number of superior genotypes assisted through transgenic and molecular tools. The reproductive biotechnology includes the following main tools.

- *Artificial Insemination (AI):* Artificial insemination is a method of breeding in which semen is obtained from the male and introduced into the female reproductive tract by means of instruments.

- *Oocyte pick-up (OPU)**:*** The technique used to retrieve oocyte/egg from the ovary of female animal to be used for subsequent fertilization.

- *Embryo transfer**:*** The process in which the embryo is placed into uterus of female animal for subsequent pregnancy. Multiple ovulation and embryo transfer has been well established for many years and still accounts for the majority of the embryos produced worldwide.

- *Parthenogenesis:* The phenomenon of virgin birth, or parthenogenesis, is the phenomenon of embryo development from unfertilized female cell, without the contribution of male parent.

- *Cloning**:*** Somatic cell cloning is a rapidly developing area and a very valuable technique to copy superior genotypes and to produce or copy transgenic animals. Cloning is a potentially useful breeding tool because it is a mean of producing “carbon copies” of elite animals that would not otherwise be available to commercial farmers.

- *Chimera formation:* Chimeras are composite animals in which the different cell populations are derived from more than one zygote. Chimera can be produced experimentally by mixing two or more cell populations at a very early stage of development or by combining tissues from two or more individuals after the period of organogenesis. Chimera can be produced by two ways viz. Morula aggregation and Blastocyst injection.

Cryopreservation of ova and embryos: The cryopreservation of ova and embryo could be used for a number of uses, including subsequent large scale multiplication and conservation of animal diversity. Successful cryopreservation of mammalian embryos can be achieved by both controlled freezing and thawing procedures, the one-step procedure, vitrification or ultrarapid freezing.

Transgenic animals: Transgenic animals can be employed either as biofactories for the production of commercial products or as living models for the study of human diseases and evaluation of

pharmaceuticals. Similarly, transgenic animals could be produced with transgenes for improvement in productivity and disease resistance, development of experimental animal models for specific disease and desirable products/pharmaceuticals.

RECOMMENDATIONS

Following recommendations were suggested by the expert panel to fully exploit the veterinary and animal health biotechnology.

- Research should be encouraged in developing new health and feed products for farm animals using biotechnological intervention.
- Efficient and better vaccines should be developed and made available at large scale to prevent disease.
- Biotechnological tools should be utilised to fully understand the molecular epidemiology for economically important diseases of animals.
- Biotechnological processes should be exploited to improve animal feed to increase production efficiency (i.e., enzymes, probiotics, feed additives & metabolic modifiers).
- Research should be encouraged in rumen biology to reduce green house gas (methane) emission from ruminants.
- Improved animal reproduction through biotechnological tools should be encouraged.
- Molecular characterizing of the genetic variation in local breeds should be made and exploited for genetic improvement.
- Biotechnological intervention should be made for the characterization and conservation of animal genetic diversity.
- Research should be encouraged for the development of transgenic animals, however, in appropriate confinement and considering all bio-safety measures.
- Limited research could also be supported in Bio-pharming and the use of animals to produce organs.
- The regulatory & ethical issues related body should be made effective to take care of all public concerns regarding veterinary and animal biotechnology.
- Attempts should be made to increase awareness about veterinary and animal biotechnology.

Chapter 7. Recommendations on Biotechnological Application to Applied Biology & Bioinformatics

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CONTEXT

Biotechnology has been benefited from major advancement in all fields of biology, while the application of biotechnological tools to biology has given birth to the era of modern applied biology and bioinformatics. Numerous industries have been involved worldwide to provide biotechnology related products and services to various academic, research and health related institutions. This area is one of the emerging avenues for developing nations to invest in and benefit from in long run. Bioinformatics, for example would require a limited investment, only in information technology section and the training of man power. They can then provide services to worldwide costumers, while setting in Pakistan. This must generate foreign earning to the nation.

VISION & MISSION

The vision & mission for biotechnological applications to applied biology and bioinformatics is to exploit the opportunities of biology related industries to provide increased employment, earn foreign revenue and reduce dependence on import for biotechnology related products and services.

OPPORTUNITIES AND CHALLENGES

The biotechnological applications to applied biology and bioinformatics have enormous opportunities and challenges. Some of these are listed below.

Bioinformatics related industries: With the decreasing cost of molecular characterization, large amount of data is accumulated worldwide. However, the human resources to deal with such a data are limited. The developing countries, with a high proportion of young population, could benefit from such a demand through training people in bioinformatics. This could provide jobs to a large proportion of population resulting in foreign earning.

Biotechnology related commodities industry: The industry which provides the basic commodities for biotechnology and applied biology also provides a huge opportunity for countries like Pakistan. The infrastructure and human resource development in such industries could give birth to new industries. These industries will not only reduce foreign dependence for biotechnology related commodities but also generate employment and enable foreign earnings. These could be chemicals, instruments and/or services. The partnership with private sector, especially the multinational partners, would be very useful in this context.

Bio-molecules industries: The potential of natural flora and fauna of Pakistan is not fully exploited. The biotechnological tools could rapidly and efficiently identify different useful compounds in natural flora and fauna and subsequent extraction. The tissue culture could also enable in-vitro production of plant metabolites for commercial exploitation.

Application to population biology and conservation genetics: The application of molecular markers coupled with population genetics theory has enabled to understand population biology of a large number of species, their adaptation, ecology and evolution. Such information is also useful for conservation of the species. Thus these tools of biotechnology could be applied to any living population ranging from microbial species to forest trees and marine organisms, to understand their population biology, ecology and evolution. This will assist in conservation of these species and a more wise and justified exploitation.

Forensic biotechnology: The forensic biotechnology utilizes the DNA finger printing to identify the criminal suspects and parentage. It is based on the fact that each individual has a unique DNA sequence. It provides a rapid and precise way of forensic tool, which can be used in criminology, paternity and any other such domains.

RECOMMENDATIONS

The expert panel suggested the following recommendations to be considered to improve the status of biotechnological application to applied biology and bioinformatics.

- The human resource and infrastructure development should be ensured to fully benefit from the potential of biotechnological exploitation to applied biology and bioinformatics.

- Special efforts should be made to encourage public-private partnership in this domain.

- The potential of industry associated with biotechnology related commodities, products and instruments should be exploited. Collaboration with neighbouring countries like China and India could be very useful in this context.

- The development of industries based on output of biotechnological intervention to biology should be encouraged. An easy and efficient mechanism should be devised to enable patents of these outputs.

- Research should be encouraged to identify the commercially exploitable products from the local flora and fauna.

- The characterization of national biodiversity and their subsequent conservation efforts should be initiated and encouraged.

- Public awareness should be increased about the utility of natural biodiversity and its conservation aspects.

Annex 1

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Thanks is also extended to members who contributed in chapter writing.

Annex I1

Different issues identified by the Biotechnology Foresight panel based on the STEEPV approach.

Social	Technological	Economics	Environmental	Political	Value
Food, Feed and Fiber Security and Health Care	Development and application of Biotechnology in Agriculture, Health, Industry, and Environment	Socioeconomic benefit via. Bio-economy	Use of biotech to solve environmental problems	Policy formulation for development and deployment	Development and Deployment of Bio-Tech product inline with Bio-Ethics
Collaborative efforts among stakeholders for Tech development & deployment	Adoption, Innovation, Dissemination and utilization with emphasis on PPP	Self sufficiency and self reliance	Enforcement and implementation of biosafety guidelines	Strict implementation of protocol conforming to int. standard	Protection of public rights of ownership
Capacity building for job opportunity	Support for result oriented and mandated activities by avoiding overlapping	Integration of biotechnology research/application into national economic planning and production processes	Environmental and health risk assessment	Mobilizing political will and support	Awareness
Ethics	Bio-info computer drug design, Dig. imaging, Biomedical, diagnostics, managing	Lack of funding for new Bio-tech incubators	Toxicology be considered... Environment Monitoring, Bio-Sensors	TRIPS, BTWC, SPS, Likely (food GMO) Plant breeder rights	National Products be promoted & certified
Social Stability	Discipline wise study or country-wise study	Lack of capacity	Future disasters due to new tech urge in GMOs	IP laws, Patent issues (no commercial patents, global issues 90% non-commercial	Religious Values
Results oriented to industries and end-users	Technology Transfer	Avoid overlapping of mandate	Manufacturing laws in public sectors	Lack of political will	Marketing by experts to gain political will
	Bio-Model devising plans which are socially accepted.	Studying national policy devising process challenges (subgroups)	Bio-Safety & Security values implementation. (issue: bureaucracy)	Lack of priorities & needs and also National Policy and Planning is missing	Weak linkages between univ, industry & R&D org.
	Priority strategic bio-tech in Pak perspective	Public private partnership	Value addition is lacking	PC-1 procedure is defective	Survey Required
	Industrial biotech & MSE in bio-tech	protection & preservation national genetic resources		Umbrella organization for bio-tech and Biotech policy for Pakistan	
	HRD & infrastructure			Funding facilitation of to bio-tech Industries	