Defence Science Journal, Vol. 51, No. 4, October 2001, pp. 327-332

REVIEW PAPER

Biotechnology in the 21st Century

M.R. Das

Rajiv Gandhi Centre for Biotechnology, Thiruvananthapuram–695 014

ABSTRACT

The two technologies that will essentially determine the shape of things to come in the present century are biotechnology and information technology. A merger of biotechnology and information technology is happening right now, a significant example of which is the success of the human genome project. Biotechnology can be said to have started with the unravelling of the structure of DNA in 1953. The next decade saw exciting developments in our understanding of the fundamentals of functioning of biological system, including the role of DNA in protein synthesis. The discovery of reverse transcriptase and restriction enzymes in 1970s paved the way for further advances, including recombinant DNA and hybridoma technologies, often called 'genetic engineering'. The discovery of polymerase chain reaction in 1986 laid the foundation for large-scale applications of biotechnology in various fields. The practical applications of mapping of the entire human genome would be enormous in terms of better overall health care (diagnosis, therapy and management of disorders). In the field of flora and fauna, it generally happens that biotechnologically-rich countries have poor biodiversity and *vice versa*. But countries like India and China that have rich biodiversity have, by the use of biotechnology, the potential to become also biotechnologically rich.

Keywords: Biotechnology, biodiversity, DNA, RNA, molecular biology, oncogenes, human genome, gene mapping, genetic engineering, hybridoma technology, reverse transcriptase technology

1. INTRODUCTION

To begin with, in writing about biotechnology and calling this century the biotech century, it is only pertinent that one looks at the development of science in a proper perspective. The two technologies that will essentially determine the shape of things to come in this century are biotechnology and information technology, the first emerging from basic developments that have happened subsequent to the determination of the structure of deoxyribonucleic acid (DNA) by Watson and Crick in 1953, and the other based on basic developments in physics, quantum mechanics, atomic physics, nuclear physics and solid-state physics. A natural merger of biotechnology and information technology was expected to happen, but it is happening even earlier than expected as a consequence of the progress made in the human genome project. The complete information in the human genome project is expected to be made available by 2002 and that will provide a wealth of information, which, in turn, will bring together information technology and biotechnology.

2. IMPORTANCE OF BIOTECHNOLOGY

The importance of coming to grips with futuristic problems, considering the fragility of the

Received 03 September 2001

environment is, in fact, beautifully described by Louis Thomas, the late Director of the Sloan Kettering Cancer Centre in an article published in the *New England Journal of Medicine*. In this vast unlimited universe, the milky way is one among the numerous galaxies. A tiny portion of the milky way is the solar system, and as every one is aware, the earth is one of the satellites of the sun and two-thirds of the planet is covered by water and only one-third is supporting land-based life forms. In fact, Louis Thomas grossly compares the land mass supporting life on earth as the peel of an orange. However, in terms of the ratio of the thickness of the peel of orange to the contents inside, the peel is much thinner as far as the earth's surface which sustains land or water-based life forms. As of now, there is no concrete evidence that life forms are present in any other part of the universe, either in the solar system, or the milky way or the boundaryless universe, underscoring the uniqueness of living things on earth.

The author is reminded of the book 'The third wave' by Alvin Toffler, the futurologist and consultant to several Govts and UN agencies. Toffler has made the point that the first major change in human civilisation happened when human beings changed their life style from nomadic to agrarian civilisation. The second wave occurred soon after the industrial revolution when applications of chemistry and metallurgy were supported with the help of physics, that is, the then available knowledge in physics. The third wave is happening now as a consequence of developments in communication and biotechnology. As a matter of fact, some of the major business magazines like *Fortune* and *Business Week* have come out with cover stories on the unimaginable possibilities of biotechnology in the next century and have christened the coming century as the biotech century.

In terms of the applications for prospects of biotechnology, the possibilities will be endless. Within less than half a century after the discovery of the structure of DNA, the biotech revolution has started.

Although the basics of genetics, based on information stored in genes, from the time of Johan Gregor Mendel are known, nobody knew how exactly the genes function. It was only after the discovery by Thomas Avery that nucleic acids are the molecules which store genetic information, that the excitement in the basic functioning of DNA started.

3. FUNCTIONING OF BIOLOGICAL SYSTEM

3.1 Structure & Functions of DNA

In 1953, Watson and Crick, using X-ray crystallographic methods, discovered the structure of DNA and showed how information can be stored in DNA in the form of a four-element language of organic molecules which forms part and parcel of the makeup of DNA Watson and Crick shared the Nobel prize (1966) for this outstanding discovery.

The next decade showed very exciting developments in terms of understanding the fundamentals of functioning of biological systems. This included the cracking of the genetic code, primarily by Marshal Nirenberg, Hargobind Khurana and Robert Holley for which they received Nobel prize. Their discovery showed how genetic information stored in the DNA can be translated to proteins. There are two kinds of proteins, functional and structural. The functional proteins take care of the myriad chemical reactions required for the normal functioning of the living organisms, including human beings (including functions, such as digestion of food). The structural proteins determine the shape of a living organism, for example, in humans, the shape of nose, hands and fingers. All these information is originally stored in the DNA.

3.1.1 *Genetic Engineering*

Subsequent to obtaining all this knowledge, there were two major discoveries in 1970s. The first was the discovery of an enzyme called reverse transcriptase. Usually, biological information is transferred from DNA to an intermediary molecule, namely RNA, and then to protein. This discovery showed that information can go back from RNA to DNA. This was a key discovery in terms of genetic engineering. The other discovery (which is also essential for molecular cloning) was that of a group of enzymes called restriction enzymes. These enzymes are capable of cutting DNA at specific sites, depending upon the availability of specific palenchamic sequences present in the DNA.

The above two discoveries made it possible for a segment of DNA, i.e., gene coding for a particular protein (for example, insulin), to be cloned by inserting this segment of DNA into the plasmid of bacteria like *Escherichia coli*, so that the protein could be obtained in copious amounts. Once this is done, the bacteria can manufacture the required protein. It is well known that human insulin is now produced and is available worldwide using genetic engineering technology. One would realise the importance of making such engineered products, once again, taking insulin as an example. Before the advent of genetically engineered production of human insulin, the insulins used earlier were extracted either from the pancreas of calf or pig. These insulin were foreign bodies to human beings. Hence they had side effects in terms of immune reactions or antibody reactions in human beings. This can be totally avoided by the use of human insulin, produced by genetic engineering.

Simultaneously with the development of molecular cloning, there was yet another Nobel prize winning discovery made by Ceasar Millstein. The technology developed by Millstein is called hybridoma technology. This technology is extremely important in terms of making what is called monoclonal antibodies. The monoclonal antibodies are specific biological reagents. They are mainly used in health care as prophylactics, diagnostics and in therapeutics. Hybridoma technology is a powerful technology mainly carried out through tissue culture procedures.

One more discovery made in 1986 which helped to lay the foundation of future biotechnology and its application was called polymerase chain reaction. This technology can amplify any gene in larger and larger quantities in geometrical progression.

4. FUTURE PROGRESS IN BIOTECHNOLOGY

It would be difficult to predict what will happen in the new millennium or even in the new century. This is simply because the knowledge that will be generated even in the next decade is quite unpredictable. It is likely that the pace with which biotechnology research has progressed in the past five decades will be telescoped in the next 10 or 20 years. At this point, it is interesting to note that internationally, the number of biological researchers far outnumber those pursuing physics, chemistry or astronomy. If one looks at some of the most popular international journals (those with the greatest impact factor), such as *Nature*, *Science* or the *Proceedings of the National Academy of Sciences* (US), the number of papers published in biological sciences are overwhelmingly greater than the number of papers published in physics, chemistry or astronomy. This statement does not degrade the very important research being carried out in non-biological areas. It is only a factual observation. Furthermore, if one looks at the distribution of funds in the American University System, the percentage of money spent for physical sciences is only 2 per cent and in engineering sciences 20 per cent, while life sciences attract as much as 55 per cent.

4.1 Human Genome Project

In terms of the developments and future possibilities in biotechnology, one of the most important things to note has to do with the human genome project. A major international effort is going on to understand the information stored in the DNA for deciding which portion of the DNA is responsible for a distinct biological function. In order to do that, a major international effort is on in sequencing the DNA completely. It is gratifying to note that very recently chromosome 22 has already been completely mapped, i.e., the sequence of the

DNA in the whole chromosome has been established, and now almost 99 per cent of the sequences have been made available. It is expected that the full sequences will be determined by 2002*.

What is the usefulness of such information, internationally and nationally? One of the most important outcomes would be the understanding of which genes are responsible for specific genetic diseases, such as sickle-cell anaemia, beta thalassemia or haemophilia, or even cancer. These diseases are more common in the tribal groups, of Kerala, but also prevalent in other groups, especially groups which are more consanguineous.

It is known that there are genes responsible for cancer, such as oncogenes and anti-oncogenes or tumour-suppressor genes. For cancer and also for other genetic diseases, gene therapy, that is, essentially putting the right genes to neutralise or replace those genes responsible for cancer, has great potentiality.

There has been a recent popular write-up on 'making cute babies'. This is a futuristic kind of article. Once the whole map of DNA from the human genome project is known, it is possible that one can initially, through genetic engineering, generate children with tailored specifications, such as eye colour, skin colour and other desired features. At this point of time, this is science fiction, but when one talks about hundred years later, it would be a more than a distinct possibility.

4.2 Developments in Plant Molecular Biology

The developments taking place in understanding the molecular biology of plants, meaning the whole plant kingdom, has also been astounding. At present, the biotechnology-rich countries are biodiversically-poor. The only two countries which have biotechnology and enriched biodiversity are India and China. Even in India, the two hot spots of biodiversity are Northeastern Himalayas and Kerala. Therefore, in principle, India has an edge over the rest in tapping the sequences available from the richness in biodiversity. The importance of the availability of medicinally important plants is unimaginable. Likewise, clonal propagation of economically important plantations of teak, eucalyptus or other timber varieties would also usher in a major revolution in timber-based industries.

It should also be added that not only one can change genes in any kind of plant through molecular biological methods to incorporate desirable characteristics that one wants, but one can also transfer this technology to the field conditions.

4.2.1 *Patenting of Plants*

Regarding the patenting of plants which includes crop plants, medicinal plants and also trees, according to even American laws, which are most favourable for multinationals to patent any plant, one has either to introduce a new gene into the plant or remove a gene from the existing plant (using essentially tissue culture methods) which changes any one of the properties of the plant or products synthesised by the plant. Consequently one does not have to be afraid of someone else patenting India's naturally available species in the plant kingdom. It may also be noted that patenting of plant kingdom is not as yet allowed in European countries.

In any case, to protect one's own interest, it becomes important that one has to generate a library of the DNA of existing plants. One can fingerprint the DNA of existing organisms. India has the capability to do that. A data bank will be generated shortly. Consequently, if anyone claims that a plant is patented, he can always be referred to this databank, checked the difference in the genetic pattern to conclude whether this patent is different from what is existing in this databank or not.

In addition, if one can improve useful species in the plant kingdom by genetic engineering, for whatever kind of products that can be made from

* See also the article of Pandit and Lalji Singh

one's own rich plant resources, one should be able to patent that.

5. BIOLOGICAL CONTROL OF INFECTIOUS DISEASES

Infectious diseases, is a very important area where international efforts are being made to control such diseases. There is major emphasis in this area of research in a few institutions in our country, but this effort needs to be strengthened for the development of diagnostic kits, vaccines and prophylactics. There are newly emerging diseases and one should have the capability to identify and provide ways and means to control such diseases.

It has already been shown that the Indian strains of hepatitis C, the major causative agent for post-transfusional hepatitis, is different from the Japanese or American strains, and India has developed diagnostic kits, which are much more specific and sensitive compared to the commercially available kits which, in turn, are manufactured from strains of infectious agents readily available to the manufacturer. However, it is well known that there are strain variations geographically in many of these infectious agents and reagents should be made using appropriate strains, taking into consideration the geographic variations of the infectious agents.

Similar efforts are urgently required for HIV, the AIDS causing virus, because of strain variation. So, the kind of things that one can do in health care, agriculture and industry are of great significance.

6. CONCLUSIONS

Over the past 10,000 years mankind has witnessed three major revolutions. The first was the transition from nomadic to agricultural societies, the second was the advent of the industrial revolution around 150 years ago, and the latest, the emergence of biotechnology and information technology, which happened only over the past half a century.

Ever since the unravelling of the structure of DNA in 1952, biotechnology has evolved by leaps and bounds. Thanks to advances in molecular biology and molecular genetics, we now have a fairly comprehensive understanding of the biological system at the most fundamental level, in terms of the structure and function of genes, and the enormous control they exert over every aspect of plant, animal and human life.

Advances in biotechnology over the last five decades (such as the unravelling of the structure of DNA, recombinant DNA technology and the discovery of polymerase chain reaction) have been of immense utility, particularly in the fields of food production, industry, environmental protection and health care, including the large-scale production of drugs like human insulin, as well as the biological control of infectious diseases. The mapping of the entire human genome has been a major achievement, providing clues as to which genes are responsible for specific genetic diseases, and has great potential in the diagnosis and treatment of diseases. The fusion of biotechnology and information technology has led to the emergence of a new discipline of bioinformatics. Developments in plant biotechnology have special relevance in our country in the areas of economically and medicinally important plants. India, with its rich biodiversity, can benefit immensely from the varied applications of biotechnology.