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REVIEW PAPER

Radiation Entomology

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ABSTRACT

The article reviews the use of radiation and radioisotopes in entomology with special reference to the use of radiotracers in entomological studies and the use of sterile insect techniques in the control of insect pests. It also presents a profile of Shri Koshy and his contributions to defence entomology, including design of an efficient device for the rearing of cockroaches, evaluation of different repellents against leeches, laboratory and pilot field studies on the use of radiation-sterilised males for the control of the mosquito *Culex fatigans*.

1. INTRODUCTION

Out of more than a million species of insects that inhabit the world, around 15,000 are harmful to animals and plants. In addition to causing direct effects on living tissue, insects can be vectors of a variety of diseases. Significant losses are caused by insects during storage of grains. It is estimated that as much as 15-20 per cent of the world's production of crops and livestock is lost by insect depredation. Human diseases, such as malaria, yellow fever, filariasis and sleeping sickness are transmitted by insects.

The advent of organic pesticides in the early 1940s and their development in the immediate post-world war II period made a powerful impact on pest control. However, within the next decade, the adverse consequences of the indiscriminate use of pesticides was realised.

Most of the insecticides are toxic to higher forms of life, are not easily degraded and lead to environmental contamination. In addition, more than 100 species of insects have acquired resistance to these. The book *Silent Spring* by Rachael Carson in the early 1960s provided a powerful impetus for serious rethinking on the subject.

The UN conference on human environment held at Stockholm, in 1972, emphasised the necessity for alternative strategies for management of pest population. It was realised that in place of the use of a single technique for pest control, the strategy should be an integrated pest management (IPM) methodology. For evolving such approach, it is necessary to have in-depth understanding of the biology of the pest and the target species, including information on the dispersal, population densities and dynamics, feeding habits, ecology of the natural predators of the pest, host-pest relationships, environmental impact of the strategy, and costs and benefits.[1]

Promising newer methods of pest control include:

(a) Use of biological agents (e.g., insect attractants, such as pheromones and juvenile hormones)
(b) Development of host resistance
(c) Chemical attractants
(d) Chemosterilisants
(e) Use of cytoplasmic incompatible strains
(f) Use of chromosome-translocated strains
(g) Radiation sterilisation.

Each of these has its own merits and demerits. None of these methods, except radiation sterilisation, has been developed extensively for large-scale application.

Sterile insect technique (SIT) is one of the most promising approaches and has been tried extensively and successfully in many parts of the world over the last four decades.

2. RADIOTRACERS FOR STUDY OF INSECT PHYSIOLOGY & ECOLOGY

Radiotracers have played a role in obtaining a deeper understanding of insect ecology which, in turn, has led to a more scientific approach in the development of an integrated pest management strategy. Radiotracers have been used for studying the physiology, mating behaviour, flight range, and dispersal pattern of insects. Unlike pigments which are smeared on to the insects for following their movements, radiotracers labelled on the insects are not eliminated during rubbing off or moulting or pupating.

Out of several radiotracers ^{32}P has been widely used for entomological studies since 1940. This radionuclide is easily available, has a convenient half-life (14.3 days), and is one of the chief constituents of insect protoplasm.

2.1 Population Densities & Population Dynamics

Population densities can be determined by the dilution technique. A known number of labelled insects are released into the area and time allowed for equilibration of these with the native population. A random number of insects are then caught, and the fraction of the total that is labelled is determined using a suitable detector like GM counter, from which the total population can be arrived at.

2.2 Radiotracers in Pesticide Research

Radiotracers have helped in evolving efficient controlled release (CR) technology and systems[2]. CR involves the combination of a pesticide and an excipient (usually a polymeric matrix) to allow delivery of the pesticide to the target at controlled rates over a period. This is highly economical.

3. STERILE INSECT TECHNIQUE

It was discovered by H.J. Muller in 1927 that X-rays could cause mutations in the fruit fly *Drosophila* and could cause sufficient genetic damage to the insect reproductive system to induce sterility[3,4]. The first paper[5], explaining in detail the theory of insect eradication by the release of sterilised males, was not published until 1955, though the idea began to take shape in an isolated laboratory in Texas, in 1937. Knipling[5] observed that the female screw-worm flies appeared to mate only once, and he suggested that if some way could be found to sterilise males without impairing their mating activity, it might be feasible to use these sterilised males to eradicate the isolated population of screw-worm flies.

With insects having a low population density, it would be possible to rear and sterilise more number of males of the concerned species than those existing in nature. The sterile males would compete with the natural males in seeking out the females and because of these being greater in numbers would have a greater chance of mating with the normal females, and rendering them reproductively ineffective. The females would lay sterile eggs. By repeating the process for a few generations, the pest population would be eventually eliminated. This is the principle of SIT.

The success of SIT would depend on

(a) Facilities for easy identification of males and rearing them in large numbers,

(b) Adjustment of the dose which would ensure sterility but would not interfere adversely with either the longevity or the mating capacity of the sterile male, and

(c) An appropriate field release strategy.

SIT approach is environmentally acceptable, is comparable in cost-effectiveness to conventional methods, is species-specific, can be applied over wide areas, is particularly effective when the population density is low, and can be integrated with other pest control measures. Compact gamma cells containing high intensity ^{60}Co sources surrounding the irradiation chamber (around 10 l), with adequate shielding for safe operation, are available at reasonable cost for irradiation of a large number of insects or pupae at a time. The required doses can be delivered in less than 5 min. Such units can easily be setup in the field area. The efficacy of SIT can be enhanced if the natural population in a given area is reduced by environmentally safe methods prior to the release of sterile males.

Computational methods are available to predict the ratio of sterile males required to be released to maintain decline in population and achieve eradication of the species[6]. The first demonstration of the technology was the eradication of the screw-worm fly from the 273.5 x 10^5 sq km in the Dutch Island of Curacao, in 1954 as a cooperative effort of the US Dept of Agriculture and the Dutch Govt.

3.1 International Programmes in Sterile Insect Technique

The International Atomic Energy Agency (IAEA) and the Food and Agricultural Organisation (FAO) have been involved in the use of isotopes and radiation[4,7-9] since 1964. The Entomology Division of IAEA's Agricultural Biotechnology Laboratory established at Seibersdorf near Vienna, Austria, in 1961 has been the nodal centre from where major SIT programmes in collaboration with local governments have been launched in different parts of the world.

The major pests of crops, livestock and human beings include the tsetse fly and the screw-worm fly. The Mediterranean fruit fly (medfly) is ubiquitous wherever citrus and soft fruits are grown. Significant success has been achieved in the control of these insects using SIT in several parts of the world. Around 10 species of insect pests are now being tackled by SIT.

3. *Tsetse Fly*

The testse fly[4,7,10,11], *Glossina*, bites both human beings and livestock, and is the sole vector that transmits the parasitic protozoan *Trypanasoma* which causes sleeping sickness in human beings and nagana in livestock. The disease, trypanosomiasis, causes cattle to quickly lose appetite and become emaciated, leading to death within a few weeks. Over 70 per cent of the infested area in Africa constitutes potential agricultural land. The tsetse fly is an ideal insect for control by SIT since it reproduces slowly, producing one offspring every 10 days, and its field population density is low. The facilities for mass rearing of the tsetse flies were built up at the Siebersdorf Laboratory in 1967, which has now the world largest collection of tsetse flies. The field programmes conducted from 1970 onwards in several parts of Africa, specially Tanzania, Upper Volta and Zanzibar, showed the feasibility of SIT. A major project initiated in 1979 resulted in complete eradication of the tsetse fly over an area of 1500 sq km in Nigeria by 1984.

3. .2 *Mediterranean Fruit Fly*

The medfly[4,7,9,12,13] *Ceratitis capatita*, is one of the most devastating insect pests, attacking 280 varieties of fruits and vegetables, specially citrus, in 82 countries. IAEA has developed techniques involving automation of mass rearing, sterilising and packaging 1000 million medflies per week. A recent innovative technology developed at Siebersdorf Laboratory is genetic sexing. In one of the approaches, genetic strains were developed, where the male pupae were white, and the female ones brown. Another approach was the development of strains where the eggs to be developed into female flies were killed at a lower temperature than the eggs to be developed into male flies.

One of the success stories of SIT has been the eradication of medfly in Mexico. The largest facility for mass rearing of sterile males is in Mexico. The programme has led to a savings of $500 million per year for the country. It has also been extended to Egypt, Gautemala and Peru.

3. 3 *New World Screw-Worm Fly*

The screw-worm fly[4,14,15] was originally found only in the tropical and sub-tropical regions of the western hemisphere. The insect has been called the worm of death. It is a pest of warm-blooded animals. The screw-worm fly itself is harmless. However, the larvae hatching from the eggs laid on the back of animals bore through the skin into the flesh. The wound they cause is called myiasis. Even when the host animal does not die, it is susceptible to disease, leading to decreased milk and meat production. Infestation in human beings causes intense pain, with death occurring in 10 per cent of the people affected. The average life cycle of the screw-worm fly lasts 10 weeks.

The screw-worm fly was eradicated from Mexico by SIT, with an estimated benefit to the economy of \$100 million per year. In the spring of 1988, the pest found its way into Libya and severe cases of myiasis surfaced, threatening the whole of North Africa. As a result of a massive SIT programme started in 1989, eradication was achieved by 1992 in North Africa, sub-Saharan Africa and the Mediterranean, at half the cost and time initially planned. The parasite has also been eliminated from Puerto Rico, Virginia Islands and Continental USA. The combined value to agricultural economies from the SIT is estimated to exceed \$3.5 billion per year.

3.1.4 *Mosquitoes*

As of today, there has been only limited success in the efficacy of SIT against mosquitoes. It is important to note that only the females of the species bite, because these require a blood meal for ovipositing; thus the release of a large number of sterile males does not have any nuisance value.

The first release of sterile male mosquitoes in the field was carried out in Florida in the late 1950s, but it was not a success. There had been a few subsequent trials at different centres[16], but the results were not spectacular. In India, the Genetic Control Unit, established by the Indian Council of Medical Research (ICMR) and World Health Organisation (WHO), working in Delhi, evaluated a variety of techniques for mosquito control. In the mid-1960s, preliminary field trials were carried out using sterilised males of *Culex fatigans*[17,18].

4. IRRADIATION FOR CONTROL OF INSECT INFESTATION IN FOOD PRODUCTS

Food irradiation[19,20] can have a number of benefits, including delay of ripening and prevention of sprouting, control of insects, parasites, helminths, pathogenic and spoilage bacteria, moulds and yeasts, and sterilisation which enables commodities to be stored unrefrigerated for long periods.

A major problem in the storage of grains and grain products is insect infestation. This is particularly the case in our country, which loses a substantial fraction of its agricultural products from this cause. Chemical fumigation with pesticides, such as ethylene dibromide, ethylene oxide, methyl bromide, and phosphine, is the most common method for insect control. These chemicals are highly toxic and hazardous to the workers handling them. Use of many of these chemicals is no longer permitted in many countries.

Irradiation is an attractive alternative. Although around 50 countries of the world (including USA) have long been making use of this technology with a very high cost-benefit ratio, the Govt. of India only recently has given limited clearance. Commercial food irradiators are available in many parts of the world. The dose required is fairly low (of the order of 0.15-0.7 kGy). Stored cereals, pulses, flour, coffee beans, dried fruits and dried nuts can conveniently be protected from insect infestation. Fresh fruits and vegetables, dried fish and meat, fresh pork, etc. can be preserved against spoilage by pests like fruit flies, the mango seed weevils, spider mites, scale insects and other organisms. Ripening of fruits can be delayed by 1-2 weeks by low dose irradiation, with significant potential for export.

A joint FAO/IAEA/WHO expert committee on the wholesomeness of irradiated food in its 1981 Report No. 18 concluded that irradiation of any food commodity up to an overall dosage of 10 kGy presents no toxicological hazards; hence, toxicological testing of food so treated is no longer required. It is also found that irradiation up to 10 kGy introduces no special nutritional or microbiological problems.

5. FUTURE PROSPECTS

In spite of the pioneering efforts undertaken in our country in the 1960s and 1970s to establish infrastructure, develop expertise and initiate pilot trials towards utilisation of the applications of the exciting field of radiation entomology, the initial momentum seems to have been lost. At present, there appears to be no major activities in this area. It would be worthwhile for the concerned scientific organisations like the Bhabha Atomic Research Centre (BARC), ICMR, Indian Council of Agricultural Research (ICAR) and Defence Research and Development Organisation (DRDO) to setup jointly an Expert Task Group that would identify and pinpoint thrust areas of immediate relevance and undertake some appropriate time-bound and cost-effective projects.

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REFERENCES

Lindquist, D.A. Insects, isotopes and radiation *IAEA Bulletin*, 1987, **29**(20), 9-12.

2 Hussain, M. Atoms in agriculture: Nuclear techniques in controlled release pesticide research. *IAEA Bulletin*, 1989, **31**(2), 36-40.

3 La Brecque, G.C. Integrated pest management *IAEA Bulletin*, 1981, **23**(3), 40-42.

4 Sigurbjornsson, B. & Vose, P. Nuclear techniques for food and agricultural development. *IAEA Bulletin*, 1994, **36**(3), 41-47.

5 Knipling, E.F. Possibilities of insect control or eradication through sterile males. *J. Econ. Entomol.*, 1955, **48**, 459-62.

6 Cuellar, C.B. *Bull. World Health Org.*, 1969, **40**, 205-13.

7 Sigurbjornsson, B. & La Chance, L.E. The IAEA and the green revolution. *IAEA Bulletin*, 1987, **29**(3), 38-42.

8 Danesi, P.R. The laboratories at Siebersdorf: Multidisciplinary research and support centre. *IAEA Bulletin*, 1987, **29**(3), 50-55.

9 Danesi, P.R. Nuclear techniques and sustainable agricultural development. *IAEA Bulletin*, 1992, **34**(4), 2-8.

10. Offori, E.D. The scourage of the tsetse. *IAEA Bulletin*, 1981, **23**(3), 43-46.

Offori, E.D. Fighting tsetse diseases in Africa. *IAEA Bulletin*, 1984, **26**(3), 43-44.

12. Lindquist, D.A. *et al.* Atoms for peace *IAEA Bulletin*, 1984, **26**(2), 22-25.

13. La Brecque, G.C. Helping eradicate the medfly from Mexico. *IAEA Bulletin Supplement*, 1982, 26-29.

4. Van der Vloedt & Butt, B. The new world screw-worm eradication programme in North Africa. *IAEA Bulletin*, 1990, **32**(4), 35-41.

15. Lindquist, D.A. & Abuwosa, M. Eradicating the new world screw-worm from the Libyan Arab Jamhiriya. *IAEA Bulletin*, 1992, **34**(4), 17-24.

16 Davis, A.N.; Cahan, J.B.; Weidham, D.E. & Smith, C.N. Exploratory studies on gamma radiation for the sterilization and control of *Anopheles quadrimaentrus*. *J. Econ. Entomol.*, 1959, **52**, 868-70

7. Ramakrishnan, S.P.; Krishnamurthy, B.S. & Roy, S.N. *Ind. J. Malar.*, 1962, **16**, 357.

18. Krishnamurthy, B.S.; Ray, S.N. & Joshi, G.C. A note on preliminary field studies of the use of irradiated males for reduction of *Culex fatigans* Weid population. 1963, Vector Control. *WHO Bulletin Supplement to Vol. 29*, Geneva.

19. WHO. Safety and nutritional adequacy of irradiated food., World Health Orgnisation, Geneva, 1994.

20. WHO. Wholesomeness of irradiated food. Report of a Joint FAO/IAEA/WHO expert committee.

World Health Organisation, Geneva, 1981 WHO-TR-659.

21. Koshy, T. & Singh, S.P. Laboratory studies on radiation-induced lethality in sperms in population control of the mosquito *Culex fatigans* Wied. *Int. J. Radiat. Biol.*, 1970, **18**(6), 521-30.

22. Srinivasan, M.N.; Chandra, R.; Koshy, T.; Singh, S.P. & Ganguly, S.K. Uptake and turnover pattern of radioactive phosphorus in three vector species of mosquitoes. *Ind. J. Exptl. Biol.*, 1980, **18**, 1248-51.

23. Koshy, T. & Mathur, G.B. Field trials of release of radiation sterile male mosquitoes and their effect on (a) control of mosquito *Culex fatigans,* and (b) control of mosquito *Anopheles stephensi.* Institute of Nuclear Medicine and Allied Sciences, Delhi, 1976. AFMRC Report No. 744/75.

24. Koshy, T. & Mallik, D. An improved method for rearing and maintaining large colonies of the American cockroach in the laboratory. *J. Econ. Entomol.*, 1968, **61**(6), 1748-50.

25. Singh, S.P.; Koshy, T., Srinivasan, M.N.; Chandra, R. & Sastry, K.G.K. Evaluation of repellency of *N*-toluyl-piperidine and other chemicals against *Haemadispa sylvestris (Blanchard)* and *Hirudo medicinalis (L)*. *Ind. J. Med. Res.*, 1980, **72**, 227-30

26. Ramachandran, P.K.; Koshy, T.; Sastry, K.G.K.; Singh, S.P.; Srinivasan, M.N. & Ganguly, S.K. Studies on leech repellents. *J. Econ. Entomol.*, 1971, **64**, 1293.

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