J Ind Microbiol Biotechnol (2005) 32: 492–495
DOI 10.1007/s10295-005-0058-z

ENVIRONMENTAL BIOTECHNOLOGY

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Environmental biotechnology for developing countries: needs and priorities

Received: 25 August 2004 / Accepted: 23 February 2005 / Published online: 17 November 2005

Progress in science and technology has led to the production of a large number of new chemicals, bringing both benefits and risks. The use of chemicals in agriculture and industry has led to rapid development in many formerly non-industrialized countries, making a substantial contribution to increases in the GNP of many developing countries, particularly in the Southeast Asia region.

However, as a result of these apparent benefits, our modern society has become, perhaps irrevocably, dependent on chemicals, and with the increased production and use of chemical compounds, man has become more exposed to the deleterious effects of over-use, including serious environmental toxicological problems.

Environmental toxicological problems in Southeast Asia

Countries in Southeast Asia share many similarities in terms of life-style, diet, climate, geography, and ecological systems, in addition to shared health and environmental problems. However, our patterns of development over the last 20 years have been somewhat different. Some countries in the region, such as Indonesia, Malaysia, the Philippines, Singapore, Thailand and, more recently, Vietnam, have experienced very rapid industrial development. However, other countries in our region, e.g., Laos, Cambodia and Myanmar, have not experienced the same degree of industrial development. These latter countries are, however, in a good position to learn from the experiences of the former group with regard to the negative impact of chemicals and industry on the environment.

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There are clear differences between the two categories of countries in the nature and severity of environmental toxicological problems as well as in the infrastructure and capacity to recognize, solve and manage such problems.

In some countries, environmental management units or agencies are still in their infancy. Environmental standards, quality criteria and legislation are still being developed. Lack of laboratory facilities and trained/qualified personnel are serious problems.

The main environmental toxicological problems that are currently being addressed include water pollution caused by uncontrolled industrial effluents and uncontrolled use of pesticides, which results in toxic substances entering the food chain and causing groundwater contamination.

In countries that have experienced rapid industrial development in the last 20 years, environmental management systems are already in place. However, the situation with regard to environmental problems is more complex. The problem of chemical waste from agriculture, mainly pesticides, is now compounded by industrial waste. As a result of the increase in the use of chemicals both in agriculture and industry, there is a concomitant increase in potentially hazardous exposure and related occupational and environmental injury. Industrial wastewater discharged from industrial enterprises is at present inadequately treated. Large amounts of toxic chemicals are discharged without routine monitoring.

Transfer of this technology from advanced, industrialized countries will facilitate the development in biotechnology in countries that already have both infrastructure and qualified manpower but will not be feasible in less developed countries in which human resource development is still the highest priority. Without appropriate numbers of qualified scientists, technology transfer cannot be accomplished. There is an urgent need for international cooperation among scientists worldwide to promote the development and application of biotechnology in developing countries.

Such cooperation should address areas such as:

- human resource development,
- research collaboration to address local needs and situations,
- assessment of risk and safety,
- Intellectual property rights.

Thailand has initiated many activities as a result of government policy and the activities undertaken at the Chulabhorn Research Institute (CRI). In Thailand, the government recognizes that scientific and technical capabilities need to be strengthened to support the developmental goals of the country while at the same time maintaining a clean environment for future generations. Although much effort has been made in recent years to provide more resources for research and development activities, the Kingdom's institutes of higher learning still face the problem of limited research funds, equipment and, most importantly of all, shortage of high caliber, experienced scientists and engineers. Recently, the Thai government has undertaken a major initiative in harnessing science and technology, particularly biotechnology, for the country's development. A national policy to facilitate rapid research and development applications and commercialization in various areas of biotechnology has been enacted. Hopefully, these initiatives will lead to overall improvements in the quality of commercial products, health, and the environment. The proposal to safeguard the environment involves regulation and tax incentives to encourage investment in waste treatment technologies and clean manufacturing practices. Strong emphasis is therefore placed on competitive research and technology development programs and human resource development in the area of biotechnology, including environmental biotechnology. Major initiatives will be introduced to attract scientists and technologists who are capable of assisting research and development programs at the highest levels. In addition, major efforts will be made in the area of education and training to generate highly skilled personnel capable of carrying out these tasks. Six sub-committees have been set up to oversee development in each of the targeted areas, one of which is environmental biotechnology and clean energy. It is likely that research centers will be set up in each of the six selected areas of biotechnology, which will be crucial to achieving national environmental and developmental goals. When put into effective use, these bold initiatives will have a major impact towards solving Thailand's environmental problems. Research funding has been allocated through various funding agencies.

Current national environmental problems require multiple strategies. Human resource development and research activities are essential areas where Thailand needs urgent input. These two activities need to develop concomitantly. Our programs are implemented through a special center—The International Center for Environmental and Industrial Toxicology (ICEIT)—which was designated UNEP Center of Excellence in 1990. ICEIT is an established and specialized center created to operate and coordinate academic and research activities in the area of environmental toxicology and technology, including biotechnology, for the protection of the environment and human health.

Human resource development in environmental biotechnology

Currently, ICEIT has designed and implemented both short-term and long-term education and training programs at national, regional and international levels as follows:

Short-term training program

The short-term training program is designed to increase the national capacity to manage environmental toxicological and health problems through the development of human resources in government, academic, and private sectors. These training courses/workshops provide up-to-date technical training in the areas of environmental biotechnology, risk assessment, toxicology and management, with participants from at least 10–12 countries from the Asia/Pacific region.

The training program comprises a series of training courses and workshops taught by world-renowned international experts, with the course "Environmental Toxicology/Pollution Control and Management" serving as the core of the training. This course covers the fundamental aspects necessary for other specific types of training courses, such as hands-on practical courses in targeted research and analytical techniques and applications, as well as courses on regulatory aspects of toxicology and biotechnology. These courses are designed to provide specialist training for future trainers, in order to ensure a multiplier effect. Training modules and a teacher's guide to assist trainers are available on request.

Training courses and workshops aimed at contributing to human resources development at the country-wide level are also organized in selected countries in the Southeast Asia region that have established technical cooperation programs with ICEIT. During 1998–2003, in-country training has been organized in Vietnam, Indonesia, Malaysia, Cambodia, Laos and Myanmar. Since 1988, ICEIT has organized approximately 30 training courses/workshops/conferences at the international level.

Long-term training program

A post-graduate program in Environmental Toxicology, Technology and Management (M.Sc. and Ph.D. levels). In parallel with the short-term training program to address the current shortage of appropriately trained personnel in countries in Southeast Asia to deal with immediate problems relating to industrial development and environmental pollution, CRI has also established a post-graduate educational program for sustained human resource development in the area of environmental toxicology, technology and management.

This innovative multi-disciplinary post-graduate program, tailored to the needs of developing countries by combining toxicology, biotechnology and environmental engineering, was launched in 1999. The curriculum was developed by ICEIT in a project supported by UNDP together with a team of local and international experts, with the aim of creating a new cadre of graduates with a broader background knowledge covering two major disciplines of health science and environmental engineering by using biotechnology as a bridge. This post-graduate program has attracted a lot of interest. Currently, 52 graduate students—22 at Masters and 30 at Ph.D. levels—from 10 countries (Finland, China, Bangladesh, Nepal, Myanmar, Mongolia, Pakistan, Indonesia, Laos and Thailand) are enrolled in the program.

To date, our human resource programs have trained a large number of personnel from both the government, and the industrial and academic sectors. The different strategies employed allow the institute to respond quickly to changing needs in the area of shortage of trained personnel. In this way, the institute has made a significant contribution towards solving the extreme shortage of trained manpower in the environment science and management field for Thailand and regional countries.

Research

Research is an important area where countries in this region have lagged behind countries in the developed world. To address local environmental problems, knowledge of local conditions, ecology and customs are needed prior to application of biotechnological or engineering techniques to solve them. Two high priority areas in environmental research are environmental biotechnology and environmental health/toxicology.

Environmental biotechnology research

Environmental biotechnology has for many years been an area of active research at CRI, with a range of research projects ranging from bioremediation of toxic compounds to the environmental effects of heavy metal pollutants on soil microbes. The most recalcitrant group of organic compounds is chlorinated benzene derivatives. The aim of one project has been to isolate bacteria capable of complete degradation of chlorobenzoate and other chlorinated benzenes from the local environment. This would alleviate the need for the extra steps that would be required for optimization of bacterial growth rate and cell mass under local conditions. Furthermore, simple genetic manipulation could result in bacteria with enhanced ability to biodegrade chlorinate compounds, which can be used in the local in situ biodegradation of contaminated areas. Using a simple selection and enrichment technique, we have isolated a number of *Pseudomonas* species from local soil near waste dumpsites that have the capacity to completely degrade chlorobenzoate and chlorobenzene compounds. The biochemical pathways for biodegradation of these compounds from these locally isolated bacteria are currently being worked out. We have also applied non-recombinant genetic techniques to mutagenize and select mutant strains with increased capacity to degrade these toxic chlorinated compounds. Research is being conducted to determine if these microbes can readily degrade chlorinated compounds in soil samples.

The second major environmental biotechnology-related project involves isolation and characterization of soil microbes highly resistant to a commonly used herbicide: Paraquat. Paraquat is one of the most widely used herbicides in Thailand due to its rapid action. Paraquat toxicity arises from the compound's ability to generate superoxide anions resulting from the redox cycling action of the pesticide. Understanding these protective mechanisms will provide insight into how non-targeted microbes tolerate herbicide toxicity. The mechanism could be adapted to protect other organisms from the toxic effects of Paraquat. Characterization of these bacteria has shown that they have enhanced superoxide anion and hydrogen peroxide metabolizing enzyme systems that protect them from Paraquat toxicity. The levels of superoxide dismutase and catalase, the enzymes that degrade superoxide anions to hydrogen peroxide and water, respectively, are much higher in these bacteria than in other soil microbes. The genes coding for these enzymes have been isolated and are being characterized at the molecular level to determine the mechanism responsible for their high levels of expression.

In another study, the effects of cadmium and arsenic on bacterial stress responses are being investigated. Heavy metals are recognized as hazardous environmental pollutants that are released from both industrial and agricultural sources. Intensive usage of high phosphate fertilizer in agriculture leads to increased accumulation of metal ions especially cadmium in the soil. Cadmium ions are highly toxic to ecosystems even at very low concentrations.

Our data show that low concentrations of both cadmium and arsenic alter the oxidative stress response of bacterial plant pathogens by making them more resistant to oxidants. Thus, exposure of the bacteria to low levels of heavy metals from the polluted environment could lead to alteration in bacterial pathogenicity and hence disease development and progression that could have significant economic impact.

Overall, these findings could have important environmental consequences. The production and accumulation of reactive oxygen species are part of the active plant defense response against microbial invasion.

In another project, we have studied chemical pollution of the aquatic environment, which has become a critical environmental problem worldwide. These pollutants have been shown to alter the biochemical and physiological functions of aquatic organisms, resulting in threatening the health of such species and eventually posing a human health risk. A project at CRI addresses this problem by investigating the effect of cadmium exposure on metallothionine induction and lipid peroxidation in Tilapia fish. The aim of the study is to use fish biomarkers to evaluate the effect of cadmium exposure. The two biomarkers being monitored are the levels of the metal binding protein metallothionine, and lipid peroxidation in Tilapia fish. This is also an attempt to evaluate the potential usefulness of these two parameters as biomarkers for exposure, and the effects of exposure, to cadmium in local fish. Both short- and long-term studies are being conducted.

Conclusion

It is my firm belief that advances in environmental health science and technology can be exploited to prevent long-term disaster and irreparable damage due to environmental negligence, and that the harmful effects of chemicals can be prevented or at least minimized by research, training and increased public awareness. At CRI, we take pride in our contribution to this important undertaking. There is an urgent need for governments to resolve these emerging problems and to plan for future prevention. In developing countries, development of human resources and building capacity in biotechnology at all levels is thus essential. The implementation of such a program requires support from government and international organizations, as well as cooperation with international partners.

By establishing an efficient network of channels of communication among scientists, policy makers, researchers, and industrialists, resources and expertise can be harnessed in order to ensure a transfer of knowledge and technology from developed to developing countries in an appropriate manner.