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A systematic review about potential use of sterile insect in integrated pest management

Haseeb Ullah Kamber[1], Nasir Abbas[2], Amara Ashraf[1], Hassan Saif Khan[3], Mariam Tallat[4], Javed Iqbal Khan[4]

[1]Department of Plant Pathology, University of Agriculture Faisalabad, Pakistan
[2]Department of Agronomy, University of Agriculture Faisalabad, Pakistan
[3]Institute of Agriculture Extension and Rural Development University of Agriculture Faisalabad, Pakistan
[4]Department of Entomology, University of Agriculture Faisalabad Pakistan
Corresponding authors: jiqbalkhan3@gmail.com; haseeb.khaaani204@gmail.com

Abstract: 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. This results in increased demands for pest control methods that are both efficient and friendly to the environment. The sterile insect technique (SIT) is an environment-friendly method of pest control that integrates well into area-wide integrated pest management (AW-IPM) programmes. During the last six–seven decades, the sterile insect technique (SIT) has been used as part of area-wide integrated pest management strategies to suppress, contain, locally eradicate or prevent the (re)invasion of insect pest populations and disease vectors worldwide. The SIT involves rearing large numbers of the target species, exposing them mainly to gamma rays (but increasingly also to X-rays to avoid the transport, security, and regulatory issues related to radioactive sources to induce sexual sterility, and then releasing them into the target population. The released sterile males' mate with wild females to prevent them from reproducing. The SIT has constantly proven its capacity to suppress, contain, prevent (re)introduction or even locally eradicate populations of selected key insect plant and livestock pests. However, there is also a continuous need to further refine and improve the efficiency as well as the cost-effectiveness.
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Introduction

Crop production is an art, a science, and an enterprise, and by adding environmental and social factors, IPM—an approach used in crop production—is also influenced by a number of factors. The concept of integrated pest management (IPM), a sustainable strategy for managing pests, has been in practice for a long time (Peterson et al. 2018). When using the sterile insect technique (SIT), it is applied usually as a component of area-wide integrated pest management (Klassen et al., 2021). To be applied against any pest, the SIT requires colonization and mass rearing of the target insect at reasonable cost, the sterilization of large numbers of the reared insects by ionizing irradiation using gamma- or X-rays, and their subsequent periodic release into the target area where they have to compete with wild males for matings with wild females. Virgin wild females that mate with released sterile males have no offspring, which in turn leads to suppression of the pest populations (Vreysen et al., 2016). Quantitative genetic studies of the life history and behavioral traits of insects are important for quality control in insect mass-rearing programs (Zafar et al., 2020; Razzaq et al., 2021; Rahman et al., 2017). Genetic processes such as the founder effect, bottleneck effect, inbreeding, genetic drift, and inadvertent selection for improved laboratory adaptation have been a continuing concern in biological control and mass-rearing projects (Miyatake et al. 2000). The effectiveness of the SIT depends on the ability of released sterile males to mate with and inseminate wild females (Knipling 1979). Therefore, information on mating performance, effect of irradiation, and dispersal ability of target pest insects is necessary for implementing successful eradication programs using the SIT and has been the focus of several studies (Kuriwada et al. 2010).

Fruit flies

In 1994, an area-wide SIT eradication programme was initiated, with twice-weekly releases of sterile Mediterranean fruit flies over the entire Los Angeles Basin. This programme was so successful and cost-effective that, in view of the many introductions, in 1996 a permanent preventive release programme was established over this area (Barry et al. 2004). Sexing strains are also used in most

Mediterranean fruit fly suppression, containment, or eradication programmes (Augustinos et al. 2017). Mastrangelo and colleagues (2021) report on an improved rearing protocol for the South American fruit fly *Anastrepha fraterculus* (Vacaria strain), including a novel larval diet in which agar has been replaced by carrageenan (Mastrangelo et al., 2021). Although SIT applications for fruit flies can be successfully implemented by releasing both sterile males and sterile females, it has been shown that the efficiency and cost-effectiveness can be increased significantly if only sterile males are released (Rendón et al.,2004; Franz et al., 2021). Ramirez and colleagues (2021) present a new GSS for *A. ludens*, namely GUA10 that is based on the *black pupae* (*bp*) gene (Ramírez-Santos et al., 2021). Comparative analysis showed that the *A. ludens* GUA10 GSS exhibits better rearing efficiency, genetic stability and overall quality than the previously developed *A. ludens* TAP7 GSS. Sassù and colleagues (2019) report on the development and comparative evaluation of a wax panel and a netted oviposition system as egg collection systems for the spotted wing drosophila, *Drosophila suzukii*. The results presented clearly show that the wax panel system is more practical, less laborious and produces significantly more and higher quality eggs than the netted oviposition system.

Coleopteran

Small hive beetle, Aethina tumida Murray (Coleoptera: Nitidulidae), is considered a serious threat to beekeeping in the Western Hemisphere, Australia, and Europe mainly due to larval feeding on honey, pollen, and brood of the European honeybee, Apis mellifera LStudies were conducted to provide information on the radiobiology of small hive beetle and determine the potential for sterile insect releases as a control strategy. Adult males and females were equally sensitive to a radiation dose of 80 Gy and died within 5–7 d after treatment. In reciprocal crossing studies, irradiation of females only lowered reproduction to a greater extent than irradiation of males only. For matings between unirradiated males and irradiated females, mean reproduction was reduced by >99% at 45 and 60 Gy compared with controls, and no larvae were produced at 75 Gy. Irradiation of pre-reproductive adults of both sexes at 45 Gy under low oxygen (1–4%) caused a high level of sterility (>99%) while maintaining moderate survivorship for several weeks, and should suffice for sterile insect releases. Sterile insect technique holds potential for suppressing small hive beetle populations in newly invaded areas and limiting its spread (Downey et al., 2015).

In Japan, Cylas formicarius (F.) group (Coleoptera: Brentidae) weevils are marked with a ßuorescent powder dye to monitor the progress of such programs. However, this monitoring technique is not fully effective because of the disappearance or contamination of the dye. Therefore, an alternative marking method is required. Currently, a rare color morph such as piceous elytra (PE) is used for visible marking of C. formicarius group weevils. A PE-monomorphic strain has previously been established by artiÞcial selection from a small locally distributed population; this can lead to reduced survival and genetic changes in behavioral traits due to inbreeding depression. In this study, we evaluated the survival rate and mating behavior of PE males of C. formicarius group. The characteristics of the PE males were similar to those of the wild strain (WS) males. Thus, we considered that PE males were suitable for visible marking in the eradication programs using the SIT (Shiromoto et al., 2011).

Kumano et al. (2010), evaluated the effect of irradiation dose intensity on fertility, mating propensity, and mating competitiveness in sweetpotato weevil, Cylas formicarius elegantulus (Summers) (Coleoptera: Curculionidae), for 16 d after irradiation. Although the mating propensity of males irradiated with 200 Gy, the dose currently used to induce complete sterility of C. f. elegantulus in the SIT program in Okinawa Prefecture, was equal to that of nonirradiated weevils for the first 6 d, the mating propensity of males irradiated with doses between of 75 and 150 Gy was maintained for the first 12 d. The potential fertilization ability of weevils was highly depressed compared with the control weevils, even in those treated with 75 Gy. Mating performance was severely compromised in weevils that were irradiated with a dose of 100 Gy or more.

The West Indian sweetpotato weevil Euscepes postfasciatus (Fairmaire) (Coleoptera: Curculionidae) is a major pest of sweet potato Ipomoea batatas (L.) Lam (Solanales: Convolvulaceae) in some countries. In order to improve mass-rearing for an eradication program employing the sterile insect technique (SIT), optimal population density of E. postfasciatus in an artificial diet was examined. Six population densities (1000, 4000, 7000, 10000, 13000, and 16000 individuals per container with 200 g of artificial diet) were compared for effect on the number of eggs collected and hatchability. The total number of eggs collected after 24 d increased with an increase in population density and reached a saturation level at 13,000 individuals, whereas hatchability was not affected by population density. The results indicated that optimal population density in mass rearing was 13,000 individuals on 200 g of artificial diet. Furthermore, we examined

cannibalism by adult weevils in the presence of other diets. The result suggested that egg cannibalism may be a major reason for the low rate of egg collection in the mass rearing of E. postfasciatus (Kuriwada et al., 2009).

Lepidoptera

As with other insects, the SIT/IS can be applied against Lepidoptera using different strategic approaches, e.g., suppression, local eradication, and containment strategies (Hendrichs et al., 2005).

The OKSIR program is the longest-running, most successful, area-wide integrated pest program for the suppression of codling moth in the world, and its implementation is accompanied by continuing extensive research (Thistlewood et al., 2019). The SIT is integrated with orchard sanitation, surveillance, tree banding, and mating disruption. After more than 20 years of operation, the codling moth populations in the valley have been drastically reduced, and as a result, the growers, the industry, and the local community have significantly reduced fruit damage and costs associated with codling moth control. The program has achieved less than 0.2% damage in more than 90% of all commercial pome fruit acreage and reduced insecticide use to control codling moth by over 95% in the valley (from 50,000 kg of chemicals in 1991 to <3000 kg in 2015). In addition, the number of chemical sprays targeting codling moth has been reduced from 1.5–2.7 sprays/acre in the early 1990s to <0.3 sprays/acre in 2013 in the southern part of the valley. A recent cost–benefit analysis showed the economic efficiency of the program, i.e., a benefit to the producers from insecticide cost savings, monitoring cost savings and reduction in codling moth injury amounting to CAN $395/acre (versus CAN $377/acre for mating disruption). The economic benefits per acre of orchard were much higher using the OKSIR strategy as compared to using conventional insecticides: the overall cost–benefit ratio of the SIT program was 1.19 for the producer and 2.51 in total. The use of sterile moths against pink bollworm started as a containment program in 1968 to protect the cotton fields in the San Joaquin Valley of California. For more than 20 years, sterile moths were released every season, covering 0.4 million hectares of cotton that prevented the establishment of the pest (Staten et al., 1993).

The success of area-wide pink bollworm management is highly dependent on participation by all segments of the agricultural community in the planning, site selection, implementation, and assessment phases of the programme. A highly effective extension-education communication programme is an essential component. The outstanding performance of *Bt*-cotton and pheromone behavioural control for pink bollworm, and the availability of historically-proven effective pink bollworm population suppression technologies (cultural controls, crop residue destruction, water management, planting dates, and sterile moth release), encouraged formulation of a multi-agency and transboundary pink bollworm eradication plan. The eradication programme was initiated in 2001-2002 in the El Paso/Trans Pecos area of Texas, in South Central New Mexico and in Chihuahua, Mexico. The results of area-wide suppression have been exceptionally encouraging and provide promising expectations for the other infested areas of the south-western USA and north-western Mexico. The pink bollworm population has been reduced to levels that can be targeted for sterile pink bollworm releases to pursue the goal of eradication (Henneberry et al., 2007).

Hemiptera

Horrocks et al (2020) investigated the irradiation biology of *N. viridula* for the potential application of SIT against this pest. Male and female *N. viridula* were gamma-irradiated at doses between 4 and 28 Gy and mated with both irradiated and nonirradiated conspecifics. Sterility of the resulting eggs followed a dose-response in each case. Irradiated males crossed with untreated females showed higher F_1 egg sterility than crosses where the female was irradiated. The greatest F_1 egg sterility was observed when both parents were irradiated. There was no obvious dose-response for the longevity of irradiated males, and for the fecundity of nonirradiated females mated with irradiated males. The fecundity of irradiated females appeared to decrease with irradiation dose. These results can be applied to a potential future application of SIT against *N. viridula*, but predominantly supports the ongoing development of SIT for *Halyomorpha halys* Stål (Hemiptera: Pentatomidae) and hemipteran pests in general.

Fifth-instar brown marmorated stink bug (Halyomorpha halys Stål) nymphs were treated by gamma-radiation 60Co at different doses of 8–64 Gy to investigate their irradiation biology and potential for the sterile insect technique (SIT). At adult emergence, males were mated with non-irradiated virgin females to assess the longevity of both sexes, female fecundity, and egg sterility. Biological parameters of their F1 progeny were investigated to determine whether negative effects from parental exposure to radiation were inherited. Results showed that irradiation significantly reduced the lifespan of male insects at doses above 20 Gy. Irradiated males did not affect the longevity and fecundity of their

female partners, nor of their resulting adult progenies, but it did reduce the developmental duration of nymphs as well as weight gain of male F1 offspring. Egg hatch was significantly reduced at all tested doses and reached complete sterility at 64 Gy. Low hatch of eggs produced by F1 or F1 crossed adults indicated that negative effects from radiation were inherited by the subsequent generation. But F1 male offspring were not less fertile than their irradiated male parent, unlike what was observed in Lepidoptera. The results support the potential for the use of SIT for H. halys management by irradiating the fifth-instar male nymphs at doses from 16 Gy to 64 Gy (Nguyen et al., 2021).

Conclusion

The successful implementation of SIT/IS in control programs against several key pests has clearly demonstrated the high efficiency and wide applicability of these environment-friendly strategies for the control of agricultural pests. The sterile insect technique (SIT) and its applications show that the (mass-) rearing, sex separation, irradiation, handling, packaging, and release process can be further refined including the quality control analysis of both the product and the process. Lack of support for the necessary underpinning strategic research also appears to be an important constraint. Hence, the case for extensive strategic research in ecology, population dynamics, density-dependent regulation, genetics, insect behavior, and insect nutrition is a compelling one. Raising the competitiveness of released males remains the major research objective for the SIT.

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