1 Biotechnology in Agriculture, Medicine and Industry: An Overview

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1.1 Introduction

Biotechnology is a rapidly booming field influencing pharmaceutical, food, agriculture and related industries. Biotechnological based interventions are vital components in virtually any industry employing microorganisms, cells and tissues for the production of biologicals. The global market for biotechnology is estimated to grow at an average compound annual growth rate (CAGR) of 11.6% from 2012 to 2017 and to reach a value of US$414.5 billion by the end of 2017. The global market was valued at approximately US$216.5 billion in 2011 (PR Newswire, 2014). India has the third largest biotech industry in the Asia-Pacific region and is amongst the 12 largest biotech destinations in the world. Increasing government expenses augment the growth of this sector and the Government of India has planned to spend US$3.7 billion on biotechnology from 2012 to 2017 during the 'Make in India' campaign. It is estimated that the biotech industry in India will grow at an average growth rate of around 30% and reach US$100 billion by 2025 (DIPP, 2014). Growing demand for healthcare services, advanced R&D activities and strong government initiatives have resulted in an increase in the market size of the biotech sector, which is expected to reach US$11.6 billion by 2017. In India, a special organization including the Biotechnology Industry Research Assistance Council (BIRAC) supports the biotech industry through mentoring, financial aid and infrastructure development. The Indian biotech sector is primarily led by pharmaceuticals, which accounted for the largest share in the biotech industry followed by bio-services, agri-biotech, industrial biotech and bioinformatics. The effect of biotechnology can be observed predominantly in major domains including agriculture, healthcare and industry.

In the area of human welfare and medicine, monoclonal antibodies, vaccines, lifesaving drugs, human insulin, disease diagnostic kits and gene therapy are some of the notable achievements of red biotechnology (pharmaceutical biotechnology). Microorganisms have formed a major role in the industrial production of biochemicals, including ethanol, enzymes, antibiotics etc. They are also being employed in the food processing industry for enhancing industrial processes leading to sustainable commercial production (industrial biotechnology). In agriculture, rapid production of disease-free planting material through tissue culture, development of novel crop varieties, somaclonal variations and transgenic crops with valuable genes for biotic and abiotic resistance through genetic engineering have ensured the enhanced crop production and better livelihood of growers (agricultural biotechnology).

1.2 Biotechnology in Agriculture

Cultivation of crops is as old as the history of humans, with the selection of better planting materials with superior traits through unintentional breeding being a predominant feature. Conventional plant breeding over the last 200 years has offered various superior crop varieties resulting in enhanced crop production and better livelihoods. In recent decades, modern agriculture has gone through significant changes, including the introduction

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of new crop varieties through mutation breeding and transgenics. Intervention of biotechnological applications has revolutionized the current scenario of food production.

The term 'biotechnology' has been used to refer to various biological processes in the production of beneficial products (Coombs, 1992; Zaid *et al*., 1999); however, in the present scenario it covers a broader area (McCouch, 2001). Earlier methods involved in modification of the genotype of plants and animals, and still used alone or in combination with various DNA-based methods, are referred to as 'conventional' plant breeding. Plants with alien genes transferred from unrelated organisms by genetic engineering are referred to as genetically modified (GM).

In 2014, the area under biotech crops was growing at the rate of 3–4% (6.3 million ha/year), reaching 181.5 million ha (Mha) and considered as the most widely adapted technology in modern agriculture (James, 2014). The most popular transgenics in 2014 included Bt cotton (25.1 Mha), herbicide-tolerant soybean (90.7 Mha), canola (9 Mha) and maize (55.2 Mha) (James, 2014). GM crops were valued at US$15.7 billion (2014) of which 72% market share was from developed countries and the remaining 28% was contributed by developing countries (James, 2014)

1.3 Biotechnology in Industry

Microbes have been associated with human health and welfare for a long time. The ability to manipulate the genotype of microbes has revolutionized life science and laid the foundation for innovations in industrial applications. Biotechnological applications in industry allow novel manufacturing processes that are environmentally safe and economically sustainable. Industrial biotechnology, commonly referred to as white biotechnology, is the application of modern biotechnology for sustainable production and processing of materials, chemicals, fuels, textiles, food and feeds, electronics and bio-energy using living microorganism and their enzymes (Tang and Zhao, 2009). Demand for sustainable production of various materials and chemicals has led to the advancement of industrial biotechnology, where microbe-based fermentation is used to produce biofuels and biochemicals (Nielsen and Jewett, 2008; Tang and Zhao, 2009; Otero and Nielsen, 2010; Du *et al*., 2011; Sauer and Mattanovich, 2012).

The industrial biotechnology sector in India recorded an 11.2% growth in 2011–2012 in terms of revenue, with total sales of Rs6970 million. This growth is credited to increased enzyme consumption in the food, detergent, pharmaceutical and energy sectors. Multinational companies have contributed about 65% of the total market whereas local companies have shared about 35%. The enzyme-based biotechnology sector recorded an 11.47% growth during the period 2002–2012. For 2011–2012, enzyme consumption in India reached Rs5270 million and exports attained Rs1700 million. For 2012–2013, estimated growth was 11.17% (Parmeshwaram *et al*., 2013). Taking into consideration that biotechnology is frequently connected with reduction in energy expenditure, lower greenhouse gas emissions and low waste production, much attention has been focused on this field. A key factor driving the growth of industrial applications of biotechnology is guaranteed economic profit, as biotechnology assures efficient production at lower operating costs. Rising demands for sustainability and eco-friendly industrial production systems associated with continuous exhaustion of natural crude oil reserves will continue to boost this trend (Soetaert and Vandamme, 2006). Expanding R&D sectors in biotechnology, encouraging government policies and other positive responses have aided the execution of industrial applications of biotechnology. Moreover, the ground-breaking innovations in enzyme engineering and technology, metabolic engineering, '-omics' science and computational systems biology are also anticipated to boost this sector.

1.4 Biotechnology in Medicine

Biotechnology encompasses processes used since biblical times, such as wine fermentation, and more recently discovered genetic engineering (Salomaa *et al*., 1995; Lubiniecki, 1997; Walsh, 2000). Biotechnology in drug development and pharmacology is generally referred to as pharmaceutical biotechnology. Biopharmaceuticals are various proteins with therapeutic activity and nucleic acid for application in gene therapy. The pharmaceutical biotechnology industry is the most dynamically growing sector over the last 30 years. The success of insulin and sulfonamides gave new heights to the pharma industry (Walsh, 2000; Weng and DeLisi, 2000). Biotechnological processes used most regularly in the pharmaceutics industry include recombined DNA technology, monoclonal antibodies, directed mutagenesis, biocatalysts, metabolic engineering, vaccine technology and gene therapy.

Table 1.1. Drugs produced by recombinant technology (Stryjewska *et al*., 2013).

Drug name	Active molecule	Disease
Humulin R, Humalog, NovoRapid, Gensulin R, Actrapid HM	Insulin	Diabetes
Factor VIII	Factor VIII	Haemophilia A in male
Factor IX	Factor IX	Haemophilia B
Human growth hormone (HGH)	Serostin, genotropin, humatrope	Growth hormone deficiency
Eprex, Epogen	Erythropoietin (EPO)	Anaemia
Rebif, Avonex, Betaseron	Interferons	Hepatitis B
Aldurazyme	α-L-iduronidase (rhIDU; laronidase)	Mucopolysaccharidosis type I non-neurological symptoms
Naglazyme	N-acetylgalactosamine-4-sulfatase	Mucopolysaccharidosis type VI
Neupogen	Granulocyte colony-stimulating factor (G-CSF)	Neutrophil production
Engerix B	Hepatitis B surface antigen (HBsAg)	Hepatitis B
Pulmozyme	Dornase alfa	Cystic fibrosis
Ceredase	Glucocerebrosidase	Gaucher's disease type 1
C1INH	C1 inhibitor	Hereditary angioedema
Activase	Tissue plasminogen activator	Dissolving blood clots
Pulmozyme	Dornase alfa	Cystic fibrosis

Pharmaceutical biotechnology was first exemplified by discovery of penicillin and streptomycin antibiotics in the 1940s. The revolution in pharmaceutical biotechnology redirected the research and development of the drugs industry. Recombinant DNA technologies have been extensively used in the production of a wide range of drugs/hormones/enzymes etc. (Table 1.1) (Bristow, 1993; Drews, 1993; Weng and DeLisi, 2000; Ausubel *et al*., 2002; Demkow *et al*., 2012). In 2014 the global biopharmaceuticals market was estimated to be US$162 billion and projected to swell to US$278 billion by 2020 growing at a CAGR of 9.4% (Persistence Market Research, 2015). Meanwhile, the global vaccine market is growing at CAGR of 12.65% and is estimated to reach US$43.5 billion by the year 2018 (PR Newswire, 2015).

1.5 Conclusion

Recent advances in biotechnological innovation have resulted in a remarkable transformation in the fields of genetics and molecular biology and have opened new vistas in the healthcare, pharmaceutical and agricultural sectors. However, despite broad applications of biotechnology, profits on investments are surprisingly slow. Intellectual property rights (IPRs), particularly patents, occupy a prominent position in the innovation systems in life sciences; but to what extent they support or hinder innovation is widely disputed. Thus, it is vitally important for universities, institutions, public research organizations and private enterprises to protect their innovation. At present, IP protection for biotechnological inventions is in a state of uncertainty. Modern biotechnological innovations are facing severe challenges under the existing IP framework. There are vast differences in opinions on the patentability of living organisms which are largely barred from patentability. However, mindsets are rapidly shifting and IP issues in biotechnology are receiving massive attention. To compete in global biotechnology-based markets developing countries are amending their patent laws in order to encourage foreign investment. Thus synchronization of international policy frameworks to provide unified guidelines for the patenting of life forms will be indispensable for the overall progress of life sciences in general and biotechnology in particular.

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