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Biotechnology Helps in Improvement of Environment

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Abstract: This review gives an insight into the recent advancements in biotechnology with respect to its application in the environment. Particular emphasis is on food production, pollution control and bioenergy production. Environmental biotechnology combines molecular biology and cell manipulation in order to produce valuable products with a lot of new, effective and acceptable properties. Global food security (good quality food, disease resistant varieties of cereal crops), use of genetic engineering to minimize pollution and plants as a source of energy, are possible by the careful use of biotechnological techniques. In the coming future biotechnology will become major driving force in the field of environment, beneficial both for underdeveloped and developed countries.

Key words: Genetic engineering % Biofuels % Bioweapons % Bt-crops % Pollution

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INTRODUCTION

The story of use of biological systems for the fulfillment of human needs perhaps started in 6000 BC, when Sumerians and Babylonians fermented a kind of beer. Beginning with fermentation, the use of biological processes experienced many changes over the centuries. But the greatest revolution till now, commenced in the 1970s and 1980s, when a new discipline termed 'Biotechnology' arose as a result of the marriage of biological science with technology. Biotechnology represents an interface between basic and applied sciences, where gradual transformation of science into technology can be witnessed [1].

Biotechnology is simply defined as the development of products by using a biological process. Production may be carried out by using intact organisms of bacteria, fungi and other microbes, or by using natural substances created by the organisms, such as enzymes. Many problems associated with water, air and soil contaminants can be fixed with new biotechnology. Modern biotechnology is currently being used in soils for growing better crops, in wastewater for eliminating odors, in toxic waste clean up and many other areas. Agriculture is the big winner as modern biotechnology progresses. The soil comes alive with beneficial creatures that can naturally control pest and disease problems. A lot of beneficial microbes work to adjust pH, make nutrients more available, improve plant health and increase crop quality and yields [2].

The drive to 'beat nature' is often considered as a driver for biotechnology. Expectations of an aging population, untreated diseases and unresolved environmental problems have provided incentives for biotechnology companies to innovate and provide quality products and services [3].

Genetic Engineering and Environmental Benefits: Genetic engineering involves a technique of altering the genetic makeup of cells or organisms by deliberately inserting, removing, or altering individual genes [4]. Genetic modification of natural biological systems for non-medical applications has a large number of diverse applications, which are already in the marketplace. Indeed, from a commercial sense, this is probably the most mature area. Some examples include:

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Food Production: This technology promises crops with higher yield and quality; improved resistance to pests and diseases; better tolerance of environmental extremes (e.g. drought and salinity); new food stuffs; modified plants to control water and soil pollution; and crops that can grow faster and in competitive production systems [5]. Corn and potato engineered with proteins from the soil bacterium *Bacillus thuringiensis* enables them to develop pesticide resistance [6]. One tomato variety (Flavr-Savr) has been modified to extend its shelf life [7]. In modern agriculture, this technique is producing food crops with enhanced nutritional and health benefit. For instance, the Golden rice variety has been enriched with beta-carotene and iron to overcome vitamin A deficiency and prevent blindness [8].

Recombinant technology is also expected to produce healthier, more productive and disease resistant farm animals. Researchers at the University of California at Davis have succeeded in inserting and expressing the genes for several human milk proteins (lactoferrin, lysozyme and the alpha-1 antitrypsin protein) in rice for the purpose of improving infant formulas [9]. Such a product could provide a test case for the debate over whether there are socially acceptable circumstances where human genes could be used in commercial, genetically enhanced food products. Such products also would necessitate the development of policies and practices to assure that rice containing human proteins would be segregated from the general food supply and that pediatricians and consumers would be fully informed about the product. There has been much concern in the media and among consumer activist groups about the possibility of inadvertently inserting an allergen into a genetically enhanced crop, causing it to be allergenic to certain people. Developers of genetically improved crops take several measures to assure the risk of such an inadvertent event is very small [10]. The “flip-side” of this situation is that genetic engineering techniques are being used to reduce allergens in food. For example, workers in Japan have reduced the content of an allergenic protein in rice by silencing the gene expressing the protein [11]. Other researchers are working to reduce the allergenicity of peanuts [12] and wheat [13]. Canola has been made to over express stearic acid by repressing the _9 desaturase enzyme; the resulting vegetable oil requires little or no hydrogenation, has no *trans*fatty acids and provides the food processing qualities of hydrogenated oil without the hydrogenation process [14]. Another approach to improve the functional properties of vegetable oils while avoiding hydrogenation and the generation of *trans*-fatty acids is to over express oleic acid (18:1 n-9) at the expense of linoleic (18:2 n-6) and linolenic acids (18:3 n-6). The reduction of polyunsaturates makes the oil less susceptible to oxidative rancidity, an important consideration in food processing and food service applications. By silencing the gene for the _12 desaturase enzyme, oleic acid conversion to linoleic acid is minimal and instead oleic acid accumulates in the oilseed. Soybean oil with 85% oleic acid and less than 5% total polyunsaturates has been produced via this transformation process [15] and the oxidative stability of the oil was shown to be similar to that of a fully hydrogenated frying shortening.

Bt-Crops: Bt (*Bacillus thuringiensis*) crops, which are resistant to different lepidopteran and coleopteran insect pests, were among the first genetically modified (GM) crops to be commercialized in the mid 1990s. Cry-proteins from *Bacillus thuringiensis* (Bt) are by far the most common insecticidal proteins that have been engineered into plants. They represent (up till now) the only insecticidal proteins that are commercially used in GM crops. Bt cry genes have been engineered into a large number of plant species such as maize, cotton, potato, tomato, rice, eggplant and oilseed rape [16].

The first country to grow Bt crops on a larger scale was the USA, where Bt maize, Bt cotton and Bt potato were commercially approved in 1995. In Canada, Bt maize and Bt potatoes were approved in 1996 and in 1997 several other countries started to grow Bt cotton, including Australia, China, Mexico and South Africa [17]. In 2007 Bt crops were grown in 22 countries on a total of 42.1 million hectares, accounting for 37% of the global area under GM crops [18]. At present Bt maize and Bt cotton are the only Bt crops with significant area shares. Other Bt crops are at advanced stages of field testing but have not yet been fully approved. Examples include Bt rice in China and Iran and Bt vegetables in India and other countries of Asia [19, 20].

The International Service for the Acquisition of Agri-biotech Applications (ISAAA) conducted a detailed survey of the Bt cotton cultivation, adoption and performance in eight countries (USA, Australia, China, India, Mexico, Argentina, South Africa and Indonesia) in 2002. All the countries that have introduced Bt cotton have derived significant and multiple benefits. These include increases in yield, decreased production costs, a reduction of at least 50% in insecticide applications resulting in substantial environmental and health benefits to small producers and significant economic and social benefits. Surveys conducted among small resource-poor farmers in developing countries, mainly in China and South Africa, revealed that Bt cotton contributed to reduction in poverty by increasing incomes of small farmers [21].

The environmental benefits of cultivating pest resistant transgenic crops are more profound and invisible. These are enumerated as following: (1) The estimated total savings of insecticides on Bt cotton in 2001 was of the order of 10,627 MT, which is equivalent to 13% of the 81,200 MT of all insecticides used on cotton globally in 2001. (2) The substantial decrease in insecticides associated with the cultivation of Bt cotton has led to significant decrease in insecticide run off into watersheds, aquifers, soils and generally into the environment. More widespread global cultivation of Bt cotton will further improve the water quality. (3) Substitution of the chemical insecticides with Bt cotton has clearly reduced the risks to farm workers and to others in the farm community. These effects are particularly important in developing countries where modern application techniques are neither always adopted nor available for use. (4) The global use of broad spectrum insecticides on cotton has adversely affected and decreased the populations of non-target species including the arthropod natural enemies that can provide effective control of non-lepidopteran pests. Various studies confirmed that the arthropod natural enemy populations in Bt cotton are greater than in non-Bt cotton. In addition to reducing the number of sprays for the bollworm/budworm complex, Bt cotton has also reduced the number of sprays for other insects such as thrips and aphids. This effect has been attributed to higher populations of beneficial predators and parasitic insects that are eliminated by insecticide sprays. (5) Reduction in the use of insecticides, many of which are highly toxic to wildlife will reduce the risks to mammals, birds, bees, fish and other organisms. Many birds are dependent on insects for food and their elimination through the use of insecticides deprives birds of their food source. (6) Lowering the demand for insecticides through the use of Bt cotton reduces tractor fuel usage as a result of reduction in number of sprays, which in turn reduces air pollution. In the Hebei Province of China, where adoption of Bt cotton increased dramatically from its introduction in 1997 to 97% in 2001, farmers have noticed a substantial improvement from the chronic air, soil and water pollution levels prior to the introduction of Bt cotton in 1997, caused by the intensive spraying of cotton with insecticides [22]. The ecological benefits of cultivating Bt-crops were recently documented in a comprehensive manner. According to this study cultivation of Bt corn and Bt cotton resulted in significant environmental benefits [61].

The effects of Bt crops on predators have been assessed in a number of studies, most of them using a tritrophic system including a plant, a herbivore and a natural enemy, i.e., predator or parasitoid [23]. Adverse effects on mortality, longevity or development of predators were only reported in studies using Bt susceptible lepidopteran larvae as prey that had ingested the Bt toxin. In particular, the green lacewing (*Chrysoperla carnea*), an important predator in many maize growing areas, has thoroughly been studied since studies suggested that this predator was negatively affected by Cry1Ab [24]. Results of subsequent studies using several different prey species reared on Cry1Ab-maize, however, showed that the insecticidal protein itself does not directly affect this predator, but that the green lacewing may be affected when feeding on prey species that are susceptible to Bt toxin [25]. The negative effect observed was thus entirely prey-quality mediated, i.e., caused by the suboptimal food quality of the lepidopteran larvae used in the experiments. Because lepidopteran larvae are not considered an important prey for *C. carnea* in the field, it is unlikely that Bt maize poses a risk for this predator [26].

Many insect species are known to act as pollinators of various crops and wild plants. They are therefore of great ecological and economic importance. Among the various insect pollinators, honey bees are the best known, but it is now recognized that other species like bumble bees and solitary bees are also important in ensuring pollination of many plant species. Feeding tests with Cry1Ab proteins were conducted on both honey bee larvae and adults and in each case no effects were observed. Further studies with bees fed with purified Bt proteins and with pollen from Bt crops, as well as when bees were allowed to forage on Bt crops in the fields have confirmed the lack of effects [27-29].

Bt toxins expressed in Bt crops can enter the soil system either via root exudates, via senescent plant material, as well as via damaged and cast-off dead root cells [30, 31]. The supply of Bt toxins by senescent plant material mainly occurs via decaying biomass remaining on or in the ground after harvest. Expression levels in the Bt maize variety MON810 are estimated to be around 4-7 times higher in leaves than in roots [32].

Persistence, degradation and inactivation of Bt toxins have been assessed in the laboratory and in the field in 11 studies using either Bt maize expressing Cry1Ab, Bt cotton containing other Cry proteins or purified toxins. These studies generally indicate an exponential degradation of Bt toxins. To date, none of the laboratory or field studies suggest accumulation of Bt toxins in soil over several years of cultivation. Experience from commercial cultivation indicates that Bt toxin will not persist for long periods under natural conditions [33-35]. Although estimates on persistence of Bt toxins differ among studies ranging from a few hours [36] to months [31], the results are not essentially conflicting. In conclusion, Bt crops are safe and beneficial to farmers, human society, non-target organisms, biodiversity and environment in general.

Biosensors: A biosensor is an analytical device which converts a biological response into an electrical signal. The term 'biosensor' is often used to cover sensor devices used in order to determine the concentration of substances and other parameters of biological interest even where they do not utilize a biological system directly. Many biological systems may be utilized by biosensors, for example, enzymes as the biologically responsive material, whole cell metabolism, ligand binding and the antibody-antigen reaction. Biosensors represent a rapidly expanding field, at the present time. Research and development in this field is wide and multidisciplinary, spanning biochemistry, bioreactor science, physical chemistry, electrochemistry, electronics and software engineering [37]. Biosensors are powerful tools aimed at providing selective identification of toxic chemical compounds at ultra trace levels in industrial products, chemical substances, environmental samples (e.g., air, soil and water) or biological systems (e.g., bacteria, virus, or tissue components) for biomedical diagnosis. Combining the exquisite specificity of biological recognition probes and the excellent sensitivity of laser based optical detection, biosensors are capable of detecting and differentiating big chemical constituents of complex systems in order to provide unambiguous identification and accurate quantification [38].

Using recombinant techniques, plants and bacteria are being modified to act as biosensors to detect and monitor hazardous materials in the environment [7]. Indeed, bacteria have been modified to be sensitive to substances such as TNT, creating opportunities for land mine detection. Environmentally, there are significant potential benefits to engineering fish to detect pollutants like dioxin or polychlorobiphenyl (PCB) [39].

Lowe and his group have been heavily committed to promoting the imaginative combination of biological science with electronics and materials science for the development of novel biosensors and diagnostics. Biosensors provide an analytically powerful and inexpensive alternative to conventional technologies by being able to discriminate the target analyte from a host of inert and potentially interfering species. They do this by combining the unique features of biomolecular recognition with appropriate physico-chemical transducers in order to convert the concentration of the analyte in the sample into an electrical signal. This requirement for chemical intelligence is particularly acute in human healthcare and veterinary medicine, the agri-food, pharmaceutical and petrochemical industries, environmental monitoring, defence and security. The development of biosensor technology has promulgated the emergence of "alternate site" diagnostic testing in the ward, outpatients, surgery, home, field and workplace. The group has pioneered a number of developments in biosensor technology over the last two decades, including a variety of new transducer concepts and a library of underpinning technologies designed to immobilize, spatially arrange and orientate biological molecules on transducer surfaces [40].

Pollution Control: For years scientists have dreamed of cleaning up the environment and eliminating pollution by genetic engineering of microorganisms. They have made some progress, but serious technical and regulatory obstacles stand in their way. Because the outlook for profits is not encouraging, industry is showing little enthusiasm for substantial development of microbial pollution control [41]. Genetically engineered bacteria that feed exclusively on oil could control oil slicks. Other microorganisms could also break down pesticides, herbicides and chemical waste and assist in environmental pollution control. Researchers at The Institute for Genomic Research (TIGR) and the University of Massachusetts, Amherst, have decoded and analyzed the genome of the bacterium *Geobacter sulfurreducens* and found that it has potential for bioremediation of radioactive metals and electricity generation. It could assist in the clean up of ground water contaminated with radionuclides and metals and in industrial sites [42].

Waste can be considered as any material or energy form that cannot be economically used, recovered or recycled at a given time and place. Growth in human populations has generally been matched by a greater formation of a wider range of waste products, many of which cause serious environmental pollution if they are allowed to accumulate in the ecosystem. In rural communities recycling of human, animal and vegetable waste has been practiced by man for centuries, providing in many cases valuable fertilizers or fuel. In urban communities where most of the deleterious waste accumulates, efficient waste collection and specific treatment processes have been developed since it is impractical to discharge high volumes of waste into natural land and waters. The development of these practices in the last century was one of the main reasons for the spectacular improvement in health and well being of the community. Mainly by empirical means a variety of biological treatment systems have been developed, ranging from cess pits, septic tanks and sewage farms to gravel beds, percolating filters and activated sludge processes coupled with anaerobic digestion. The primary aims of all of these systems or biotreaters is to alleviate health hazards and to reduce the amount of oxidizable organic compounds and thus produce a final effluent or outflow which can be discharged into the natural environment without producing any adverse affects. Biotreaters rely on the metabolic versatility of mixed microbial populations for their efficiency. The fundamental feature of biotreaters is that they should contain a range of microorganisms with the overall metabolic capacity to degrade any compound entering the system. Controlled use of microorganisms has lead to the virtual elimination of such water-borne disease as typhoid, cholera and dysentery in industrialized communities [43].

Many industrial processes cause volatile organic and inorganic odorous compounds to be emitted in large quantities. These compounds create hazards to the ecosystem and to humans. The demand for odor and air pollution control systems that provide breathable air is therefore growing. Biotechnology offers one of the most economical and environmentally friendly methods for controlling odor and air pollution. An international team of authors from academia and industry describe biotechnological methods ranging from those in laboratory stages to pilot evaluation to full scale process implementation. Topics include bioprocesses for the treatment of odors and air pollutants in wastewater treatment plants, rendering plants, chemical production facilities and food and flavor manufacturing facilities [44].

Power and Energy: We are slowly depleting our fossil fuel energy resulting in the need to seek out alternative sources of energy. So far, these have included the harnessing of hydro, tidal, wave and wind power, the capture of solar and geothermal energy supplies and nuclear power. There is now a growing appreciation of biological solar energy systems and biotechnological advances in this area will soon bring economic reality to selected processes. As fossil fuel resources are depleted and become increasingly more expensive, conversion of organic residues to liquid fuels will become a more economically attractive consideration. There are three main directions that can be followed to achieve biomass supplies: (1) cultivation of so-called energy crops, (2) harvesting of natural vegetation and (3) utilization of agricultural and other organic wastes. The conversion of the resulting biomass to usable fuels can be accomplished by either biological or chemical means or by a combination of both. The two main end products that will be formed will be either methane or ethanol although other products may arise depending on initial biomass and the processes utilized, for example solid fuels, hydrogen, low energy gases, methanol and longer chain hydrocarbons. Although biomass may ultimately only supply a relatively small amount of the world's energy requirements, it will nevertheless be of immense overall value. In some parts of the world, such as Brazil and countries of similar climatic conditions, biomass will surely attain wider exploitation and utilization [43].

Genome sequencing of the *G. sulfurreducens* bacterium indicated evidence of aerobic metabolic, one carbon and complex carbon chemotactic behavior. It also possessed two component sensors and c-type cytochromes. These characteristics provide the bacterium with the capability to reduce metal ions or create electricity as part of its energy generating metabolism [45].

A great potential is hidden in plants that do not serve neither as food nor fodder that are planted only as an energy source. They provide the energy in the form of biomass, i.e. their bodies consisting of cellulose, starch, proteins and other substances. A great example is a species of sour dock whose cultivation is currently tested, another potential energetic plant is the giant knotweed. Another important group are the fat depositing plants, that can be used as a source of fuel. The example of this group could be the Jatropha. The Jatropha curcas shrub, also called Barbados nut, belonging to the Euphorbiceae (spurge) family, grows primarily in the subtropical region, but it can be accommodated to colder climate. The people of Central America, Africa and Asia used to make candles and laxatives out of the plant. Cows contribute to the greenhouse effects by producing methane. The gas is produced by a community of protozoa and anaerobic bacteria residing in their rumen. The scientist planted such a community into a fermenting machine that processed the stuff that stinks in our trash containers under the name of "mixed waste". They even added the paper waste there. The result was a biogas consisting of methane, a small amount of carbon dioxide and a bit of hydrogen. There is also a perspective research of processing sawdust and crushed wood pulp waste in this way [46].

Economic Potential of Sustainable Resources - Bioproducts from Non-food Crops (EPOBIO) is an international project funded through the European Union's Sixth Framework Programme (FP6) to realize the economic potential of plant derived raw materials. The EPOBIO objective is to design new generations of biobased products derived from plant raw materials that will reach the market place 10-15 years from now. To date, EPOBIO desk studies have produced eight reports addressing a range of bioproducts and feed stocks and assessing their potential for developing biorenewables with high value and utility to society. The opportunities offered by land based agriculture, forestry and their many applications for non-food industrial products are well recognized. Most recently, the use of lignocellulose biomass for generation of transport fuels is a much debated topic in the design of future energy production systems, again illustrating the versatility of plant raw materials for both energy and non-energy products. In this context, the potential of marine biomass is increasingly discussed. These aquatic resources, comprising both marine and fresh water habitats have immense biodiversity and immense potential for providing sustainable benefits to all nations of the world [47].

At a Workshop held in Wageningen in May 2006 a wide range of experts considered the Flagship theme of plant cell walls in relation to biorefining. They identified the need to improve the efficiency with which lignocellulosic plant cell walls, the most abundant renewable resource on earth, can be converted into sugars and other useful bioproducts through biorefining. Biorefining is the production of chemicals, materials, fibres, products, fuels or power from agricultural/forestry raw materials. First generation biorefineries use simple feedstocks such as sugar, starch or vegetable oil, but second and third generation biorefineries are already in development and will use biomass feedstocks that largely consist of lignocellulose cell walls from plant based feedstocks. The biorefinery is already recognised to have a key role to play in the production of renewable fuels including bioethanol and biodiesel. Significantly, future generations of biorefineries will be integrated, zero waste systems producing many bioproducts and materials from a diverse range of feedstocks. Cost effective, efficient conversion of plant cell walls into their components is key to realising the full potential of the biomass lignocellulose feedstock. Plant cell walls have evolved to resist breakdown, whether from mechanical or chemical forces or from microbial attack. This resistance to breakdown is a massive bottleneck for the development of second generation biorefineries. Understanding the complexity of plant cell walls and ways in which sugars can be more efficiently released from the walls (saccharification) were considered to be a major priority for EPOBIO. From a policy and regulatory perspective, the development of efficient and cost effective biorefineries is important for a number of reasons. Biorefineries can make a positive contribution to the delivery of international targets and governmental commitments for reductions in greenhouse gas emissions whilst also addressing energy supply issues. Innovation directed to the development o new generations of more efficient biorefineries will deliver a major improvement in the level of the greenhouse gas emission reductions achieved. Biorefineries are a key strategy of the Knowledge-Based Bio-Economy (KBBE), delivering renewable and sustainable products able to compete with existing fossil derived products [48].

Micro-algae have great potential for both energy and non-energy products. These are microscopic photosynthetic organisms that are found in both marine and freshwater environments. Their photosynthetic mechanism is similar to land based plants, but due to a simple cellular structure and submerged in an aqueous environment where they have efficient access to water, CO_2 and other nutrients, they are generally more efficient in converting solar energy into biomass. Exploitation of micro-algae for bioenergy generation (biodiesel, biomethane, biohydrogen), or combined applications for biofuels production and CO_2 mitigation, by which CO_2 is captured and sequestered, are under research [49-53]. It has also been suggested to grow heterotrophic algae in conventional fermentors instead of photobioreactors for production of high-value products [54]. Instead of light and photosynthesis, heterotrophic algae are relying on utilizable carbon sources in the medium for their carbon and energy generation [55].

The feasibility of producing liquid fuel or biooil via pyrolysis or thermochemical liquefaction of micro-algae has been demonstrated for a range of micro-algae [56, 57]. Miao *et al*. proposed using micro-algae harvested from lakes both to produce biooil via fast pyrolysis and as an environmental solution to reduce algae blooms. Up to

24% of the dry biomass was recovered as biooil. The pyrolysis oils had better properties than the oil from lignocellulosics, however, they still have a much higher oxygen content compared to fossil oil and their heating value is low with 29 MJ kg^{-1} compared to 42 MJ kg^{-1} of fossil oil [58].

In another study, Miao and Wu produced a biooil with improved properties via fast pyrolysis of heterotrophically grown *Chlorella protothecoides*. The heterotrophically grown algae had a higher lipid content (about 55%) compared to autotrophically grown algae (about 14%). The heating value of 41 MJ/kg was nearly as high as that of fossil oil and the nitrogen content was reduced to about 1%. This biooil still had a relatively high oxygen content of some 11% compared to fossil oil with 0.05 to 1.5%. Key to improving the biooil quality was the increase in lipid content in the biomass. This can be achieved by growing the algae heterotrophically under laboratory conditions or in controlled closed systems, however, algae harvested from lakes do not necessarily contain a high concentration of lipids and biooil quality may be of lower quality [59].

Many species of algae accumulate large amounts of oils that to a large extent are made up of triacylglycerols consisting of three fatty acids bound to glycerol. Non or mono unsaturated fatty acids of 16 or 18 carbon length are preferable sources to be used for the production of biodiesel [60, 61]. Oil extracted from the algae is mixed with alcohol and an acid or a base to produce the fatty acid methylesters that makes up the biodiesel. It is the only renewable biodiesel that can potentially completely displace liquid fuels derived from petroleum. Economics of producing microalgal biodiesel need to improve substantially to make it competitive with petrodiesel, but the level of improvement necessary appears to be attainable [62]. Hydrogen can also be produced by algae under specific conditions [49, 63, 64].

Bioweapons and Environmental Deterioration: Studies on genome sequencing, molecular biology and genetic engineering have produced large quantities of information and knowledge of the biology of plants, animals, insects and humans. This has increased people's understanding of genetics particularly that of biological function in pathogens and target hosts. There is concern that, while this knowledge may benefit humankind by improving health, it also provides opportunity for terrorists groups and foreign governments to use the new biomedical methods for the development of biological weapons for military purposes. The capability could develop enhanced biological agents to circumvent current or planned counter measures [7].

It is possible to synthesize simple viruses from scratch. US researchers were able to synthesize a viable poliovirus from commercially available chemicals and the genome sequence for polio obtained by mail order supply. The recipe was downloaded from the Internet. This proved that these viruses could be reconstructed from blueprints [65].

Future biological agents could be engineered at the molecular level to target specific human biological systems such as cardiovascular, immunological, neurological and gastrointestinal systems. They could also be used to target a specific civilian population based on genetic or cultural traits. The emerging biotechnologies pose a threat to civilian and military populations and present challenges to biological defense strategies [66].

Anticipated advances in microbiology, molecular biology and genetic engineering may play a dual role. While contributing to improve the quality of human life, easy access to the readily available information provides unlimited opportunities for individuals with a motive to develop sophisticated biological weapons. A biological weapon attack could result in death and economic losses to society [67].

CONCLUSION

Genomic based applications could produce transgenic crops with enhanced nutritional value, pesticide and herbicide resistance, extended shelf storage and crops that can grow faster and tolerate harsh environments. Other possibilities include modified plants and bacteria to monitor the environment for pollutants and farm animals that have been genetically engineered to resist diseases and enhance production. The realization of these applications will depend on a variety of factors such as social and cultural acceptance of technological change, levels of technology and infrastructure investment in respective countries, market drivers and other structural determinants. Technological impacts may also vary between the developed and developing countries. Developments in biotechnology are also raising significant social and cultural issues and challenges. There are concerns that some of these developments may lead to new forms of ideology and could threaten established social structures. Indeed, some of these perceptions have contributed to limit the extent of certain aspects of biotechnology research and development. An emerging threat from biotechnology is the potential for bioweapons development and proliferation, which may change conventional war patterns and threaten regional security. There is a danger for bioweapons to be incorporated into the weaponry of terrorist organizations and states experiencing regional instability where they could be used for social and political purposes.

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