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Possibility of Application of Biotechnology for Pest Control (**)

Introduction

Agricultural biotechnology promises to cause a new agricultural revolution. This further modernisation of agroecosystems is based mainly on the spectacular increase of science and technology integration, high level of capital investment, and rapid technology transfer and commercialization.

Today the range of biotechnology research and development in agriculture is covering almost all crop process and crop management activities.

As a consequence the agricultural progress pattern is shifting from a linear to an exponential manner; this necessary change implies an increase in production efficiency (based on accurate measures of input-output ratio) and efforts to evaluate environmental, social and political impacts.

So the large extensive application of biotechnology in modern western agriculture has not to be regarded as a model for the developing countries where the agricultural practices are part of a social and economic organization complex system (Bray, 1982).

There is a large number of areas where biotechnology can contribute to approach food associated problems, and some of them can make significant contributions to solve the two current major agricultural problems of developing countries: plant production and plant protection. Here only the biotechnology application related to this last area and limited to pest control area will be discussed.

This paper will first briefly review the status of research and development of biotechnology considered of most general importance. Then it will examine the possibility of applying these techniques in relation to the life-system of pests.

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Finally it will attempt to view their appropriate use according to the pest ecological situation in the environment.

For more appropriate references on pest control biotechnology the following examples represent a rich array of information (Kirshbaum, 1985; Klocke, 1986; Payne, 1986; Plimmer, 1985; Schneiderman, 1984; Whitten, 1985; Young, 1986).

Research and Development of Biotechnology

The area of plant protection offers some enormous challenges to biotechnology, the implementation of which promises to develop powerful control tools, modifying dramatically the agricultural practices and protecting efficiently wide cultivated and forest areas.

Figure 1 summarizes the current research and development in this area.

1. *Bio-engineering.*

Important areas of investigation should include:

— development of remote sensing technique for agricultural and forestry monitoring, in terms of spatial and temporal resolution, to reduce cost of pest managing information;

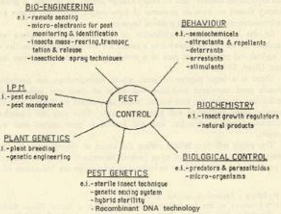

Fig. 1. - Synopsis of main researches & applications of biotechnologies to control pests.

— design and development of microelectronic facilities for detection and identification of pest species in the environment and stored products;

— improve pesticide application technologies to bring economically and efficiently the chemical product into contact with the target pest.

The importance of this technology has been underlined by Pimental and Levitan (1986), who estimated that less than 0.1% of pesticides applied in the United States reaches the target pests while over 99% of them, about 500 milion kg., move in the ecosystem.

— design and development of technique and facilities to mass rear, transport and release useful insects and organisms.

2. Behaviour

The research and development of behaviour modifying compounds have made considerable progress in the identification and formulation of species-specific pest control products. Among these are:

— pheromones, such as sexual, trail, alert;
— attractants; deterrents (i.e., feeding, oviposition deterrents);
— arrestants, stimulants.

Currently the attractants and pheromones have a major role in pest management and can be used to:

— monitor and survey pest population;
— mass-trap;
— lure and kill, in combination with insecticides, pathogens and baits;
— disrupt the mating system.

The efficacy of these products is continually improved by new formulation technology.

Although the use of behaviour modifying compounds requires a good ecological pest knowledge, they offer great promise in integrated pest management programmes (Plimmer, 1985).

3. Biochemistry

Advance knowledge of plant and insect biochemistry associated with modern instrumental techniques has contributed to develop new environmentally acceptable pesticides. Among these are:

— insect growth regulators (IGRs) such as: benzoylphenil urea analogs;
— naturally occurring plant insecticides, such as: Pyrethroids, Rotenone and Rotenoids, Nicotine, N-Isobutylamides;
— new biological insecticides based on neuropeptides.

This field of biotechnology indicates a potentially new approach to and development in pest control.

4. *Biological control*

The increasing knowledge and application in this area are making revolutionary advances in insect, disease and weed control. The major progress of this biotechnological development in pest management are:

a. Mass rearing and release of parasitoids and predators to biocontrol insects and mites. Currently interesting developments in this sector are:

— utilization of artificial diet to rear these insects (i.e., *Trichogramma* spp. in China);

— employment of behavioural chemicals to augment the effectiveness of beneficial natural enemies;

— genetic improvement of predators and parasitoids, and of predatory mites resistant to pesticides.

b. Use of microorganisms for insect biocontrol. A wide range of naturally-occurring micropathogens, and parasitic nematodes have been used and commercially produced.

Advance developmental biotechnology in this field include:

— improvement of fermentation tehnology to produce bacterial and fungal biomass;

— development of formulation systems to protect and deliver the bioinsecticides in the environment;

— genetic engineering to produce more virulent strains or to extend toxic agents against a broad range of pests, or to encode the protein toxin gene of *Bacillus thuringiensis* into soil micro-organisms to protect the plant roots from insects (microbial pesticides).

5. *Pest genetic control*

Increased study and application of genetic approaches to control several pest species, include:

— sterile insect technique (SIT) to suppress many pest species over large areas;

— genetic sexing systems to improve SIT, as has been recently demonstrated by suppression of the Medfly in the island of Procida (Cirio and Economopoulos, 1986);

— hybrid and F1 sterility; meiotic drive.

Recent advances in molecular biology on *Drosophiyla* spp. have stimulated new research methods for controlling pests. Recombination DNA technology to attempt desirable genetic modification of pests seems promising.

6. *Plant genetic control*

This biotechnology offers a great possibility for pest control. Efforts in this area may include:

a. Use of classical breeding techniques, such as pyramiding of genes, sequential release of resistant lines, which have already permitted the development and commercialization of a wide range of cultivars resistant to numerous pest species.

b. Applyng genetic engineering which:

— allows the introduction of foreign genes into plants to develop new cultivars able to produce their own insecticides;

— alters the inherent defense mechanisms or induces an "immunization" of plants to elicit resistance to pests.

7. *Integrated pest management*

The utilization of all suitable techniques and methods to maintain the pest populations at the levels below those causing economic injury has been recognized as the most desirable approach for controlling pests. The development of this approach involves basic disciplines of ecology, entomology, economics and mathematics.

The growth of modern computing facilities has now permitted the modelling and analysis of complex pest situations which suggest appropriate approaches to the practical management and control of pests.

Application of Biotechnology

Using biotechnology (Fig. 2) we can attempt to control pests using a number of different procedures (Geier, 1966). This can be described as follows:

1. Genetic manipulation of pests aimed at long-term crop protection by affecting the intrinsic properties of pest species.

2. Biological control, new insecticides, and plants producing own insecticides attempt to reduce rapidly the pest population by killing the individuals directly.

3. Behavioral control and genetically resistant plants aim to modify the performances of the species by altering a population's environmental qualities.

Technologies of the first group become more desirable when a pest is difficult to control by other methods, causes economic damage at low population density, requires long term control, or offers social economic advantages when it is suppressed in wide areas.

The second group includes procedures which are applied to stabilize or drastically reduce the population below the density causing economic damage. The intensity and frequency of their use normally decrease from biological control to plant genetic methods listed in point 2 of Figure 2. The biotechnologies of the last group tend to keep pest numbers constant within tolerable levels. Behavioral control is mostly used for monitoring and surveying the pest and is integrated with other procedures.

1. AFFECTING THE INHERITED PROPERTIES OF PESTS :

1.1. GENETIC CONTROL:
- Release of sterile insects ____ causes sterility *
- Introduction of deleterious ____ modification of genes into pest population — pest fitness

2. ACTING DIRECTLY UPON THE PEST :

2.1. BIOLOGICAL CONTROL:
- Release of mass-reared bene ____ causes mortality * ficial organisms ;
- Release of genetic engineering microbial insecti ____ causes mortality cides.

2.2. NOVEL INSECTICIDES:
- Use of chemicals altering the ____ causes mortality * life function of pest.

2.3. PLANT GENETICS:
- Growth varieties with foreign ____ cause mortality insecticide genes.

3. ALTERING THE QUALITY OF ENVIRONMENT :

3.1. BEHAVIOURAL CONTROL:
- Use of chemicals to affect pest ____ modification of behaviour. — pest performances

3.2. PLANT GENETICS:
- Growth varieties with resistant ____ modification of genes. — pest performances*

(* in use)

Fig. 2. - Schematic representation of main biotechnical measures available for different pest control strategies (according to Geier, 1966).

The plant genetic technique provides long-term protection if resistance is not overcome by the formations of new pest race.

Some of these major biotechnological procedures which can be used to affect the life cycle of pests, are shown in Figure 3.

Ecological Consideration

The ecological approach to pest control in the context of knowledge, function, and structure of the agroecosystem has proved useful for pest management programmes.

This basic understanding of pest population ecology and dynamics has

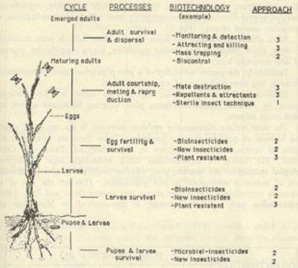

Fig. 3. - Processes in the life cycle of pest to be affected by biotechnological control approach (1: altering inherited properties; 2: direct kill; 3: modifying environment quality) (after Conway, 1976).

permitted the improvement of control techniques and the discovery of agronomic and cultural methodologies to manipulate the life system of target species.

For example, the plantation of olive trees under subtropical climatic conditions and in hillside forest zones has posed unexpected and serious pest problems (Fig. 4). The high polyphagous xylophagous species are more difficult to control with pesticides compared to olive pests of the Mediterranean areas.

Clearly, different strategies are required to minimize olive pest problems in the subtropical areas. Among these are:

— to avoid the olive trees' growth in mixed forest zones;

— to grow olive trees in bush system for reducing the damage of these insects.

Investigations on population performance in its "functional" environment allow us to predict the effect of any manipulation of ecosystems upon the target pest. Among the numerous performances which a pest can exhibit within a definite time-space cropping system are: pest genetic variability, reproduction strategies, spatial distribution, economic injury level. Each of these indicates an appropriate control strategy (Fig. 5).

From general consideration it arises that the most difficult pests to control are those which present a high genetic variability, strong reproduction strategy, and low economic injury level.

Particularly, the genetic variability of a pest population has important implications in lorg term application of control techniques.

Resistance of insect population can develop under increased selection pressure by chemical toxicants, resistant plant varieties, behavioral agents, and sterile insect releases.

The most serious contemporary problem, however, is the rapid and continuous increase of pest resistance to pesticides. Today there are more than 400 species of insects, and mites resistant to these chemicals (Dover and Croft, 1986). The advent of recombination DNA technology aims to improve biological insecticides and resistant plant varieties could delay or avoid development of resistance mechanisms in pest populations. However the rise of resistance is unpredictable and differs among pest species (Bush and Hoy, 1984). Understanding pest population strategy as hypothesized by MacArthur and

CHARACTERISTICS	OLIVE AGROECOSYSTEM	
	MEDITERRANEAN	SUB-TROPICAL(CHINA-HUBEI)
-MAN MADE	Has been grown since prehistoric times.	Recently made(about 20 years)
-CLIMATE TYPE	Mediterranean	Sub-tropical
-DIFFUSION	Extends over large areas as monoculture or mixed plantation.	Few small scattered grove generally extended in hillside forest zones
-CULTIVATION TECHNIQUE	More or less applied	Poor or not applied
-PEST STATUS	Relative stability; prevailing monophagous, multivoltine and r-strategist species	Low stability;prevailing xylophagous, high polyphagous, long life cycle, and low fecundity species
- ECONOMICAL	Very high	Unknown

Fig. 4. - Comparative characteristics between olive agroecosystems situated in different areas of the world.

BIOTECHNOLOGY	PEST CHARACTERISTICS			
	Genetic variability low high	Reproduction strategy K r	Dispersal low high	Economic injury level low high
-Biological control	←——	——→←——	←——	——→
-Behaviour control	←——	←——	←——	——→
-Chemical control	←——	——→	←——	←——
-Pest genetic control	←——	←——	←——	←——
-Plant genetic control	←——	←——	←——	——→

Fig. 5. - A schematic representation of efficiency of different biotechnologies in relation to pest population ecology.

Wilson (1976), Conway (1976) and Southwood (1977), provides useful insights to establish relative priorities among the different control strategies (Conway, 1984).

The r-pests, such as fruit flies, characterized by high efficiency resources of colonization, rapid outbreaks and strong dispersal, may theoretically be better controlled by chemical insecticides. However, their large reproductive rate allows pests to recover rapidly from chemical control treatments so that further applications are often required.

Monitoring and surveying of these pests over wide areas are now very much facilitated by the availability of powerful behavioral products which permit optimization of the treatment in time and space. Vice versa, k-selected species, such as the codling moth, characterized by a slow population growth rate, more specialized niches and less dispersion ability, are more suitable to control by other techniques.

The pest density-damage relationships play a key role in determining the procedure to control pests. Chemical and insect genetic controls offer the most effective approach against species which cause economic damage to crops at low population density. However, to estimate this threshold of pest damage requires scientific background, extensive data collection and high costs. Although modern biotechnologies to control pest species possess a high species-specific action and minimal side effects, the complex interaction processes which regulate the homeostasis of agroecosystems limit the efficacy of a single approach to pest control and may cause serious negative boomerang effects (Isaev *et al.*, 1984).

The integrated pest management (IPM) approach has provided a more effective strategy for crop protection.

For example, the Consortium for Integrated Pest Management (CIPM), comprising 17 land grant USA Universities, has made impressive gains in studying and developing appropriate IPM systems for alfalfa, apple, cotton and soybean.

In developing countries there is a number of international, national and regional organizations devoted to the implementation and development of IPM programmes (Zelazny *et al.*, 1985).

However, although some improvements have been obtained, the progress of IPM is very slow. Among the reasons are the lack of resources, extension service and ecological research. These serious setbacks are limiting the introduction of modern technology needed for IPM programmes. In spite of these problems the principles of IPM are equally valid in the Third World, particularly considering the effort to raise land productivity and the insights from outbreaks of pests which have caused the collapse of certain agricultural systems and serious environmental problems.

Conclusion

Cooperation between different basic disciplines and applied science biotechnology has improved knowledge and created the incentive to develop a new generation of more efficient pest control.

Theoretically their advent promises to make simpler and easier the approach to pest control and to overcome most of the disadvantages of traditional techniques.

However, the ecological principles remain fundamental to pest management and relevant to selecting the most appropriate control tactics.

In fact the use of new biotechnologies raises important social questions; for instance, the release of engineered organisms may pose health and environmental risks. Recently an ocular infection with biological insecticide Dipel (*Bacillus thuringiensis*) was identified in a farmer who splashed the insecticide in his eyes (Samples and Buettner, 1983).

Regulatory plans for registering and testing such biocontrol agents are seriously requested by the Environmental Protection Agency (EPA).

Modernization of the agroecosystem requires a greater management precision to sustain productivity and avoid oscillations in crop yields. For the future, high crop production will continue also to depend on rational and effective pest management.

The use of new technologies can help to increase yield in both industrial nations and in developing countries.

REFERENCES

BRAY F. (1982) - *World agriculture: A Historical Prospective.* « ISV », *7*, 202-209.

BUSH G.L. and HOY M.A. (1984) - *Evolutionary Processes in Insects.* In: C. Huffaker and R. Rabb (Eds), *Ecological Entomology* (New York, John Wiley & Sons), pp. 248-304.

CIRIO U. and ECONOMOPOULOS A. (1986) - *Medfly control by releasing genetic sexing mass-reared strain in Procida island.* Proceed. 2nd Intern. Symp. on Fruit Flies, Crete, 15-22 Sept. 1986.

CONWAY G.R. (1976) - *Man versus pests.* In: R.M. May (Ed.), *Theoretical Ecology Principles and Applications* (Oxford: Blackwell), pp. 257.

CONWAY G.R. (1984) - *Strategic Models.* In: G.R. Conway (Ed.), *Pest Population Control-Strategic, Tactical and Policy Models* (New York, John Wiley and Sons), pp. 15-28.

DOVER M.J. and CROFT B.A. (1986) - *Pesticide resistance and Public Policy.* « Bioscience », *36*, 78-85.

GEIER P.W. (1966) - *Management of insect pests.* « Ann. Rev. Entomol. », *11*, 471-490.

ISAEV A.S. and NEDORERZOV L.V. (1984) - *Pest Population Control.* In: G.R. Conway (Ed.), *Pest and Pathogen Control — Strategic, Tactical and Policy Models* (New York, John Wiley and Sons), pp. 29-39.

KIRSHBAUM J.B. (1985) - *Potential implication of genetic engineering and other biotechnology to insect control.* « Ann. Rev. Entomol. », *30*, 51-70.

KLOCKE J.A. (1986) - *Discovery and development of new insect control agents from bacteria and plants.* Proceed. of the Agrobiotec Conference on Advanced Biotechnology and Agriculture, Bologna, 1976, Italy.

MACARTHUR R.H. and WILSON E.O. (1967) - *The Theory of Island Biogeography.* Princeton Univ. Press., Princeton N.J., pp. 203.

PAYNE C.C. (1986) - *The control of insect pests by pathogenes and insect-parasitic nematodes.* Proceed. of the Agrobiotec Conference on Advanced Biotechnology and Agriculture, Bologna, 1976, Italy.

PIMENTAL D. and LEVITAN L. (1986) - *Pesticides: Amounts Applied and Amounts Reaching Pests.* « BioScience », *36*, 86-91.

PLIMMER J.R. (1985) - *Role of Natural Product Chemistry.* In: P.D. Hedin (Ed.) (Bioregulators for Pest Control), (Washington D.C. American Chemical Society), pp. 324-335.

SAMPLES J.R. and BUETTNER (1983) - *Ocular Infection Caused by Biological Insecticide.* « J. Infectious Diseases », *148* (3), 614.

SCHNEIDERMAN H.A. (1984) - *What Entomology has in store for Biotechnology.* « ESA Bull. », pp. 55-61.

SOUTHWOOD T.R.E. (1977) - *The relevance of population dynamic theory to pest status.* In: J.M. Cherrett and G.R. Sagar (Eds.) *Origins of Pest, Parasite, Disease and Weed Problems.* Proceed. 18th Symp. Br. Ecol. Soc. (Oxford: Blackwell), pp. 35-54.

WHITTEN M.J. (1985) - *The Conceptual Basis for Genetic Control.* In: G.D. Kerut and L.I. Gilbert (Eds.), *Comprehensive Insect Phytiology, Biochemistry and Pharmacology* (New York, Pergamon Press), pp. 465-528.

YOUNG B. (1986) - *The Need for a Greater Understanding.* « Application of Pesticides-Outlook on Agriculture », *15*, 80-87.

ZELAZNY B., CHIARAPPA L. and KENMORE P. (1985) - *Integrated Pest Control in developing countries.* « FAO Plant Prot. Bull. », *33*, 147-158.