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Sterile Insect Technology for Pest Control in Agriculture

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Abstract

Insects are known to cause significant damage to crops and affect agricultural productivity. Loss of major crops due to insect pest varies between 10 and 30%.The indiscriminate use of broad-spectrum insecticides has caused major problems with pest resistance, residues in food, environmental contamination, outbreaks of secondary pests, and reductions in populations of beneficial insects. Humans are exposed to such chemicals while still in the womb of the mother. Therefore, human life would be threatened not only directly by pesticides in environment, but indirectly by contaminated food chain. These developments combined with the mounting awareness of the general public, have increased demands for pest control methods that are both efficient and friendly to the environment. A very powerful method for integration in IPM programs as a final eradication component is the sterile insect technique (SIT).This genetic control method exploits the insect's mate-seeking expertise to introduce genetic abnormalities into the wild population. In view of the increasing demand of environmental-friendly control tactics, it is anticipated that the SIT, will increasingly gain an importance in the years/decades to come in India, as BARC Mumbai is working on potato tuber moth (*Phthorimaea operculella)* and red palm weevil (*Rhyncophorus ferrugineus)*; Delhi University, Dept. of Zoology is working on Tobacco caterpillar (*Spodoptera litura);* UAS RAICHUR is working on Red gram Webber (*Maruca vitrata)*. Hence this article discuss a critical overview of its principles/practice, need for further research, development, and application for the pest control in agriculture.

Keywords: SIT, bio-control, potato tuber moth, tobacco caterpillar, red gram webber

1. Introduction

Herbivorous insects are said to be responsible for destroying one fifth of the world's total crop production annually. India is basically an agro-based country where more than 80% of Indian population depends on agriculture. Insects are known to cause significant damage to crops and affect agricultural productivity (Kandagal and Khetagoudar, 2013). Loss of major crops due to insect pest varies between 10 and 30% (Ferry et al., 2004).

World population is increasing by an estimated 97 million per year (Saravi and Shokrzadeh, 2011). This means that agricultural output has to almost double within the next thirty years to meet the growing demand for food (Hendrichs, 2000). Despite the annual use of three million tons of pesticides worldwide and a 5% increase annually, 3.7 billion humans still suffer from malnourishment (Pimentel, 2007).

Pesticides are an undeniable part of modern life, used to protect everything from flower gardens to agricultural crops from specific pests. Pesticides have contributed significantly to improving quality of life and safeguarding the environment. The indiscriminate use of broad-spectrum insecticides has caused major problems with pest resistance, residues in food, environmental contamination, outbreaks of secondary pests, and reductions in populations of beneficial insects. The food we eat, the water we drink, the air we breathe, and the environments we live in are contaminated with toxic xenobiotics. Humans are exposed to such chemicals while still in the womb of the mother (Lederman, 1996; Xavier et al., 2004). Therefore, human life would be threatened not only directly by pesticides in environment, but indirectly by contaminated food chain. These developments combined with the mounting awareness of the general public, have increased demands for pest control methods that are both efficient and friendly to the environment (Vreysen et al., 2006).

Eventually, it leads to the management of pest, using a combination of several control methods in an area-wide integrated pest management approach (AW-IPM) to establish pest-free areas (eradication), areas of low pest prevalence (suppression) or to maintain areas free of the pest through prevention. A very powerful method for integration in these programs as a final eradication component is the sterile insect technique (SIT). (Vreysen, 2006)

This genetic control method can be employed as a form of biological control of pest species which exploits the insect's mate-seeking expertise to introduce genetic abnormalities into the eggs of the wild population. The concept of controlling, managing and eliminating insect pests by manipulating reproduction was conceived as early as the 1930s (Knipling, 1955).

The SIT technique relies on the rearing of the target insect in large numbers in specialized production centers, the sterilization with ionising radiation of one of the sexes and the sustained sequential release of the sterilized insects over the target area. Contrary to conventional control methods, the sterile insect technique becomes more efficient with decreasing density of the target population. Hence, the technique fits well within the concept of integrated pest management, as its complementary use in a phased approach with other suppression techniques, results in maximum efficiency (Vreysen, 2006).

In view of the increasing demand of environmental-friendly control tactics, it is anticipated that the SIT, as part of area-wide pest management (AW-IPM) approaches, will increasingly gain in importance in the years/decades to come.

2. Fundamentals of Sterile Insect Technology

The SIT is a form of birth control imposed on an insect pest population to reduce its numbers. The SIT harnesses the sex drive of insects. According to the International Plant Protection Convention (IPPC) (FAO, 2005), the SIT is defined as:

"A method of pest control using area-wide inundative releases of sterile insects to reduce fertility of a field population of the same species."

Thus far the SIT has involved rearing large numbers of the target pest species, exposing them to gamma rays to induce sexual sterility, and releasing them into the target population of the pest on an area-wide basis. Another kind of SIT avoids the need to mass-rear the target insect pest species since individuals of the wild populations are attracted to a chemosterilant, e.g. Mediterranean fruit fly (Navarro- Llopis *et al*., 2004) and *Glossina* spp. tsetse flies (Hargrove and Langley, 1990; Langley, 1999). Thus treated insects are prevented from reproducing; they act as biological agents that nullify the biological potential of untreated individuals with which they mate. Both kinds of SIT are effective only against pest species that reproduce sexually.

3. How Sterile Insect Technology Works

The type and level of sterility induced in mass-reared and released insects is critically important. A sterile insect is defined (FAO, 2005) as:

"An insect that, as a result of an appropriate treatment, is unable to produce viable offspring."

Fecundity is the number of progeny produced per female. Thus only females can be infecund. Sterility may be caused by: (1) the inability of females to lay eggs (infecundity), (2) the inability of males to produce sperm (aspermia), or inability of sperm to function (sperm inactivation), (3) the inability to mate, or (4) dominant lethal mutations in the reproductive cells of either the male or female (LaChance, 1967; LaChance et al., 1967). All of these mechanisms may be induced by exposing insects to gamma rays, X-rays, or certain chemicals (Bakri et al., 2005). In addition, sterility may be induced by insect growth regulators which can be transferred from a treated male to an untreated female during mating, subsequently disrupting the development of the embryo by interfering with endocrine mechanisms (Hargrove and Langley, 1990).

Dominant lethal mutations, which are manifested by the inability of a treated individual to reproduce, are almost always caused by chromosome breaks (Muller, 1954) induced in the germ cells. Chromosome breaks do not interfere with the ability of the gametes to participate in fertilization. The breaks persist, but the affected sperm fertilizes the egg in the normal fashion, and the dominant lethal mutations kill most embryos during the first few cleavage divisions (Robinson, 2002).

4. Mass-rearing for Sterile Insect Release

As the sterile insect technique (SIT) relies upon released sterile male insects efficiently competing with wild males to mate with wild females, it follows that mass-rearing of insects is one of the principal steps in the process. Mass-rearing for the SIT presents both problems and opportunities due to the increased scale involved compared with rearing insects for most other purposes.

In general, methods of rearing for the SIT are developed from those used to rear insects for other purposes, but on a much larger scale. The techniques are similar, but the issues of quality control require a different approach. The concept of quality control can be divided into three areas: production control (monitoring all rearing operations in terms of personnel, materials, equipment, schedules, and environment, etc.), process control (sampling immature insect stages to predict quality and determine sources of variability), and product control (both at the output from a rearing facility and in the field).

For the SIT, a rather different approach is needed, with due attention being paid to all the factors affecting quality, fecundity, and cost. Even though Singh (1985) listed more than 1300 species that have been reared on artificial diet in the laboratory for part or all of their life cycle, relatively few species have been mass reared for the SIT (IDIDAS, 2004). The details of the rearing protocol for any one species will not be discussed here, but examples to illustrate key points and issues common to the successful application of the SIT will be given.

4 .1. Facility design and location

Tween (1987) discusses a modular approach to constructing a rearing facility that has been adopted in Guatemala for the Mediterranean fruit fly facility. The modular approach has the advantage of simplifying design and expansion, but it also means that there is little economy from increased scale as each additional module costs the same as previous ones, the only saving coming from the common areas. However, it has the advantage of allowing the facility to be easily scaled to the required size, so as to maintain the utilization efficiency; if demand falls, complete modules can be closed without affecting production in the remaining modules, or converted to rearing another insect. The principal factors, not in order of priority, are:

- Logistical access eases of delivery of rearing supplies and equipment
- Geological stability earthquake risk, hurricanes, flooding, etc.
- Political stability
- Acceptance of the facility by the local community
- Local government requirements or restrictions
- Access to water and utilities, reliability of supplies
- Construction and maintenance costs
- Availability of support and repair services
- Labor costs and availability
- Waste disposal
- Access to a suitable airport for rapid delivery of insects
- Distance from release area
- Quarantine considerations- can the insect survive in the surroundings?

4.2. Escapes and environmental concerns

A problem unique to the SIT is that the pest insect itself is being reared. For other large-scale rearing, e.g. classical or augmentative biological control, the reared insect is not the pest itself, so any escape from the rearing process is unlikely to pose a threat. However, when the pest is being reared, any escape of fertile material poses a risk. Usually the rearing is done in an area where the pest is already present, but if an eradication program is successful, the rearing facility can become stranded behind the eradication front and poses a substantial reinfestation risk. This happened to both the Mexican facility producing the New World screwworm *Cochliomyia hominivorax* (Coquerel) and the Japanese facility producing the melon fly *Bactrocera cucurbitae* (Coquillet).

4.3. Strain management

Strain management ensures that a strain continues to perform the function required of it, i.e. it remains sexually compatible with wild insects and does not gradually deviate from wild behaviour. The strain must also maintain fecundity, and potential problems with contaminant organisms must be suppressed or eliminated. Fisher (1984), Schwalbe and Forrester (1984), and Singh and Ashby (1985) discussed strain management.

4.4. Automation of rearing

In areas with low-labour costs, the drive towards automation will be reduced, but in high-wage areas, e.g. Japan, automation is essential to reduce costs. Other reasons to automate include: (1) reduction in human error, with increased product performance and consistency, (2) reduction in microbial contamination from personnel, and (3) increased space utilization efficiency, resulting in lower costs–for building and for energy for environmental control. Another aspect of automation is in climate-control systems. Air-handling is essential to control temperature and humidity, reduce airborne particulates and microbial contamination of the colony, and reduce medical problems of the staff. Smith (1999), Smith and Nordlund (1999), and Opiyo et al. (2000) reviewed aspects of mass-rearing automation. For almost all stages of the process, descriptions of automated systems are available–egg collection (Pearson et al., 2002), diet preparation and dispensing (Gantt and King, 1981), larval holding and pupal harvesting (Hartley et al., 1982), and environmental-control systems (Oborny, 1998, Peng and Ohura, 2000).

4.5. Diet

Diets for many insects have been described in the literature (Smith 1966, Singh and Moore 1985, Gerberg et al., 1994), with a gradual progression from natural-host material towards synthetic and defined diets. A natural host diet is limited by the availability of the host, which may be seasonal or limited in distribution, and variable in quality. It tends to be expensive, but should provide a complete diet and avoid changes in host-location behavior. Semi-synthetic, synthetic, and defined diets offer the convenience of shelf storage and consistent product, but risk being deficient in one or more factors. Often natural-host material needs to be incorporated into the diet for initial colonization, but then can gradually be removed as the colony adapts. Generalist herbivore insects tend to be the easiest to feed, with specialist herbivores and predators being more difficult. Singh (1985) worked on a range of diets suitable for many species, even across different orders. However, even though general diets are unlikely to provide optimum nutrition and cost, they do act as a good starting point for developing diets for newly colonized species.

4.6. Sex separation

The sexes often show a variation in developmental rate, and this can sometimes be used to separate them. Female tsetse flies emerge first and, by manipulating temperature conditions during pupal development, sex separation based on the timing of adult emergence is possible (Opiyo et al., 1999, 2000); the efficiency was more than 99%, and eliminated the laborious hand-sorting work in a chiller.

4.7. Marking

To mark or not to mark sterile insects for release, that is the question. It is usually assumed that marking is essential for field monitoring of sterile to wild ratios so as to follow program progress, but the hugely successful New World screwworm eradication program has never used any form of marking.

4.8. Storage

Successful field operations using the SIT require a timely and predictable supply of sterile insects, and this can present logistical problems. In an ideal situation, the rearing would be continuous, with some means to stockpile the insects over winter in preparation for release in the spring. For these reasons, the ability to store insects, and to manipulate quiescence or diapauses, becomes very valuable. For shorter timescales, storage for a few days may be useful to synchronize insects for periodic release, and storage in a quiescent state for a period of hours may be desirable for delivery to the release site and for the release process itself.

5. Sterilizing Insects with Ionizing Radiation

Exposure to ionizing radiation is currently the method of choice for rendering insects reproductively sterile for area-wide integrated pest management (AW-IPM) programmes that integrate the sterile insect technique (SIT). Gamma radiation from isotopic sources (cobalt-60 or caesium-137) is most often used, but high-energy electrons and X-rays are other practical options. Insect irradiation is safe and reliable when established safety and quality-assurance guidelines are followed. The key processing parameter is absorbed dose, which must be tightly controlled to ensure that treated insects are sufficiently sterile in their reproductive cells and yet able to compete for mates with wild insects. To that end, accurate dosimetry (measurement of absorbed dose) is critical. Irradiation data generated since the 1950s, covering over 300 arthropod species, indicate that the dose needed for sterilization of arthropods varies from less than 5 Gy for blaberid cockroaches to 300 Gy or more for some arctiid and pyralid moths. Factors such as oxygen level, and insect age and stage during irradiation, and many others, influence both the absorbed dose required for sterilization and the viability of irradiated insects. Consideration of these factors in the design of irradiation protocols can help to find a balance between the sterility and competitiveness of insects produced for programmes that release sterile insects.

5.1. Electron beam

In the near future, the use of high-energy (5–10 MeV) electrons to sterilize insects will likely increase. Such electrons are generated by an electron accelerator, which does not involve any radioactive materials.

5.2. X-Rays

When a beam of electrons strikes material with a high atomic number, e.g. tungsten, X-rays are generated. X-rays, like gamma rays, are electromagnetic radiation. Gamma rays from 60Co or 137Cs, and X-rays, penetrate irradiated materials more deeply than electrons.

For example, for 60Co gamma rays, dose decreases to half at a depth of about 23 cm in water, but for 10-MeV electrons, the useful depth is only about 4 cm.

6. Arthropod Species Subjected to Radio Sterilization

In the past five decades, at least 217 species of arthropods of economic Importance, found in 136 genera, 61 families, 7 insect orders and 2 arachnid orders have been subjected to irradiation studies for the purposes of research, biological control, or pest management programmes integrating the SIT. Of these, 31% are Diptera, 25% Lepidoptera, 24.5% Coleoptera, 9% Hemiptera, 5.5% Acari, 3% Dictyoptera, 1% Araneae, 0.5% Thysanoptera, and 0.5% Orthoptera. Out of 66 entries on Diptera from 15 families and 26 genera, 21 species belong to the Tephritidae, indicating the importance of this group in pest management and international trade. The Culicidae and Pyralidae follow Tephritidae in terms of the number of species radio sterilized.

7. Use of Sit in Implementing Pest Management Strategies

A pest management "strategy" is a broad overall plan. The merits of a pest management strategy may be judged by its short- and long-term ecological, economic, sociological and political impacts (Rabb, 1972; Enkerlin, 2003; Enkerlin et al., 2003)

The major pest management strategies are:

(1) Suppression of local populations,

(2) Suppression of total populations under an AW-IPM approach,

(3) Eradication of well-established pest populations, and

(4) Containment (exclusion) and prevention of invasion.

The last three of these strategies are variants of AW-IPM (Hendrichs *et al.*, 2002). The SIT is a pest-specific tactic that can play a role in implementing all of these strategies. Highly selective tactics include the SIT and other genetic techniques, pheromones, pest-resistant crop varieties, certain insect pathogens, parasitoids and predators, and certain artificial land naturally occurring attractants. Light traps, some attractant baits, "general" predators, parasitoids and pathogens, and certain insecticides, are only moderately selective.

8. Active Coordinated Research Projects on Sit around the World

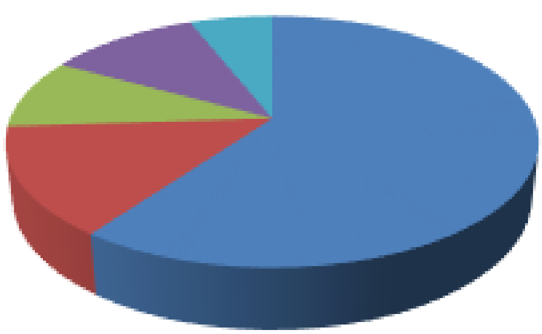
(Source: http://www-naweb.iaea.org/nafa/ipc/crp/active-crps-ipc.html)

- Integration of the SIT with Bio control for Greenhouse Insect Pest Management
- Improved Field Performance of Sterile Male Lepidoptera to Ensure Success in SIT Programmes
- Comparing Rearing Efficiency and Competitiveness of Sterile Male Strains Produced by Genetic, Transgenic or Symbiont-based Technologies
- Exploring Genetic, Molecular, Mechanical and Behavioural Methods of Sex Separation in Mosquitoes
- Dormancy Management to Enable Mass-rearing and Increase Efficacy of Sterile Insects and Natural Enemies
- Use of Symbiotic Bacteria to Reduce Mass-Rearing Costs and Increase Mating Success in Selected Fruit Pests in Support of SIT Application

8.1. Work Going on In India

Agency	Insect species	Common name
BARC, Mumbai	*Phthorimaea operculella*	Potato tuber moth
BARC, Mumbai	*Rhyncophorus ferrugineus*	Red pal weevil
Delhi university dept. of zoology	*Spodoptera litura*	Tobacco caterpillar
WHO, DRDO	*Culex pipiens*	Mosquitos
UAS, Raichur	*Maruca vitrata*	Red gram webber

8.2. Countries engaged in use of this technique (% share)



9. Research Needs

• In operational programs, correlation of frequency of mating of sterile males with wild females and the dynamics of the pest population. There is a paucity of published data that relate sterile male releases to population suppression.

• Determine if the competitiveness of sterile males is correlated with density. Rogers and Randolph (1985) suggested that the competitiveness of sterile males is strongly impaired by high density, and Hargrove (2003) made a similar claim without providing any mechanism.

• Study the detection and sampling of very sparse populations. Disagreement, on the interpretation of sample data, enveloped area-wide programs against the boll weevil in an especially bitter and costly controversy (NRC, 1975). Similar difficulties have been encountered in programs against tsetse flies *Glossina* spp., screwworms, the gypsy moth, etc.

• Automate the collection of field data, resulting in substantial cost savings in area-wide programs, for example, insect traps (baited with a species-specific attractant) that send a radio signal when a catch is made or a use of GIS or remote sensing based population detection techniques.

• Determine the full host range of many pest species.

• Identify sociological barriers, and opportunities to surmount them, in implementing AW-IPM programs.

10. Knipling's Imperative

When the World Food Prize was awarded to E. F. Knipling and R. C. Bushland, Knipling (1992b) stated:

"If major advances are to be made in coping with most of the major arthropod pest problems, then the tactics and strategies for managing such insects, ticks and mites must change. They must change from the current, limited scale, reactive, broad-spectrum measures to preventive measures that are target-pest specific and rigidly applied on an area-wide basis."

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