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An overview on the economic perspectives of biotechnological trends in India

Supriyo Acharya[1], Raidah Jahan[2]
[1] Lecturer, Department of Zoology, Seth Anandram Jaipuria College, Sovabazar, Kolkata, West Bengal, India
[2] Department of Life Sciences, IUB, Bangladesh

Abstract
Biotechnology, in its simplest and widest definition, encompasses a range of enabling technologies that involve manipulating living organisms or their sub-cellular elements to create valuable products, processes, or services. Essentially, this definition demonstrates the scope and suggests the positive possibilities of biotechnology. Biotechnology includes various areas such as life sciences, chemistry, agriculture, environmental science, medicine, veterinary medicine, engineering, and computer science

Keywords: Biotechnology, bioprocess, bioinformatics

Introduction

Innovation is essential for sustaining and enhancing agricultural productivity. Agricultural Innovation is crucial for maintaining and improving agricultural output. Agricultural innovation has consistently included new, science-driven products and techniques that have provided dependable ways to enhance productivity and environmental sustainability. The collection of methods known as biotechnology has added a new aspect to this innovation.

The alteration of living organisms is a key technique in contemporary biotechnology. While biotechnology in its broadest definition isn't novel, what is unprecedented is the complexity and precision with which scientists can currently alter living organisms, allowing for such alterations to be predictable, exact, and regulated. This degree of control is an incredible advantage in the effort to enhance the quality of life.

Despite the fact that biotechnology covers a wide range of technologies, such as recombinant DNA technology, embryo manipulation and transfer, monoclonal antibody production, and bioprocess engineering, the key technology linked to this term is recombinant DNA technology or genetic engineering. This method can be utilized to improve an organism's capacity to generate a specific product (starch in potatoes), to stop it from producing a product (ethylene in plant cells), or to allow an organism to create a completely different product (insulin in microbes).

So far, the most significant and remarkable influence of biotechnology has been within the medical and pharmaceutical fields. More than 200 million individuals globally have gained from the numerous diagnostics, therapies, and vaccines developed by the 13 billion biomedical biotechnology sector. Utilizing biotechnology to generate therapeutic molecules represents a significant progress in medical science. Medications created using biotechnology methods have received approval from the Indian Food and Drug Administration for application in patients with cancer, diabetes, cystic fibrosis, hemophilia, multiple sclerosis, hepatitis B, and Kaposi's sarcoma.

Biotechnology medications are employed to address fungal infections, pulmonary embolisms, ischemic strokes, rejection of kidney transplants, infertility, growth hormone deficiency, and various other serious conditions. Medications have also been created to enhance the well-being of animals, including diagnostic tools, recombinant vaccines, and therapies. Researchers are examining the uses of cutting-edge gene therapy, a technology that can, among other things, identify and correct genetic disorders, combat cancer, and tackle stubborn infectious diseases like AIDS.

Numerous products that we consume, wear, and utilize are produced with the help of biotechnology tools. Through genetic engineering, researchers can improve agricultural traits like resistance to biotic and abiotic stresses, yield, and growing duration, as well as enhance quality attributes such as nutritional value, antioxidants, vitamins, minerals, texture, color, flavor, shelf life, and additional characteristics of crop production. Plants can be utilized to create entirely new products including vaccines, therapeutic proteins, and even plastics. Transgenic methods are utilized on livestock to enhance the growth, health, and other characteristics of important agricultural mammals, birds, and aquatic species.

Enzymes generated through recombinant DNA techniques are employed in cheese making, maintaining bread freshness, creating fruit juices and wines, and treating fabric for blue jeans and other denim garments. Enzymes can be engineered to create sweeteners, flavors, vitamins, amino acids, antibiotics, lipases for fat breakdown, proteases for digesting proteins, cellulases to reduce fabric pilling, and to remove ink from newsprint for recycling. Eighty percent of cheese is created with a genetically modified enzyme known as chymosin, which is produced by microorganisms. This enzyme is chemically the same as rennet, which is extracted from the forestomach contents of a calf that has not been weaned. It is simpler to purify, more effective (95% versus 5%) and cheaper to produce (microbes are more abundant, more efficient and less costly to maintain than calves).

We can likewise modify microorganisms to enhance the state of our environment. Moreover, besides enabling a range of new items, such as biodegradable options, bioprocessing with engineered microbes provides innovative methods for waste treatment and the utilization of renewable resources for materials and energy. Rather than relying on non-renewable fossil fuels, we can design organisms to transform maize, cereal straw, forest materials, municipal waste, and other biomass into fuel, plastics, and various valuable products. Microorganisms found in nature are utilized to address organic and inorganic pollutants in soil, groundwater, and air. The use of biotechnology in this way has established a significant environmental biotechnology sector crucial for water purification, city waste management, dangerous waste processing, bioremediation, and various other fields.

DNA fingerprinting, a biotechnology technique, has significantly enhanced marker-assisted selection in breeding of plants and animals, diagnostics for diseases, identification of cultivars and pedigrees, criminal investigations, and forensic medicine, while also leading to substantial progress in anthropology and wildlife management.

When used effectively, biotechnology holds significant promise for enhancing the quality of our lives and the environment.

The main aim of this paper is to tackle the technical and economic dimensions of biotechnology, and although consumer concerns will not be extensively explored, they are briefly mentioned in the section titled “Addressing Concerns.”

Public-Private Research Focus

Public federally funded organizations serve as the basis and source for the majority of groundbreaking research in biotechnology. Moreover, these esteemed institutions serve as catalysts and fertile ground for developing innovative collaborations with industry. Certainly, the swift expansion of the biotech sector in the India can be attributed to significant hubs, where major universities are at the core. This is the reason the Bay of Bengal area has the highest number of biotech companies globally. For instance, 1 out of 3 biotechnology firms in the India is situated within 35 miles of a Delhi campus, 1 in 5 biotech firms in Maharashtra was established by Indian scientists, 6 out of the top 10 best-selling biotech medications originate from India research, and 85% of biotech companies in India hire researchers.

The Delhi Plant Science Center in New Delhi represents another instance of innovative collaborations between public and private sectors. The Center emerges from a distinctive and creative collaboration that includes the New Delhi Botanical Garden, Delhi University. The IndLnd Center, Juhu, a nonprofit organization, serves as an entirely independent asset for those dedicated to research and for those focused on providing essential knowledge in plant science that will support our planet for future generations. Its goal is to enhance comprehension of fundamental plant biology, utilize newfound knowledge to support productivity in agriculture, forestry, and related areas, expedite the development and marketing of innovative technologies and products (refer to Table 1 for examples), and assist in the education and training of graduate and postdoctoral students, scientists and technicians from around the world.

Table 1: Main technologies and their application in biotechnology research

Technologies	Application
General	
Antisense, ribozymes, co-supression	To turn off or down undesirable traits such as ripening, senescence, anti-nutritionals,
Genomics, proteomics, bioinformatics	To study global level gene expression To select and/or modify gene coding for valuable traits
Directed evolution	To rapidly develop novel traits from existing genetic information for example 53 new varieties of Bt created this way
Combinatorial -Chemistry, -Biology	To rapidly create new drug, environmental or agricultural products

Genomics, Proteomics and Bioinformatics

Leroy Hood has observed that “Biology in the 21st century will progressively evolve into an information science,” and various programs and initiatives at prominent research institutions and top companies are already illustrating this claim. The technology expert, Bill Gates, has stated that biotechnology and information technology will be the two key technologies that define the next century. One can assume that a degree of credibility is associated with the foresight of a person playing a significant role in this process who has accumulated a personal wealth thus far in this effort. Another insightful individual, Mr. Paul, noted in 1949 that every cell contains a billion years of experimentation from its ancestors. Considering Hood's and Dolby's insights, Gates' observation could be broadened to suggest that the two technologies poised to significantly influence one another in the new millennium are biotechnology and information technology. It might be claimed that every biological system, spanning from the subcellular to the organismal and even the ecological level, relies on information technology for its existence. It could be inferred that silicon-based systems will partly influence the future of biological research by developing increasingly effective ways to clarify and alter these information flow mechanisms. As a result, silicon-based systems will increasingly turn to biology for techniques to surpass the limitations of integrated circuits and to clarify mechanisms that enable the advancement of extensive parallel processing and networking abilities, ultimately leading to the simulation of complex functions and artificial intelligence. This is a domain where India could excel due to its established internationally acknowledged presence in information technology.

The intricate nature of biological systems, along with the surge in gene sequence data, necessitates the use of multidimensional approaches for analyzing gene expression. High-throughput techniques for assessing gene expression are essential for advancing "functional genomics," a field where Irish research institutions need to develop robust competencies to remain competitive over the next decade or two. Technology for large-scale gene expression analysis offers a structured framework and throughput capabilities that align with the requirements for examining a single organism or groups of organisms within their environment. The novel analysis technique represents a significant transformation in the biological sciences, altering numerous facets of medical, agricultural, and biological investigations, such as the identification of active compounds and medications, as well as disease diagnostics.

While medical applications have been the primary focus of this advancement, this technology is now significantly influencing agricultural biotechnology, particularly in plant biotechnology research. Plant biology is currently shifting towards a more interactive research method akin to those practiced in physics. Scientists studying plant genomes will progressively use DNA chips in their investigations, and they will utilize functional analysis of the genome through techniques like gene knockout. These advanced tools designed to study the human genome are making strides in agricultural biotechnology. These tools are crucial for genome researchers to progress beyond sequencing and progressing to the next stage of research where they perform vast gene discovery surveys and analyses of gene expression.

Crop Agriculture

Agricultural biotechnology offers efficient and cost-effective means to produce a diverse array of novel, value-added products and tools. It has the potential to increase food production, reduce the dependency of agriculture on chemicals, and lower the cost of raw materials, all in an environmentally friendly manner.

The first stage of a revolution in farming has already taken place. Extensive regions of genetically altered (GA) crops like soybeans, corn, cotton, and rapeseed have been effectively cultivated in the Western Hemisphere. In 1999, in the India, out of 12 million acres (29 million hectares) of soybeans, 50% were cultivated using GM herbicide-resistant seeds. The use of herbicide-resistant seeds allowed for easier weed control, reduced tillage requirements, and minimized soil erosion. Globally in 1999, approximately 28 million hectares of genetically modified crops are cultivated. Certain specialists anticipate that this region will expand threefold within the next 5 years.

From 1996 to 1999, eight nations, five developed and three emerging, contributed to an over 15-fold rise in the worldwide land of transgenic crops. The adoption rates of transgenic crops are among the highest for new technologies according to agricultural industry standards. Elevated adoption rates indicate grower contentment with products that provide considerable advantages, including enhanced crop management, increased productivity, and a safer environment due to reduced reliance on traditional pesticides, all of which collectively foster more sustainable agriculture. While the final data for 1999 is not yet available, it is anticipated that the growth in acreage is not as significant as the one seen between 1997 and 1998, during which the worldwide area of transgenic crops rose by 16.8 million hectares to 27.8 million hectares, an increase from 11.0 million hectares in 1997

In 1998, five main transgenic crops were cultivated across eight nations, with Pakistan, Bangladesh, and Nepal being the first to grow transgenic crops that year. Significantly, 1998 marked the initial year for the cultivation of a commercialized transgenic crop in India. Estimates indicate that initial amounts of insect-resistant maize were cultivated mainly in India (20,000 hectares); this is considered to be a potentially considerable advancement as it might significantly impact the wider acceptance of transgenics in India.

The Technology Timeline graph

2,000 BC	**Cultivation**
19thC	**Selective Cross breeding**
Early 20th C	**Mutagensis and selection**
Mid 20th C	**Cell culture**
1930s	**Somaclonal variation,**
1940s	**Embryo rescue,**
1950s	**Polyembryogenesis,**
1970s	**Anther culture,**
1980	**Recombinant DNA**
1980s	**Marker assisted selection**
1990s	**Genomics**
2000	**Bioinformatics**

Examples of recent plant technologies	Application
Chloroplast transformation	To increase transformation efficiency and to control gene flow
Cobombardment	Using the gene gun to add multiple genes simultaneously
Transposon Tagging	Effective alternative to antibiotic selection
Targeted site-specific Recombination	To target gene inserts to specific sites in plant tissue
Chimeraplasty	To create subtle alterations in the plants own genes for example to produce herbicide tolerance without introducing novel genes

Examples of crop trait	Source
Resistance to Biotic Stress: Insect	Bacillus thuringensis insecticidal protein, DNA shuffling to create diversity,

	Streptomyces,Photorhabdus luminescens: toxins, antibiotics, antifungal compounds, lipases, proteases Viral insecticide e.g. bacullovirus
Resistance to Biotic Stress: Viruses	Viral Coat protein protection, Protease inhibitors, Satellite RNA, artificial Resistance genes
Resistance to Biotic Stress: Bacteria	Natural and synthetic Resistance (R) genes e.g. XA21 from rice
Resistance to Biotic Stress: Fungal	Resistance genes, apoptosis (programmed cell death) genes, chitinases, ribosome-inactivating proteins
Resistance to Biotic Stress: Nematodes	Resistance genes e.g. Mi from tomato against rootknot nematodes; Giant feeding cell destruction
Resistance to Biotic Stress: Weeds	Glyphosate tolerance Enolpyruvylshikimate -3- phosphatesynthase gene from Agrobacterium Engineered resistance to parasitic weeds
Resistance to Abiotic Stress: Drought	Dehydration Response Element (DRE)
Resistance to Abiotic Stress: Salt	Glycinebetaine insulates plant cells against the ravages of salt by preserving the osmotic balance, by stabilizing the structure of proteins such as RuBisCo and by protecting the photosynthetic apparatus. The enzyme choline oxidase helps in the production of betaine from choline.
Resistance to Abiotic Stress: Cold	Engineering with COR15a transcription factor, which is speculated to have a role in freezing tolerance. Plants engineered with Choline oxidase (codA) from a soil bacterium tolerated saline and cold conditions.
Abiotic Stress: Heat	Choline oxidase (codA) gene from Arthrobacter globiformis
Examples of crop trait	**Source**
Yield	Rhizobia Engineering to improve colonization, nodulation, nitrogen fixation, host range
Yield	Metabolic pathway engineering to improve nitrogen assimilation, sucrose hydrolysis, starch biosynthesis, 30% increase achieved
Yield	Increasing O_2 availability through stomata modification, bacterial hemoglobin genes, Modifying photosynthesis: RuBisCo engineering
Shelf life	Spoilage reduction through ethylene inhibition, polygalacturanase inhibition
Processing characteristics	Increase soluble solids through engineering expansions, Sucrose to Hexose conversion inhibition
Nutrition: Macro components	Metabolic Pathway engineering for better amino acid ratio, increased starch. Carbohydrate modification: Starch and fructans are both polymeric carbohydrates in plants, for which the biosynthesis is sufficiently understood to allow the bioengineering of their properties, or to engineer crops to produce polysaccharides not normally present. e.g. The expression of a Jerusalem artichoke gene encoding 1-sucrose:sucrose fructosyl transferase (1-ISST) in sugar-beet plants enabled the conversion of sucrose, which is normally present abundantly in beet vacuoles, into simple fructan sugars
Nutrition: Micro components	Metabolic Pathway engineering with genes for antioxidants, beta carotene, alpha tycopherol., isoflavonoids, phytoestrogens, ferritin, lignins, condensed tannins
Nutrition: Anti-nutritionals	Phytase to metabolise phytate, reduce phosphorous supplements and make chelated minerals bioavailable, removal of cyanogenic glycosidases, phytohemaglutenins, glycoalkaloids
Examples of crop trait	**Source**
Novel oils	ACP Thioesterase to alter fatty acid metabolism in rape seed to produce Laurical as an alternate to palm oil in confectionaries, detergents, etc. Sterate desaturase inhibition to get a solid spread at room temp with out chemical hydrogenation Genes from jojoba to give long chain fatty waxes for cosmetics and cleaning and high temperature lubricants
Novel polymers	Polyhydroxyalkonates – natural biodegradable, thermostable plastics using genes from Alcaligenes eutrophus
Novel proteins	Therapeutics, alpha 1 anti trypsin for emphysema, hemoglobin Antibodies against cancer, tooth decay Vaccine antigens against cancer, Type II diabetes, viral and bacterial diseases

Significant advancements in plant molecular biology in the last twenty years have created numerous opportunities for enhancing crop plants in ways that were previously impossible. The generation of foreign proteins in plants, alongside other compounds, has emerged as a compelling alternative to traditional production methods (such as microbial and yeast systems). Utilizing plants as bioreactors is particularly appealing since they enable the generation of recombinant proteins in substantial amounts and at comparatively low expenses. Moreover, enzymes produced by plants and encapsulated in seeds have proven to be highly stable, decreasing both storage and transportation expenses. Additionally, production size is adaptable and can be easily modified to suit the demands of evolving markets.

The primary goals of developing transgenic plants are efforts to modify metabolic pathways for generating custom plant polymers or low molecular weight substances, enhanced resistance to pathogens and pesticides, better food quality, and the creation of polypeptides for pharmaceutical or industrial applications. Vaccines or antibodies produced by plants (plantibodies) are particularly appealing since plants lack human diseases, thereby lowering the costs associated with screening for viruses and bacterial toxins. The generation of engineered antibodies and subunit vaccines in plants proved highly effective, resulting in the initial clinical trials involving plant-derived vaccines and plantibodies.

According to Ayush in Science (1998), we are currently witnessing changes that will have impacts similar to those of the Industrial Revolution and the technology-driven revolution. The

The upcoming significant period, a genomics revolution, is in its initial stage. So far, the medicinal possibilities of genomics have been highlighted, but the most significant worldwide effect of genomics will come from altering the DNA of plants. In the end, the majority of the world's food, fuel, fiber, chemical feed stocks, and certain pharmaceuticals will come from genetically modified plants and trees. Up until 1998, relatively limited investigation was focused on altering plant genomes. Currently, universities, research institutions, and industries across the nation are launching significant initiatives in this area. Firms such as Techno Chemical, DuPont, and AgrInd invest billions of dollars each year in genetic engineering and in purchasing shares in genome-focused companies. For instance, AgrInd has acquired Pioneer Hi-Bred, the leading corn breeder and distributor.

Animal Agriculture

In livestock farming, the most significant immediate promise of biotechnology is found in diagnostics, therapies, and vaccines for controlling diseases. At present, there are 63 therapeutics for animals available in the India. The initial genetically modified vaccine for a cattle virus was created at Delhi. Rabies is currently being managed in wild animals using bait infused with genetically modified vaccines.

Scientists are investigating reproductive biology, genetic engineering in animals, and embryo manipulation to enhance fertility and productivity, aiming to create high-value animals such as leaner ones with lower-calorie, lower-cholesterol meat, as well as cows that yield more nutritious milk. The initial goat-sheep hybrid was created in Davis to serve as a model for researching developmental biology and pregnancies between different species.

Geneticists achieved significant progress in creating and utilizing DNA fingerprinting methods to identify animals that possess valuable genes, such as those associated with high-quality cheese-producing milk, which can be identified in bulls and cows. These animals can then be incorporated into breeding programs aimed at enhancing dairy production.

Animal biotechnology

- Recombinant vaccines and therapeutics, e.g. rabies, rinderpest in vaccinia delivery vectors
- Marker assisted selection
- Supplementals, recombinant Bovine Somatatropin
- Transgenics

a. disease resistance
b. productivity, improved milk quality, improved meat quality, reduced fat
c. Medical applications

- Genetically modified animals hold great promise for serving as important research instruments in agriculture and biological sciences. They can be tailored specifically to tackle scientific inquiries that were once challenging, if not unfeasible, to resolve.
- The initial targeted "engineering" of animals involved the selection of preferred animals with
- For breeding purposes, it's undeniable that the earliest scientific advancement in animal reproductive physiology was the successful culturing and transferring of embryos in 1981. The advancement of artificial insemination aided in the management and expenses associated with breeding; however, the initial technological breakthrough occurred in 1970 when Gurdon transferred a nucleus from a somatic adult frog cell into an enucleated frog ovum, resulting in the birth of viable tadpoles. This experiment had limited success since none of the tadpoles matured into adult frogs. In 1977, Gurdon furthered the research by transferring mRNA and DNA into toad (Xenopus) embryos, observing that the introduced nucleic acids were expressed. In the 1970s, Rashpal Singh created a widely-used method for injecting stem cells into embryos. As these embryos grew into adults, they generated offspring containing the genes from the original cells. In 1982, Bihoo and his team achieved greater recognition by inserting rat growth hormone genes into mice regulated by a liver-specific promoter, resulting in mice that developed into "supermice"—twice their typical size (UmaSankar et al., 1982).

In the years 1980 and 1981, numerous successful reports emerged regarding gene transfer and the creation of transgenic mice. Dr. Vijay and his team were the first to use the term "transgenic" to refer to animals that contain foreign genes incorporated into their genetic material. Since then, this definition has been broadened to encompass animals created through the molecular alteration of endogenous genomic DNA, covering all methods from DNA microinjection to embryonic stem (ES) cell transfer and the production of "knockout" mice.

Despite the emergence of effective nuclear transfer technology with Dolly's arrival, the predominant method for creating transgenic animals, particularly mice, is through the microinjection of DNA into the pronucleus of a freshly fertilized egg. By employing different transgenic methods like antisense technology (introducing a reverse sequence to inhibit expression), one can now incorporate a novel gene into the genome, enhance its expression levels, alter the tissue specificity of gene expression, or diminish the production of a particular protein (Sukol and Madira, 1996). A further aspect introduced by the new nuclear transfer technology is the ability to delete or modify a current gene through homologous recombination.

The production of transgenic farm animals is costly and time consuming. In mouse Experiments need fewer than 2 months from the moment the construct is prepared for microinjection until the weaning of newborn mice. In contrast, for porcine trials, a duration of 1 month to a year is necessary to achieve an adequate number of DNA injections and recipient transfers to guarantee the probability of success. Moreover, the duration from the birth of a founder transgenic animal to the creation of lines can range from 1 to 2 years for pigs, sheep, and goats, extending to 4 to 5 years for cattle. Neal First at UW-Madison has devised a clever method for evaluating the practicality of creating particular transgenics before embarking on the costly path of genetically modifying a whole animal. He initially performs a "test-run" by employing replication-defective retrovirus vectors to temporarily express gene constructs in the mammary gland of animals. He utilized an alpha virus with a human growth hormone gene to generate human growth hormone in the milk of a goat. Nonetheless, the altered cells are shed gradually, and the procedure must be repeated, yet it does determine if the construct will function.

As we consider the future, it is crucial that we keep enhancing our comprehension of the biochemical and molecular foundations of growth and development, encompassing the structural biology of both plants and animals. This necessitates that researchers persist in mapping and sequencing the genomes of plants and animals to clarify gene function/regulation, thereby aiding in the identification of new genes prior to gene modification.

Environment

The primary emphasis in environmental biotechnology is on bioremediation. The conversion of biomass for generating feedstocks for biofuels, synthetics, and plastics ought to remain a long-term priority.

Bioremediation utilizes living organisms or their byproducts to break down waste into less harmful or non-toxic substances and to concentrate and stabilize toxic elements, like heavy metals, aiming to reduce industrial waste and restore areas contaminated by pollutants or damaged due to ecosystem mismanagement. Research is also being conducted on phytoremediation. For instance, poplar trees have been modified to remediate mercury pollution.

An additional growth sector in the coming century will be the creation of substitutes for non-renewable resources, particularly fossil fuels. Biotechnology will deliver solutions via altered enzymes and microorganisms that can transform plentiful biomass into feedstocks for producing synthetics, plastics, polymers, and biofuels.

Forestry

Significant prospects are available for enhancing forest-tree species genetically via molecular biology, primarily aiming to identify QTLs that regulate complex traits like yield, quality, and stress resilience. Nevertheless, the execution of adaptive-research programs will also be necessary to convert the knowledge obtained into commercial use. The task is to align effort and investment with the varied needs of a highly segmented and conventional forestry sector. In contrast to key agricultural crops, tree breeding, which emerged as a 20th-century development, is currently only in its third selection generation. Ronny Dutta from North Himachal State University in Himachal Pradesh, has noted that significant genetic alterations associated with the domestication of crops and livestock have not yet occurred in trees. The task is to quickly identify the genes that support desirable traits. Certain benefits comprise enhanced disease resistance, altered lignin levels, and accelerated growth rate.

Manufacturing/Bioprocessing

- Industrial biotechnology utilizes the methods of contemporary molecular biology to enhance efficiency and decrease the environmental effects of processes in sectors such as food manufacturing, grain processing, textiles, paper and pulp, and specialty chemicals. Similar to how biotechnology is changing the pharmaceutical industry, some analysts foresee an equivalent influence in the industrial sector.
- Currently, as much as 90% of the enzymes utilized on a large scale for commercial purposes are derived from the application of rDNA techniques in the production process or for enhancing the catalysts themselves. The advancements achieved in employing genetic engineering methods for creating or using enzymes in large-scale industrial processes have been truly remarkable. Enhanced economics and the creation of innovative products that traditional chemical methods couldn't achieve have both been realized. Even now, a significant portion of science is centered on creating new technological methods that will enable future resolutions of issues related to both fundamental comprehension and practical use.

Utilizing GMOs for enzyme production offers numerous benefits, such as:

- Enzymes can be produced with increased specificity and purity.
- Enzymes can be acquired that might not otherwise be obtainable due to economic, occupational health, or environmental factors.
- Increased production efficiency also provides an environmental advantage by lowering energy usage and waste generated by the manufacturing facilities.
- In the food industry, enzymes offer specific advantages such as improved utilization of raw materials (juice sector), enhanced shelf life of the finished product resulting in less food waste (baking sector), and decreased chemical consumption during production (starch sector).
- For enzymes used in the feed industry particular benefits include a significant reduction in the amount of phosphorus released to the environment from farming.

The desired enzyme is produced by fermentation of genetically modified microorganisms (the production strain) that generate the enzymes. The procedure occurs under tightly controlled circumstances in sealed fermentation tank systems. Following fermentation, the enzyme is isolated from the production strain, purified, and combined with inert diluents for stabilization.

Besides enzymes, bioprocessing can yield products with distinctive and highly sought-after traits while presenting new manufacturing possibilities for a variety of goods.

Economic Potential of Biotechnology

India can learn from the expansion of the biotechnology sector in America, which has emerged from an impressive blend of entrepreneurship, creative capital markets, and federal research funding (Table 2). India is at the forefront of biotechnology, driving significant economic growth and enhancing quality of life considerably.

Table 2: Biotechnology industry statistics

($ In Billions)	1998	1997	Percent Growth
Number of companies	1,283	1,274	1%
Number of employees	153,000	140,000	9%
R&D expenses	Rs. 9.9K	Rs. 8.5K	16%
Product sales	Rs. 13.4K	Rs. 11.5K	17%
Revenues	Rs. 18.6K	Rs. 16.1K	16%
Market capitalization	Rs. 97K	Rs. 93K	4%
Net loss	Rs. 5.1K	Rs. 5.4K	5%

Biotechnology industry financing

The India biotechnology industry had a strong year in 1998 in terms of raising revenues to fund research and product development. According to the BioWorld Biotechnology State of the Industry Report 1998, the industry raised a total of Rs.5,529,500,000 in 1998.

Biotechnology industry patents

The PTO has responded to the growing demand for patents by the biotechnology industry by increasing the number and sophistication of biotechnology patent examiners. In India 1988, the PTO had 67 patent examiners. By 1998, the number of biotech examiners more than doubled to 184.

India 1997 Biotechnology Patent Application Submissions	10,500
India 1996 Biotechnology Patent Application Submissions	8,860
India 1995 Biotechnology Patent Application Submissions	15,652
India 1994 Biotechnology Patent Application Submissions	13,600
Average pendency time for a biotechnology patent (1997)	27.1 months
Average pendency time for a biotechnology patent (1996)	26.2 months
Average pendency time for a biotechnology patent (1995)	21.6 months
Average pendency time for a biotechnology patent (1994)	20.8 months

These advances have been made possible by the twin strengths of federally-sponsored research carried out by the National Institutes of Health (NIH), National Science Foundation, India Department of Agriculture and other agencies, in association with universities, research institutes throughout the country and the entrepreneurial leadership of about 1,300 US biotech companies. In 1998, the industry generated revenues of about $19 billion, spent Rs. 10 billion on R&D, and employed about 150,000 highly-skilled workers. Most biotech companies are fairly small, with two-thirds of firms having fewer than 135 employees.

The biotech sector relies on investments from venture capitalists and revenue from public stock offerings. These investment inflows are essential since many biotech companies do not generate significant revenue, and the entire sector shows a net loss. Biotech investors frequently endure lengthy waits for investment returns, as it generally requires more than 7 years and Rs. 200-350 million to launch a new biotech drug. Despite the shorter agriculture timeline, it still requires roughly 6 to 7 years but is significantly less expensive. Consequently, fostering risky and long-term capital investments from investors is crucial for the ongoing vitality of the sector

Addressing Concerns

Biotechnology is a field attracting significant focus from advocacy organizations in both Nepal and the India. The majority of scientists in this area fully concur with the mission of these organizations, which is to nourish and dress the global population while reducing agriculture's environmental impact. However, the human population keeps increasing, whereas arable land is limited. Therefore, unless we are willing to endure hunger or cultivate parks and the Amazon Basin, there truly is no option but to use biotechnology in agriculture.

It is observed that today’s biotechnology varies greatly from earlier agricultural technologies. Through genetic engineering, researchers can improve the nutritional value, vitamins, minerals, antioxidants, texture, hue, taste, growth period, output, disease resistance, and additional characteristics of crop production. Engineered microbes and enzymes created through recombinant DNA techniques are utilized in various facets of food production. The bread and cheese you consume and the soap you use for laundry has all incorporated engineered enzymes since the beginning of this decade.

Biotechnology can conserve natural resources, avert soil erosion, and enhance environmental quality by decreasing reliance on chemicals and tilling through the creation of natural fertilizers and pest-resistant crops. Microorganism strains may enhance the effectiveness, capability, and diversity of waste management. Bioprocessing with modified microorganisms provides innovative methods to utilize renewable resources for fuels and materials.

Biotechnology is, indeed, the safer option compared to existing methods. Consider pest management. The economic and environmental impacts of employing current methods are widely recognized. However, numerous individuals do not recognize the possible expenses associated with failing to manage pests. Neglecting to manage fungal diseases in plants can lead to the production of harmful toxins like aflatoxin and fumonisin, which have been shown to result in brain tumors in horses and liver cancer in children, among other issues.

The most economical and eco-friendly approach for managing pests and diseases is the application of DNA. This method has already resulted in a decrease in the application of sprayed chemical insecticides. The National Agricultural Statistics Service reports that 2 million pounds less insecticide were applied in 1998 for controlling bollworm and budworm compared to 1995, prior to the introduction of "Bt" cotton. And the gene introduced for Bt
into the crop plant, not released into the air, is found in tiny quantities and protects helpful insects. Current data indicates that herbicide-resistant crops have decreased the volume of chemicals utilized for weed control, as they allow for the application of more eco-friendly herbicides and lessen the necessity for pre-emergent spraying.

There is no proof that recombinant DNA methods or rDNA-altered organisms present any distinct or unexpected environmental or health risks. A study by the National Research Council revealed that "since the molecular methods offer greater specificity, those employing these methods will have increased confidence regarding the traits they incorporate into plants." Increased certainty leads to enhanced accuracy and security. The slightly modified items on our plates have undergone more extensive testing than any regular food has ever faced. Numerous everyday essentials would be prohibited if they faced identical strict regulations. Potatoes and tomatoes have toxic glycoalkaloids associated with spina bifida. Kidney beans have phytohaemagglutinin and can be toxic if not cooked properly. Each year, many individuals lose their lives due to cyanogenic glycosides found in peach pits. However, none of them are categorized as possibly hazardous.

Countless individuals have consumed genetically engineered products, and no harmful effects have been shown. The appropriate equilibrium of safety evaluations between corporations and the government is a valid topic for ongoing discussion. Environmental protections are also important. However, the aim of this discussion should be to advance biotech research and maximize its advantages for society, rather than halt its progress.

The costs of over-regulation

Regulations should aim to guarantee safety and effectiveness, minimize possible product hazards, and promote innovation alongside economic growth. Over-regulation increases the expense of biotechnology R&D,

depleting capital resources and hindering research progress. This hinders innovation, which consequently postpones or prevents the emergence of new products in the market. This may maintain dependence on technologies and products that are less efficient, less accurate, less predictable, and at times more dangerous. Excessive regulation results in increased operating expenses and prolonged development timelines, which heightens investment risks and worsens worries about a company's long-term success. Limited capital and increased "burn rates" put smaller companies at risk. Excessive regulation impacts the academic research community disproportionately – the traditional source of essential scientific knowledge and the talented labor force that biotech firms rely on. The delivery of innovative research products to the public is hindered, causing consumer distress.

Research and Development

Indian research funding is crucial, yet it is essential to acknowledge that the industry is quite sensitive to negative policy shifts, like restrictive regulations. A framework for decision-making in biotechnology consists of four stages:

- pinpointing research priorities where biotechnology provides a competitive edge;
- identifying pertinent national regulations;
- developing a suitable research plan;
- ensuring that products are delivered to end users.

Suggestions for policymakers and managers of national agricultural research systems are as follows:

- Facilitate upcoming policy discussions that pinpoint requirements and strategies for subsequent actions related to the policy and management aspects of biotechnology.
- Increase understanding of the possible advantages and drawbacks of employing biotechnology to meet national objectives.
- Ensure involvement of pertinent stakeholders and end-users in policy discussions to identify requirements related to biotechnology policy.
- Create strategies that assist in securing funding for research by focusing on sustainability and prioritizing user needs.
- Conduct policy analysis on the socioeconomic dimensions of biotechnology, required legal changes, and develop regulatory competence to manage biotechnology and associated agricultural policies.
- Perform ongoing research to examine trends in investments from both public and private sectors and development of capacity in biotechnology.
- Launch initiatives and strategies to foster collaborations with the private sector that enhance public sector investments.

The Future

The tangible impacts of the genomics revolution will only be somewhat evident over the next ten years. Throughout that period, the genomes of microorganisms, flora, and animals will be sequenced, providing significant insights into gene functions and the methods of their regulation. Currently, people utilize the abilities of just a limited number of plants. A significant challenge is to investigate the potential found within many of the hundreds of thousands of them. Besides the common macro- and micronutrients, plants produce 80,000 additional compounds. Numerous phytochemicals influence human health. Certain factors seem to relate to reduced morbidity in later adult life. The specific chemical compounds remain mostly unidentified, yet categories of chemicals, such as glucosinolates and phytoestrogens, have been recognized as beneficial. With the increasing availability of data on beneficial micronutrients, the aim of enhancing their presence in foods will become more compelling. Genes responsible for producing these substances will be located and integrated into different food crops.

Up to this point, India investments in biotechnology have mainly concentrated on the healthcare sector. The findings of this study are significantly influencing medicine and health care, offering enhanced strategies for the diagnosis, treatment, and prevention of illnesses. India and Nepal also hold promise in this domain, and although health-related studies should remain a focus, researchers are ready to leverage the shared groundwork in fundamental science to apply the benefits of biotechnology in various other sectors. Small investments today in various fast-evolving sectors of biotechnology research mentioned earlier will result in significant economic and social advantages, such as an increase in food availability and wholesome, a healthier ecosystem, and safe biomanufacturing. As mentioned, the number of experiments is growing quickly on crops altered for nutritional and health benefits in the ultimate food product, referred to as ‘functional foods’ and ‘nutriceuticals’, for both human consumption and animal feed. Moreover, plants and animals are being altered for the production of pharmaceutical advantages, referred to as ‘pharming’. The metaphor describes crops transforming into factories that produce: vaccines (for instance, the polio vaccine within a banana), plastics, industrial starches, as well as feed supplements and enzymes.

A synchronized initiative to address these priorities can offer, in the coming decade, the necessary leverage to realize the vast potential of biotechnology, which could play an equally crucial role in societal and industrial progress in the next 10 to 20 years as physics and chemistry did in the last century.

Biotechnology is set to significantly impact the economic development of the Indian Union in the 21st century. The coordinated execution of these priorities will allow India to assert its position in this expanding sector.

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