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Integrated Pest Management for eggplant fruit and shoot borer (*Leucinodes orbonalis*) in south and southeast Asia: Past, Present and Future

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ABSTRACT

The integrated pest management (IPM) strategy for the control of eggplant fruit and shoot borer (EFSB) consists of resistant cultivars, sex pheromone, cultural, mechanical and biological control methods. Eggplant accessions EG058, BL009, ISD006 and a commercial hybrid, Turbo possess appreciable levels of resistance to EFSB. Use of EFSB sex pheromone traps based on (E)-11-hexadecenyl acetate and (E)-11-hexadecen-1-ol to continuously trap the adult males significantly reduced the pest damage on eggplant in South Asia. In addition, prompt destruction of pest damaged eggplant shoots and fruits at regular intervals, and withholding of pesticide use to allow proliferation of local natural enemies especially the parasitoid, *Trathala flavo-orbitalis* reduced the EFSB population. The IPM strategy was implemented in farmers' fields via pilot project demonstrations in selected areas of Bangladesh and India and its use was promoted in both countries. The profit margins and production area significantly increased whereas pesticide use and labor requirement decreased for those farmers who adopted this IPM technology. The efforts to expand the EFSB IPM technology to other regions of South and Southeast Asia are underway.

INTRODUCTION

Eggplant (*Solanum melongena*) is one of the most important vegetables in South and South-East Asia. It is grown on over 678,000 ha, which is about 37% of the world eggplant area, with a production of 10.50 million t (FAO, 2007). Eggplant fruit and shoot borer (EFSB), *Leucinodes orbonalis* Guenée (Lepidoptera: Pyrallidae) is one of the most destructive pests on eggplant in South and Southeast Asia. Larvae of this insect bore inside plant shoots and fruits adversely affecting plant growth, yield and fruit quality, and thus making it unfit for human consumption. The yield reduction could be as high as 70% (Islam and Karim, 1991; Dhandapani *et al*., 2003). Hence, the farmers in the region rely exclusively on the application of chemical insecticides to combat EFSB which has resulted in a tremendous misuse of pesticides in an attempt to produce damage-free marketable fruits. Survey of pesticide use in Bangladesh indicated that farmers spray up to 180 times with chemical insecticides during a year to protect their eggplant crop against EFSB (SUSVEG-Asia, 2007). The pesticide use is equally intensive in the Philippines. It was about 56 times during a cropping season and the total quantity of pesticide used per hectare was about 41 l of the different brands belonging to the four major pesticide groups (Gapud and Canapi, 1994; Orden *et al*., 1994). In addition to the adverse effects on environment and human health, such pesticide use increases the cost of production making eggplant expensive for poor consumers. For instance, the share of the cost of pesticide to total material input cost was 55% for eggplant and it ranked first when compared to tomato (31%) and cabbage (49%) in the Philippines (Orden *et al*., 1994), whereas it was 40-50% in Bangladesh (SUSVEG-Asia, 2007). Hence, many farmers refrained from growing eggplant because of this pest (Gapud and Canapi, 1994). Any single method of pest management cannot achieve a level of EFSB control acceptable to producers in the region. The integrated pest management (IPM) techniques could provide satisfactory control, but it should be simple and economic. Some IPM models have been suggested in the past and the farmers were given training on IPM. However, the impact of the IPM training was ambivalent, as the farmers increased the level of pesticide use after receiving training (Potutan *et al*., 1997). Probably the absence of economical IPM solutions for this pest was a key constraint in the region (IPM CRSP, 2001). AVRDC – The World Vegetable Center has recently developed, validated and promoted an IPM strategy for the control of EFSB in South Asia during 2000-2005 (Alam *et al*., 2003; Alam *et al*., 2006). The IPM strategy is composed of healthy seedling production, use of resistant cultivars, and EFSB sex pheromone to continuously trap the adult males, prompt destruction of pest damaged eggplant shoots and fruits at regular intervals, and withhold

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Table 1. Natural enemies of EFSB in South and Southeast Asia

Natural enemy species	Family and Order	Country where recorded	Reference
Predators			
Chrysopa kulingensis	Chrysopidae, Neuroptera	China	Yang, 1982
Campyloneura sp	Miridae, Heteroptera	India	Tewari and Moorthy, 1984; Tripathi and Singh, 1991
Cheilomenes sexmaculata, Coccinella septempunctata, Brumoides suturalis	Coccinellidae, Coleoptera	India	Kadam *et al*., 2006
Parasitoids			
Pseudoperichaeta sp	Tachinidae, Diptera	India	Patel *et al*., 1971
Phanerotoma sp	Braconidae, Hymenoptera	India, Sri Lanka	Patel *et al*., 1971; Tewari and Moorthy, 1984; Tripathi and Singh, 1991; Sandanayake and Edirisinghe, 1992
Apanteles sp	Braconidae, Hymenoptera	Philippines	Navasero, 1983
Chelonus sp	Braconidae, Hymenoptera	Philippines, Sri Lanka	Navasero, 1983; Sandanayake and Edirisinghe, 1992
Brachymeria lasus	Chalcididae, Hymenoptera	Philippines	Navasero, 1983
Dermatopelte sp	Eulophidae, Hymenoptera	China	Yang, 1982
Trathala flavoorbitalis	Ichneumonidae,	Bangladesh, India, Malaysia, Philippines, Sri Lanka	Alam and Sana, 1964; Patel *et al*., 1967 ; Yunus and Ho, 1980; Naresh *et al*., 1986; Mallik *et al*., 1989 ; Sandanayake and Edirisinghe, 1992; Gapud *et al*., 1998; Yasodha and Natarajan, 2006
Cremastus hapaliae	Ichneumonidae, Hymenoptera	Malaysia	Yunus and Ho, 1980
Xanthopimpla punctata	Ichneumonidae, Hymenoptera	Philippines	Navasero, 1983
Itamoplex sp	Ichneumonidae, Hymenoptera	India	Verma and Lal, 1985
Eriborus argenteopilosus	Ichneumonidae, Hymenoptera	India	Tewari and Sardana, 1987
Diadegma apostata	Ichneumonidae, Hymenoptera	India	Krishnamoorthy and Mani, 1998
Entomopathogens			
Bacterium		China	Yang, 1982
Fungus (*Bipolaris tetramera*)		India	Tripathi and Singh, 1991
Baculovirus		India	Tewari and Singh, 1987
Nuclear polyhedrosis virus		India	Tripathi and Singh, 1991

pesticide use to allow proliferation of local natural enemies to encourage the pest suppression.

EFSB Resistant Cultivars

One of the major elements in any IPM program is the use of resistant cultivars to insect pests. Resistant varieties have successfully been developed in several crops such as rice, wheat, corn, soybean, common bean, tomato, potato, etc against key pests. Despite the attempts which have been made to explore resistant sources as well as to develop resistant varieties against EFSB in the region, no commercial cultivar with appreciable levels of resistance has been developed. Because, most of the screening programs involved only few eggplant accessions and the programs were not mostly continued which may be due to lack of adequate levels of resistance. For instance, a screening program in Bangladesh involved only 24 local and exotic eggplant accessions, and only one accession exhibited comparatively lower infestation, but it was a low-yielding accession (Mannan *et al*., 2003). Another screening program involved only 20 accessions, and none of them exhibited significant levels of resistance (Hossain *et al*., 2002). Similar efforts have also been made in India with few dozens of eggplant accessions and they ended with few or none as resistant to EFSB (Darekar *et al*., 1991; Singh and Kalda, 1997; Behera *et al*., 1999; Doshi *et al*., 2002). Some of the wild *Solanum* species such as *anomalum*, *gilo*, *incanum*, *indicum*, *integriifolium*, *khasianum*, *sisymbriifolium*, *xanthocarpum*, etc were reported to possess high resistance to EFSB (Khan *et al*., 1978; Sharma *et al*., 1980; Chelliah and Srinivasan, 1983; Singh and Kalda, 1997; AVRDC, 1999; Behera *et al*., 1999; Behera and Singh, 2002). However, the resistance in these wild species should carefully be evaluated and confirmed before attempting to transfer the resistance to cultivated eggplant, because *S. indicum* had been reported as an alternate host to EFSB (Isahaque and Chaudhuri, 1983), although it was reported as a resistant source in other reports. In addition, the crossability and hybridization of cultivated eggplant with its wild relatives generally pose difficulties due to breeding incompatibilities (Dhankhar *et al*., 1982), and in several cases, crosses were only successful if in vitro embryo rescue was employed (Kashyap *et al*., 2003).

Research at AVRDC – The World Vegetable Center identified an eggplant accession (EG058) that consistently suffered less damage to shoot and fruits (AVRDC, 1999). This accession was later tested with a known susceptible check (EG075) in Bangladesh, India, Sri Lanka and Thailand. In most places except Bangladesh, it was less damaged than EG075 (Alam *et al*., 2003). Hence, EG058 could be an important source of resistance to develop EFSB-resistant cultivars for several countries in the region, except Bangladesh. Turbo, a commercial F1 hybrid grown in Thailand also exhibited significant resistance to EFSB in Thailand and Taiwan (Alam *et al*., 2003 and Srinivasan *et al*., 2005). In addition, two Bangladesh accessions *viz*., BL009 and ISD006 possess appreciable levels of resistance in Taiwan. Further research on these resistant sources indicated neither the trichomes nor the antibiosis as the basis of resistance (Srinivasan *et al*., 2005). Instead, the anatomical characters may probably contribute to the resistance as explained by Mishra *et al*. (1988) in some resistant accessions, which needs to be confirmed in further studies.

Sex Pheromones

Sex pheromones are important component of IPM programs and they are mainly used to monitor as well as mass-trap the male insects. Zhu *et al*. (1987) identified (E)-11-hexadecenyl acetate (E11-16: Ac) as the major component of EFSB sex pheromone in China. They synthesized this chemical in the laboratory and used at the rate of 300-500 µg per trap to attract the EFSB males in the field. Attygalle *et al*. (1988) and Gunawardena *et al*. (1989) also identified the presence of this compound from the sex pheromone glands of EFSB in Sri Lanka. In addition, they have also identified trace quantities of (E)-11-hexadecen-1-ol (E11-16:OH). E11-16:Ac was synthesized in the laboratory and tested for its attraction in Sri Lanka. Although it attracted male moths in the laboratory, its performance under field conditions was inferior to live virgin female moths (Gunawardena, 1992; Gunawardena *et al*., 1989). However, E11-16:Ac when used alone or in combination with E11-16:OH attracted significantly high numbers of male moths in India and Bangladesh, although E11-16:OH alone showed no attraction at any concentration (AVRDC, 1996; Srinivasan and Babu, 2000). Cork *et al*. (2001) at the Natural Resources Institute (NRI), UK also identified the presence of E11-16:Ac as a major component and E11-16:OH as a minor component in the pheromone gland extracts of EFSB from India and Taiwan. They also found that E11-16:Ac and E11-16:OH (100:1) attracted significantly more numbers of male moths than E11-16:Ac alone in India. Hence, the EFSB sex pheromone was included as a potential component in the EFSB IPM program that was implemented by AVRDC in South Asia.

Delta traps and funnel traps could be used for the EFSB sex pheromone lures in field conditions. However, the trap design that would attract more numbers of insects will vary from one location to the other. Hence, it had to be confirmed in repeated field experiments. For instance, in the AVRDC-led EFSB IPM program in South Asia, delta traps consistently caught more EFSB male moths than funnel traps in Gujarat, whereas funnel traps performed better than delta and water-trough traps in Uttar Pradesh (Alam *et al*., 2003). Similarly, delta traps caught and retained ten times more moths than either *Spodoptera* or uni-trap designs in Bangladesh (Cork *et al*., 2003). The optimal trap height will also vary with locations. As an example, the traps placed at crop canopy level caught significantly more male moths than traps placed 0.5 m above or below the crop canopy in Bangladesh (Cork *et al*., 2003), whereas traps installed 0.25 m above crop canopy caught higher moths than either at crop canopy or at 0.25 m below crop canopy in Uttar Pradesh (Alam *et al*., 2003). The traps should be erected at every 10 m or less for effective attraction (Prasad *et al*., 2005). In general, it has been suggested to place the traps at a density of 100 per ha (Cork *et al*., 2003). Thus, the EFSB sex pheromone traps as a component of IPM significantly reduced the fruit damage and increased the yield in South Asia (Alam *et al*., 2003; Cork *et al*., 2003).

Cultural and Mechanical Control

Cultural control methods involve the manipulation of crop environment as well as management, whereas mechanical control involves the use of mechanical forces or manual operations to interfere with the insect feeding, shelter and reproduction. For instance, sanitation of the field before, during and after the cropping, removal of the alternate food sources for the pests and mechanical barriers are some of the cultural and mechanical control measures to manage EFSB in the field.

Solanum nigrum, *S. indicum*, *S. torvum*, *S. myriacanthum*, tomato and potato were recorded as alternative host plants of EFSB (Fletcher, 1916; Menon, 1962; Nair, 1967; Das and Patnaik, 1970; Mehto *et al*., 1980; Isahaque and Chaudhuri, 1983; Srinivasan and Babu, 1998; Murthy and Nandihalli, 2003; Reddy and Kumar, 2004). Although it may be a rare occurrence, and it is not clear about the size of EFSB population that would develop and migrate from these plants, the new plantings or seedling nurseries can be kept free of or away from these *Solanum* species and fields. However, EFSB moths that emerge from the pupae in soil or migrate from neighboring eggplant crops are important sources of infestation.

In addition to these known sources of infestation, dry eggplant stalks from previous crop that have been stored by the farmers as fuel for cooking serve as another important source of EFSB infestation (Alam *et al*., 2003). Sometimes, farmers may grow their eggplant seedlings in the vicinity of dry eggplant stubble heaps, which may likely to get infested by those moths emerging from the stubble heaps. However, this needs to be investigated in detail. In general, it would be ideal to grow the seedlings away from the dry eggplant stubble heaps, or under net-tunnels if it is grown in the vicinity of dry eggplant stubble heaps.

Removal and prompt destruction of the EFSB infested shoots and fruits at regular intervals have been suggested as an effective strategy to manage the EFSB on eggplant in South and Southeast Asia (Rahman *et al*., 2002; Talekar, 2002; Arida *et al*., 2003; Satpathy *et al*., 2005). This pruning is especially important in early stages of the crop growth, and this should be continued until the final harvest. This will be more effective when it is being followed by the whole community in a particular region than an individual grower. In addition, this pruning will not adversely affect the plant growth as well as yield (Talekar, 2002; Srinivasan, unpublished data).

As the EFSB adults are relatively small moths and weak fliers, it was hypothesized that the inter-field movement could effectively be restricted by erecting suitable barriers. This hypothesis was tested by erecting 2 m high nylon net barrier around the eggplant soon after transplanting in Bangladesh, India, Sri Lanka and Thailand. The use of barriers combined with prompt destruction of the EFSB infested shoots significantly reduced the damage to shoots than by using either the barrier or the sanitation alone (Alam *et al*., 2003). However, the damage to fruits was not so significant, although the reduction in damage over untreated control was about 33%. Protective cultivation such as net-house or poly-house production systems are emerging in states like Punjab in India. Kaur *et al*. (2004) found that sanitation and neem spraying recorded 50% lower fruit damage in net-house cultivation than the damage under open field conditions in Punjab. Hence field sanitation and mechanical barriers could significantly reduce the EFSB damage and could be an effective component in EFSB IPM. However, economic feasibility of adopting net-barriers or net-houses should be considered while promoting this technology among resource-poor eggplant growers.

Biological Control

Although several natural enemies (predators, parasitoids and entomopathogens) have been recorded against EFSB in South and Southeast Asia (Table 1, modified from Waterhouse, 1998), their role in keeping the EFSB population at levels below causing economic damage is not significant (Srivastava and Butani, 1998). However, *Trathala flavoorbitalis* seems to be a potential candidate in biological control of EFSB among all these natural enemies, because of its presence in several countries in the region as well as its higher rate of parasitism in field conditions. But, it is not a specific parasitoid of EFSB as it could also attack other pyralid insect pests. For instance, it was introduced in the Fiji Islands from Hawaii for the control of rice leaf-folder, *Marasmia exigua* in 1928 (Islam and Cohen, 2007).

Although *T. flavoorbitalis* has been recorded on EFSB in several countries, its potential role in EFSB management has not been studied in detail. Hence, AVRDC has started exploring the local natural enemies including *T. flavoorbitalis* that have the potential to control EFSB in the region. *T. flavoorbitalis* was the only active parasitoid against EFSB in Sri Lanka, Gujarat (India) and Bangladesh, with maximum parasitism of 61.7%. In addition to *T. flavoorbitalis*, *Goryphus nursei* (Ichneumonidae: Hymenoptera) was recorded in Uttar Pradesh. This was an active parasitoid during winter season, with maximum parasitism of 7%. Similarly, few specimens of *Pristomerus testaceus*, *Elasmus corbetti* and *Euagathis* sp. have been recorded from EFSB in Thailand, although *T. flavoorbitalis* remained predominant species. The level of parasitism by *T. flavoorbitalis* has significantly increased after withholding the pesticide use (Alam *et al*., 2003). Hence, *T. flavoorbitalis* would be an ideal bio-control candidate in EFSB IPM program in the region.

Promotion of EFSB IPM in South Asia

In a later phase during 2003-2005, the EFSB IPM strategy was promoted among the eggplant growers in selected areas of Bangladesh and India. The promotional activities included organization of farmers' field days on pilot project sites, meetings between farmers and researchers, training of farmers in the use of IPM, production and distribution of extension publications, news releases and telecasting of an IPM documentary film in local languages to drive home the message of IPM, especially to farmers and consumers. The pilot projects were implemented in an area of about 325 ha owned by about 2000 growers, in which nearly 35 Farmers' Field Days have been organized over a period of two years. About 10,000 farmers were trained on the IPM technology, and about 22,000 extension publications in local languages have been distributed (Alam *et al*., 2006).

In addition, small and medium sized entrepreneurs (SMEs) were also involved in the project activities to encourage commercialization of sex pheromone and promotion through them the use of this pest control tool as a part of IPM. Nine SMEs were selling the EFSB sex pheromones in India by the end of 2005. The sales volume of EFSB sex pheromone lures by four of these SMEs have nearly tripled from 74,000 in 2002 to 193,000 in 2004 (Alam *et al*., 2006), which reflected the adoption of the technology by the eggplant growers.

Socioeconomic Impact and Future of the EFSB IPM Technology

The profit margins and production area significantly increased whereas pesticide use and labor requirement decreased for those farmers who adopted this IPM technology. For instance, socioeconomic studies in Bangladesh revealed that the adoption of EFSB IPM has reduced about 30% of the total production cost when compared to the non-IPM adopters (Alam *et al*., 2003). In West Bengal, the IPM adopters has reduced their labor requirements by 5.9%, sprayed pesticides 52.6% less often than before and increased their eggplant production area by 21.6%. The economic surplus model revealed an internal rate of return of 38% and a benefit cost ratio of 2.78 (Baral *et al*., 2006). It has clearly been proven that this IPM technology has positive impacts on the lives of eggplant growers in the region. Hence, AVRDC – The World Vegetable Center is currently exploring grants to expand the EFSB IPM program to other regions of South and Southeast Asia, especially Bangladesh, India (Andhra Pradesh, Karnataka, Maharashtra, Tamil Nadu and West Bengal), Nepal and the Philippines. In addition to the upscaling of the IPM technology, partnerships will be strengthened with the existing national IPM programs in the region to enhance the capacity building.

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