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Review Article

BIOLOGY AND MANAGEMENT OF EGGPLANT FRUIT AND SHOOT BORER, *Leucinodes orbonalis* Guenee (LEPIDOPTERA: PYRALIDAE): A REVIEW

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Abstract

Eggplant (*Solanum melongena* Linnaeus) is one of the most economically important vegetable of tropics having hot-wet climate. The key pest, eggplant fruit and shoot borer, *Leucinodes orbonalis* Guenee found to be most destructive and first ranked threat especially in South Asia, hence become hot issue for research in this region. It inflicts sizeable damage up to 80 percent in terms of fruit and content of vitamin-C. This situation refrained the farmers growing eggplant, hence relevant literatures were gleaned and overviews regarding biology and management of borer with supportive facts and figure for safe and healthy eggplant production. As integrated approaches of pest management have been gaining popularity nowadays, this article outlines all the components of IPM including use of resistant varieties, sex pheromones, cultural methods, physical and mechanical barriers, bio-pesticides and bio-control agents, botanical and chemical means of management including basic biological parameters associated with management.

Keywords: eggplant, eggplant fruit and shoot borer, biology, IPM

Introduction

Eggplant, *Solanum melongena* Linnaeus is one of the most important vegetables in South and South-East Asia (Thapa, 2010) having hot-wet climate (Hanson *et al.*, 2006). The cultivation of eggplant is more than 1,600,000 ha producing around 50 million Mt throughout the world, among which, ninety percent of production from five countries, of which china shares 58 percent of output, India, 25%, followed by Iran, Egypt and Turkey (FAO, 2012). The higher yield and longer fruiting and harvesting period lure the farmer on eggplant production (Ghimire *et al.*, 2001). However, eggplant production is in threat in recent years due to increased cost of production on management of insect pest complex.

Eggplant fruit and shoot borer, *Leucinodes orbonalis* Guenee is the key pest of eggplant (Latif *et al.*, 2010; Chakraborti and Sarkar, 2011; Saimandir and Gopal, 2012) inflicting sizeable damage in almost al the eggplant growing areas (Dutta *et al.*, 2011) and is most destructive, especially in south Asia (Thapa, 2010). As a result of its feeding inside fruit, the fruits become unmarketable and yield losses up to 90 percent (Baral, *et al.*, 2006). It also reduces the content of vitamin C in fruit up to 80 percent (Sharma, 2002). Hence, many farmers leaving growing eggplant because of this pest (Gapud and Canapi, 1994). Therefore, pertinent literatures were gleaned and overviews prepared for the management of the *L. orbonalis* with consideration of supporting literature helpful for management.

Methodology

An extensive review was done to collect pertinent data with consultation of journal articles, proceedings, annual reports, thesis works etc. covering mainly management aspects of the pest and basic part directly or indirectly supporting to management. Pertinent and relevant information were arranged systematically by summarizing with conclusive outline.

Technological finding: A Review

Taxonomy

Leucinodes orbonalis Guenee was described by Guenee in 1854. The preferred scientific name of the eggplant fruit and shoot borer is *Leucinodes orbonalis* Guenee, 1854. Walker designated it as the type species of the genus *Leucinodes* in 1859 (CABI, 2007). The taxonomic position according to CABI (2007) is given as:

Phylum: Arthropoda
Class: Insecta
Order: Lepidoptera
Family: Crambidae (Syn: Pyralidae)
Genus: *Leucinodes*
Species: *orbonalis*
Scientific name: *Leucinodes orbonalis* Guenee

Host range

L. orbonalis Guenee is practically monophagous, feeding principally on eggplant; however, other plants belonging to family Solanaceae are reported to be hosts of this pest.

In the area of global eggplant cultivation, *L. orbonalis* also occurs on different host plants. Major recorded are: *Solanum melongena* Linnaeus (eggplant), *Solanum tuberosum* Linnaeus (potato) but there are several minor host, like *Ipomoea batatas* Linnaeus (sweet potato), *Lycopersicon esculentum* Mill (tomato), *Pisum sativum* var. *arvense* Linnaeus (Austrian winter pea) *Solanum indicum* Linnaeus, *Solanum myriacanthum* Dunal, *Solanum torvum* Swartz (turkey berry) and wild host *Solanum gilo* Raddi (gilo), *Solanum nigrum* Linnaeus (black nightshade) (CABI, 2007). In addition, *Solanum anomalum* Thonn (Singh and Kalda, 1997) and *Solanum macrocarpon* Linnaeus (Kumar and Sadashiva, 1996) are wild hosts of *L. orbonalis.*

Distribution

The pest is reported from regions of eggplant cultivation in Africa, South of the Sahara and South-East Asia, including China and the Philippines (CABI, 2007). In Asia, it is the most important and the first ranked pest of India, Pakistan, Srilanka, Nepal, Bangladesh, Thailand, Philippines, Cambodia, Laos and Vietnam (AVRDC, 1994). Its distribution is mostly higher in those areas having hot and humid climate (Srinivasan, 2009).

Life cycle

Like other members of the order Lepidoptera, *L. orbonalis* goes through four growth stages: egg, larva, pupa and adult. The larval period is the longest, followed by pupal and incubation period.

Egg: Oviposition takes place during the night and eggs are laid singly on the lower surface of the young leaves, green stems, flower buds, or calyces of the fruits and number of eggs laid by a female varies from 80 to 253 (Taley *et al.*, 1984; Alpuerto, 1994), however, reported as high as 260 (FAO, 2003). The eggs are laid in the early hours of the mornings singly or in the batches on the ventral surface of the leaves (CABI, 2007). They are flattened, elliptical with 0.5 mm in diameter and colour is creamy-white but change to red before hatching (Alam *et al.,* 2006). The egg takes incubation period of 3-5 days in summer and 7-8 days in winter and hatche into dark white larvae (Rahman, 2006).

Larva: The larval period lasts 12 - 15 days during summer and 14 - 22 days during winter season (Rahman *et al.*, 2006). Larvae pass through at least five instars (Atwal, 1976) and there are reports of the existence of six larval instars (Baang and Corey, 1991; FAO, 2003). Sandanayake and Edirisinghe (1992) studied the larval distribution on mature eggplant. They found first instars in flower buds and flowers, second instars in all susceptible plant parts, third and fourth instars in shoots and fruits and fifth instars mostly in fruits. In general, the size of the first instar larvae are less than 1mm in length, the last instar larva is 15 – 18 mm long but Sandanayeke and Edirinsinge (1992) reported the size of last instar larva to be 18 to 23 mm. Larval feeding in fruit and shoot is responsible for the damage to eggplant crop. One fruit contain up to 20 larvae in Ghana (Frempong, 1979).

Pupa: The full-grown larvae come out of the infested shoots and fruits and for pupate in the dried shoots and leaves or in plant debris fallen on the ground within tough silken cocoons. There were evidences of presence of cocoons at soil depths of 1 to 3 cm (Alam *et al.,* 2003). They pupate on the surface they touch first (FAO, 2003). The pupal period lasts 6 to 17 days depending upon temperature (Alam *et al.*, 2003). It is 7 - 10 days during summer, while it is 13 - 15 days during winter season (Rahman, 2006). The color and texture of the cocoon matches the surroundings making it difficult to detect.

Adult: The adult is a small white moth with 40-segmented antennae (Sexena, 1965) and having spots on forewings of 20 to 22 mm spread. Young adults are generally found on the lower leaf surfaces following emergence or hiding under the leaves within the plant canopy (Alam *et al.,* 2003). During day, they prefer to hide in nearby shady plots but at night all major activities, like feeding, mating and finding a place for egg-laying take place (FAO, 2003). Only dying adults can be found in an eggplant field.

The adult gains full maturity in 10 to 14 days. Longevity of adults lasts 1.5 to 2.4 days for males and 2.0 to 3.9 days for females. The pre-oviposition and oviposition periods range 1.2 to 2.1 and 1.4 to 2.9 days, respectively (Mehto *et al.*, 1983). The adult male dies after mating and the female moth dies after laying eggs (Kar *et al.,* 1995). The overall life cycle completes in 22 to 55 days. It gives rise five generations a year and is active throughout the year.

FAO (2003) showed the effect of climatic conditions in the life cycle of the *L. orbonalis* in eggplant. *L. orbonalis* is active in summer months, especially during the rainy season and less active from November to February. Peak populations are often reported in June-August. Development of the different stages of the insect takes longer during the winter months. *L. orbonalis* populations are reported to increase with average temperature, relative humidity and rainfall. As temperature increases and humidity decreases, fecundity increases and the duration of the life cycle decreases.

Nature and extent of damage

L. orbonalis attacks mostly on flowering, fruiting and vegetative growing stage on fruits/pods, growing points and inflorescence (CABI, 2007). The higher percent of the larvae was in fruits followed by shoots, flowers, flower buds and midrib of leaves (Alpuruto, 1994).

Within one hour after hatching, *L. orbonalis* larva bores into the nearest tender shoot, flower, or fruit. Soon after boring into shoots or fruits, they plug or clog the entrance hole (feeding tunnel) with excreta (Alam *et al.*, 2006). In young plants, caterpillars are reported to bore inside petioles and midribs of large leaves (Butani and Jotwani, 1984; Alpureto, 1994; AVRDC, 1998) thereby wilting, drop off and wither of the young shoots leading to delay on crop maturity, reduction on yield and yield parameter. Larval feeding inside the fruit results in destruction of fruit tissue. In severe cases, rotting was common (Neupane, 2001). Larval feeding in flower was rare, if happen, failure to form fruit from damaged flowers (Alam *et al.*, 2006).

Damage to the fruits, particularly in autumn, is very severe and the whole crop can be destroyed (Atwal, 1976). *L. orbonalis* is active throughout the year at places having moderate climate but its activity is adversely affected by severe cold.

Management practices of *L. orbonalis*

Resistant varieties

The use of resistant varieties is regarded as the farmer's first line of defense against pests and one of the safest and most compatible approach with other control strategies (Lit, 2009). Several attempts have been made in South Asia to develop cultivars resistant to *L. orbonalis*, but after 40 years of efforts, no commercial cultivars have been developed with appreciable level of resistance. But, it necessities the further practice in future due to its obvious usefulness (Srinivasan, 2008).

FAO (2003) documented resistant and tolerant varieties of eggplant against *L. orbonalis* in India. Pusa Purple Cluster, Bhagyamathi, Annamalai, Nurki, Singhnath (Behera, 1999), Arka Kusumakar, Nischintapur, Brinjal Long Green, Altapati, Arka Shirish, Manjpur, Makra, Chikon Long (Gangopadhyay, 1996) were tolerant, while Chaklasi Doli, Doli-5, Pusa Purple Cluster (Jyani, 1995), Long Purple (Mehto, 1981) were resistant variety against *L. orbonalis*. Local eggplant cultivars of semi arid region of Rajasthan, like Pusa Puple Long - 74 and Navkiran were found to be promising varieties with low shoot and fruit infestation (Mathur *et al.*, 2012). Srinivasan (2008) reported that eggplant accessions EG058, BL009, ISD 006 and a commercial hybrid Turbo have substantial level of resistant to *L. orbonalis*. EG203 from Philiphines is also a promising variety to yield and there were number of native and wild relatives of eggplant resistant, to be be utilized as parent material for crop improvement (Lit, 2009). Thapa *et al.* (2007) documented that hybrids were highly preferred, whereas open pollinated variety Nurki, Neelam Long and Pusa Purple Long were the least preferred genotypes in Nepal by the pest. NARC (1998) reported that Pusa Kranti and Nurki had lowest fruit infestation than Pusa Purple Long (PPL) and even local landraces.

The susceptible varieties showed higher shoot infestation as compared to resistant varieties (Kale *et al.*, 1986). Resistant varieties showed low fruit infestation. Long narrow fruited variety suffered less because of low egg laying preference compared to short and wide fruited. Because of antibiosis, resistant varieties resulted low larval survival and weight gain of pupae significantly lower (Chandha, 1993).

Dense pubescent varieties with long tuft erect trichomes on the surface distress both oviposition and hatching (Panda and Das, 1974). The wild type and other resistant varieties have high silica and crude fiver contents and comparatively less ash and crude fat protein in the shoot making unfavorable to the larval feeding and digestion (Kale *et al.*, 1986). Genotypes bearing thin fruits with short calyx and lower number of calyx with lower diameter and thin shoot are being considered tolerant to *L. orbonalis* attack (Malik *et al.*, 1986).

Sex pheromones

Sex pheromones are important component of IPM programs mainly used to monitor as well as mass-trap the male insects. The IPM strategy based on sex pheromone for managing the *L. orbonalis* has reduced pesticide abuse and enhanced the activities of natural enemies in Indo-Gangetic plains of South Asia (Srinivasan, 2012). The sex pheromone confused the male adult for mating and thus preventing fertilized egg production by trapping significant number of male moths, which resulted reduction of larval and adult population build–up (Rahman *et al.*, 2009). Thus, this technology can be expanded as IPM technology may be beneficial in holistic manner (Mathur *et al.*, 2012).

Zhu *et al.* (1987) identified (E)-11-hexadecenyl acetate as the major chemical component of *L. orbonalis* sex pheromone in China. The use of this chemical @ 300-500 μg per trap attracts the adult males in the field. The pheromone was synthesized in the laboratory and tested for its efficacy in Sri Lanka but the synethtic product was inferior to live virgin female moths (Gunawardena, 1992; Gunawardena *et al.*, 1989). However, combination of chemicals (E)-11-hexadecenyl acetate and (E)-11-hexadecen-1-ol continuously trap high number of male moths on pheromone trap and significantly reduce the pest damage in India and Bangladesh (AVRDC, 1996; Alam *et al.*, 2003; Srinivasan and Babu, 2000; Srinivasan, 2008).

In field experiment, installation of pheromone trap 65 number per hectare, starting from 15 days after transplanting till final harvest and changing the lure at monthly interval gave quite substantial protection in shoot damage (58.39%), fruit damage (38.17%) and increase in yield (49.71%) over control (Dutta *et al.*, 2011).

The studies by Cork *et al.* (2001) concluded the sex pheromone was potential component in the IPM program. Delta traps and funnel traps are useful for the adult luring by the sex pheromone in the field conditions. However, the trap design that would attract more numbers of insects varies from one location to the other.

Cultural methods

The culture techniques of pest management help to improve the plant condition in many ways. Ghimire and Khatiwada (2001) reported that cultural methods, like crop rotation and intercropping manipulate the environment to make it less favorable to pests. However, no significant result was obtained for reduction of infestation by intercropping with corn or stringbeans. Likewise, application of animal manures (cow, carabao and chicken manure) and a processed organic fertilizer (cocorich) did not significantly reduce *L. orbonalis* infestation but supported the plants with luxuriant growth especially the chicken manure (Gonzales, 1999).

The cultural practice, i.e. pruning of infested twigs and branches prevents the dissemination of *L. orbonalis* (Neupane, 2000). Similarly, the periodic pinching/pruning of wilted damaged shoot, their collection and burrying or burning helps to reduce pest infestation (Rao and Rao, 1955; Som and Maity, 1986; Ghimire *et al.*, 2001). Pruning will not adversely affect the plant growth as well as yield (Talekar, 2002). It is especially important in early stages of the crop growth and this should be continued until the final harvest. In addition, prompt destruction of pest damaged eggplant shoots and fruits at regular intervals, reduced the pest (Srinivasan, 2008). Weekly removal of damaged fruits and shoots resulted in the highest weight of healthy fruits and lowest incidence of damaged fruits among the treatments (Duca *et al.*, 2004).

The removal of the alternate food sources of the pest and mechanical barriers are some of the cultural and mechanical measures. *Solanum nigrum* Linnaeus, *Solanum indicum* Linnaeus, *Solanum torvum* Swartz, *Solanum myriacanthum* Dunal, *Lycopersicon esculentum* Mill and *Solanum tuberosum* Linnaeus were recorded as alternative host plants of the *L. orbonalis* (Murthy and Nandihalli, 2003; Reddy and Kumar, 2004).

It is better to destroy dry eggplant stalks from previous crop that serves as the pest source. It will 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 (Rahman *et al.*, 2002; Talekar, 2002; Arida *et al.*, 2003; Satpathy, 2005). The cultural practice at community level of a particular region is effective than an individual grower.

Physical or mechanical barriers

The moth is not a good flyer only flies short distances from one plant to another or from one plot to the next. So, eggplant can be protected by preventing adults by erecting suitable nylon net barrier at suitable heights (NARC, 2000). The use of barriers combined with prompt destruction of the pest significantly reduced the damage than any single methods (Alam *et al.*, 2003). The highest marketable fruit yield and as well as lowest fruit infestation for number and weight was obtained from use of barrier + clipping practices followed by the use of barrier alone but is best for farmers practice in small scale production, especially for off-season production (Ghimire, 2001).

Kaur *et al.* (1998) reported that cultivation of eggplant under net-house or poly-house is under practice in different part of the world. Further, he showed that cultivars BH-1, BH-2 and Punjab Barsati resulted in significantly higher marketable fruit yield and total fruit yield in net house than other varieties. So, there is no doubt that mechanical barrier is most efficient technology of *L. orbonalis* management, however, economic feasibility of adopting net-barriers or net-houses should be considered, while promoting this technology.

Bio-pesticides and other bio-control agents

Bio-pesticides have high compatibility with other pest management techniques, such as natural enemies, resistant varieties, etc. Therefore, it could play a vital role in IPM strategies although they cover only about 4 percent of the global pesticide market (Srinivasan, 2012). They have minimal effect on non- target organisms. Similarly, the potential human health effects are not known so far. The combination of plant products and synthetic microbial pesticides are reported to possess insect controlling properties. These insecticides can provide environmentally safe product for bio-rational management of eggplant pest.

Among the bacteria, the spore forming species, *Bacillus* spp. have been most important in insect suppression. Different commercial products of Bt are available on market and the efficacy also vary according to place and product type. Saimandir and Gopal (2012) showed that Biolep was not effective; however, PUSA Bt gave better control against *L. orbonalis* at similar dose. Chatterjee and Mondal (2012) reported that *Bacillus thuringiensis* (Berliner) performed well in reducing damage and increasing yield. Bt formulation Biolep was found to be effective than synthetic insecticide (Sharma, 2002) and efficacy increased in successive days of spray (Mainali *et al.*, 2012). However, the efficacy of Bt formulation was lower or comparative to pesticides as reported by Singh (2010) that the marketable yield from Bt formulation halt was comparatively lower but as efficient as Spinosad, Emamectin Benzoate, Diafenthiuron, Endosulfan and Indoxacarb.

Similarly, to date more than 450 viruses have been described. The majority of these cause diseases in lepidoptera, hymenoptera and diptera. The best-known virus of insect is the Nuclear Polyhydrosis Viruses (NPV). Under field condition, even lepidopteran larvae are very sensitive to these biocides (Gupta and Rosan, 1995). However, the efficacy NPV against *L. orbonalis* is lower but it can be used as one of the important options of management (Ghimire, 2001).

Under natural conditions, natural enemies keep the pest populations under reasonable control. As many as sixteen parasitoids, three predators and three species of entomopathogens have been reported as natural enemies of *L. orbonalis* from all over the world (Khorsheduzzaman *et al.,* 1998). Among them, the egg parasitoid *Trichogramma chilonis* Ishii have been demonstrated to be most effective (Krishnamoorthy, 2012) and it was slightly more efficient than *Trichogramma evanescens* Westwood in parasitizing the egg in test tube and in caged conditions. Hence, it can be further integrated with other pest management tactics to increase the yield (Gonzales, 1999). Bustamante *et al.* (1994) recorded the egg parasitoid *Trichogramma chilonis* Ishii is most effective against *L. orbonalis* that contributed highest yield followed by Endosulfan and Endosulfan + Deltamethrin, botanical and fungus *Metarhizium anisopliae* (Metchnikoff), respectively.

Sandanayake and Edirisinghe (1992) reported a high level of parasitism of *L. orbonalis* larvae by a parasitoid, *Trathala flavo-orbitalis* (Cameron) (Hymenoptera: Ichneumonidae). This parasitoid has been reported to be present in India (Naresh *et al.,* 1986) and Bangladesh (Alam and Sana, 1964), Nepal (Kafle 1970) however; its contribution to pest control has hardly been documented and does not appear to be significant. However, Srinivasan (2008) reported that practice of withholding of pesticide use to allow proliferation of local natural enemies especially the parasitoid, *T. flavoorbitalis* reduced the *L. orbonalis* population.

In Nepal, Kafle (1970) documented the endo-parasitoids, such as *Camptothlipsis* sp., *Campyloneurus mutator* Fabricius, *Chelonus* sp. and *Cremastus* (*Trathala*) *flavoorbitalis* (Cameron) (Hymenoptera) as natural enemies of the *L. orbonalis*. Even natural condition, the parasitism of *L. orbonalis* population reached on an average of 23.33 percent by hymenopterous parasite during May-June (Ghimire *et al.,* 2001). These finding necessities the need of efforts to identify local natural enemies and study their potential role in pest control. Monitoring of seasonality of pest and parasitoids, therefore, is necessary. There is also significant relationship between incidence of *L. orbonalis* in terms of shoot infestation and with coccinellids and spiders (Singh *et al.,* 2009).

Botanical pesticides

It has been found that there are many plant species available throughout the tropics so far having some kind of pesticidal properties. According to Kiritani (1979), eco-friendly, less costly measures, such as, cropping system approach, botanicals (Prakash *et al.,* 2008) are more advantageous over insecticides, as they fit well in IPM. The safer plant products are useful in developing sound pest management strategies (Gupta and Singh, 2002).

Azadirachtin or azadirachtin containing extracts from neem seeds have antifeedant and sterilent properties. It was found that azadirachtin also act as a chitin synthesis inhibitor which control over the neuroendocrine system, ecdysone and juvenile hormone synthesis. However, the result regarding use of azadirachtin based pesticides on management of *L. orbonalis* vary greatly. In the same experiment Saimandir and Gopal (2012) reported that NSKE was effective, however NimboBas non-effective. Udaiyan and Ramarathinam (1994) reported by Muregesam and Murugesh, (2009) proved the effectiveness of Nimbecidine. The product Neem cake extract @ 5 percent and *Calotropis gigantean* (Linnaeus) @ 5 percent were also quite effective in *Kharif* crop reducing fruit damage by more than 50 percent.

The oil product of botanicals was found to be efficient for *L. orbonalis* management. Neem oil @ 2 percent was the best treatment both in *Kharif* (60.20%) and *Rabi* (59.91%) followed by Nimbecidine @ 2 ml/litre (57.42%) (Murugesam and Murugesh, 2009). Several earlier workers have also demonstrated the effectiveness of Neem oil against *L. orbonalis* (Udaiyan and Ramarathinam, 1994). Similarly, Mathur *et al.* (2012) showed that 2 percent of newer botanical oils of Pungam (*Pongamia pinnata* Linnaeus) and Iluppai (*Madhuca indica* Gmelin) in IPM modules proved to be quite effective in lowering both shoot and fruit infestation and can thus be utilized in resistance management strategy.

All the botanicals, such as Ecogold @ 10 ml/litre of water; Alata soap @ 5 g/litre of water; Garlic @ 30 g/litre of water; Neem oil @ 3 ml/l of water); Papaya leaves @ 92 g/litre of water and Wood ash @ 10 g/plant significantly reduced the different pest of eggplant including *L. orbonalis*. Therefore, it is considered as pest management options to reduce insect pest populations and increase eggplant productivity (Mochiah *et al.,* 2011).

Among many other plant products, Chitra *et al.* (1993) reported the ether extracts of *Aregemon maxicana* Linnaeus 0.1 percent was comparable to Monocrotophos 0.04 percent and Endosulfan 0.07 percent. Equally effective were *A. indica* A. Juss. and *Annona squamosa* Linnaeus against eggplant pest complex including *L. orbonalis* with first spray 3 days after transplanting and later 3 at fortnightly intervals.

Chemical methods and their adverse effects

The farmers depend on chemicals right from the land preparation and seed sowing to final harvest and marketing of eggplant. The farmers' knowledge and traditional pest management are invaded and destroyed with the increased use of modern agrochemicals (Pandey, 1993).

Chemicals, like Carbofuran, Aldicarb granules, Phorate, Mephofolan, Dimethoate, Carbaryl, Dizinon or Difolatan were used in soil in various concentrations (Mote, 1976;

Gupta *et al.*, 1989). Carbosulfan having different trade names are widely used and verified as efficient chemical. It (Marshal 20 EC @ 1.5 ml LG1) performed the best ensuring the lowest shoot and fruit infestation, which was followed similar dose of Cartap Hydrochloride (Suntap 50 SP). Carbosufan and Cartap Hydrochloride also performed the best among insecticides by ensuring the highest healthy fruit yield followed sex pheromone and other options as compared to untreated check (Rahman *et al.*, 2009). In both laboratory and field trial, the Carbosulfan 20 EC and Flubendiamide 24 WG showed higher efficacy in terms of increment on healthy fruits and reduction of shoot and fruit infestation. This was followed by Cartap and Thiodicarb with moderate efficacy in both the season (Latif *et al.*, 2010).

Results showed that Flubendiamide, Spinosad and Chlorfenapyr were highly effective in reducing the damage caused by *L. orbonalis* on eggplant and led to increases in yield. Emamectin Benzoate, Methoxyfenozide and *Bacillus thuringiensis* (Berliner) also performed well in reducing damage and increasing yield (Chatterjee and Mondal, 2012). A pesticides belonging to newer molecule, Abamectin significantly incurred highest marketable yield and lower shoot/fruit infestation (Mainali *et al.*, 2012).

On the basis of the pooled means, the results revealed that three sprays of Chlorpyriphos + Cypermethrin @ 0.01 percent a.i. in 15 days intervals was found to be the most economical, resulting in minimum shoot (2.15%) and fruit (12.95%) infestation, followed by alphamathrin @ 0.01 percent a.s. with a highest marketable yield of 87.77 q/ha. It is therefore, suggested that the combination of Chlorpyriphos 50% EC + Cypermethrin 5% EC, being the most effective and economically viable insecticide, can be utilized as a valuable chemical component in Integrated Pest Management for *L. orbonalis* in eggplant crop (Sharma *et al.*, 2012).

The results on bio-efficacy of insecticides showed that Emamectin Benzoate (0.002%) and Endosulfan (0.05%) were found superior in terms of shoot infestation and reduction of fruit infestation. Novaluron (7.00) followed this in terms of shoot infestation, while Agrospray oil (0.2%) and Spinosad in terms of reduction in fruit infestation. However, cost benefit ratio was the highest in Agrospray oil (0.2%) followed by Lambda-cyhalothrin (0.004%), Endosulfan (0.05%) and Deltamethrin (0.0028%) (Sharma and Sharma, 2010).

The results of chemical control trial indicated that Protenfos @ 0.1 percent was the most effective followed by Spinosad @ 0.01 percent individually and their combinations with Novaluran in reducing the population as well as in giving higher yield (Singh *et al.*, 2009). Adiroubane and Raghuraman (2008) suggested that Spinosad (45 SC @ 225 g a.i. /ha) was found to be effective along with Oxymatrine (1.2 EC @ 0.2%) against *L. orbonalis*. Spinosad was superior in terms of marketable yield as it reduced the fruit damage and was on par with oxymatrine.

Abrol and singh (2003) showed the efficacy of various insecticides either alone or in combination. The efficacy was in the order Endosulfan + Deltamethrin (0.07%, 0.0025%) = Endosulfan + Fenvalerate (0.07% + 0.005%) Carbaryl + Fenvalerate = Dichlorvos + Fenvalerate (14.9%) > Malathion + Fenvalerate (16.4%) > Fenvalerate + Deltamethrin (16.6%) > Dichlorvos = Carbaryl + Deltamethrin = Malathion = Dichlorvos + Deltamethrin = Malathion + Deltamethrin (18.3%) > Endosulfan (20.0%) > Carbaryl (21.6%) with mean percent of damage 13.3 14.9, 16.4, 18.3, 20.0, 21.6 and 69.8%, respectively. Among the various combination, Carbaryl was the least effective (225.7 q/ha) but its combinations with pyrethroids proved superior over carbaryl alone. The combination of Dichlorvos + Fenvalerate combination gave the highest yield of 263.45 q/ha. Srivastav and Singh (1974) reported the efficacy of insecticide against *L. orbonalis* with urea were more effective than insecticide alone.

The excessive use of chemical pesticides has destroyed natural enemies of *L. orbonalis*, resulting in a resurgence of the pest's population (Baral *et al.*, 2006). AVRDC (1994) reported that farmers use insecticides up to fifty sprays in 5/6 months crop season. The over uses of pesticides resulted resurgence of *Thrips palmi* Karny. The fresh eggplant on sale at market had residue of Malathion, Parathion, Fenitrothion 0.64, 0.36 and 0.64 ppm, respectively (Thapa, 1997). Thirty days after spraying the various parts shows residue of 1.5 to 4.0 ppm except during December, January when it was 7 ppm on fruits and 11.7 ppm on leaves. The residue of Endosulfan last longer than 15 days and safe period is 15.97 and 14.89 days, respectively at 0.5 and 1.0 kg a.i./ha on eggplant during fruiting stage. Teotia and Singh (1971) recorded relative toxicity increasing among the chemicals Malathion, Thiometon, Diazonon, Fenitrothion, Chlorodane, Dichlorovos, Heptachlor, Isobenzene, Endrin, Carbaryl, Dieldrin based on LD_{50} value.

Integrated pest management

The integrated pest management (IPM) strategy for the control of *L. orbonalis* consists of resistant cultivars, sex pheromone, cultural, mechanical and biological control methods (Srinivasan, 2008). Successful adoption of IPM in eggplant cultivation increase profits, protect the environment and improve public health (Alam *et al.*, 2003).The profit margins and production area significantly increased, whereas pesticide use and labor requirement decreased for those farmers who adopted the IPM technology. But, the efforts to expand the *L. orbonalis* IPM technology to other regions of South and Southeast Asia are underway (Srinivasan, 2008).

Use of crop management practice in IPM model is easy method of pest management. The interaction of intercrop and antifeedant showed that coriander-intercropped eggplant along with foliar spray of Neemarin significantly reduced fruit damage (Satpathy and Mishra, 2011).

Different researcher developed the different module of pest *L. orbonalis* management. Chakraborty and Sarkar (2011) found that integration of phytosanitation, mechanical control and prophylactic application of Neem Seed Kernel Extract (NSKE) exerted a satisfactory impact on the incidence and damage of *L. orbonalis*. Sanitation and destruction of alternate host reduces the pest damage to fruit if such practice is coupled with other community wide means to reduce immigration of pest adults into the area (Alam *et al.*, 2003).

Use of pheromone and microbial is compatible strategy in pest management. Krishnamoorthy (2012) indicated that integration of egg parasitoid release with NVP, Neem and pheromone trap has been proved as possible in IPM modules. Out of different module tested by Dutta *et al.* (2011), the module with three different component, *viz.* pheromone trap, mechanical control and application of Peak Neem (neem based insecticide) was found best in reduction of shoot damage, fruit damage and yield increment followed by pheromone trap + Peak Neem in terms of shoot damage, farmers practices in terms fruit damage and pheromone trap + Peak Neem in terms of yield increment. The integration of *T. chilonis* and sanitation reduced infestation of *L. orbonalis* by 15 to 35 percent in the field and increased yields by 35-100 percent (Gonzales, 1999).

Again, the use of insecticides based on different chemistry and with varying modes of action is an important component of an IPM strategy. Hence, insecticides continue to be an integral component of pest management programs due mainly to their effectiveness and simple use (Braham and Haji, 2009). Use of pesticide was not suggested at first hand but judicious use as last option of pest management was suggested globally.

Chakraborty (2012) demonstrated the efficient model of IPM based on yield. They are i) need-based application Flubendiamide together with NSKE, NLE, Deltamethrin + Trizophos; ii) application of new molecule of Rynaxypyr, NLE, NSKE, Clorpyriphos; iii) NSKE, Emamectin Benzoate, NLE , Clorpyriphos, Neem and Oil. The efficacy of first one is the highest and lowering on later.

The use practice of pesticides of different group was proved efficient by Abrol and Singh (2003) that Endosulfan + Deltamethrin (0.07%, 0.0025%) and Endosulfan + Fenvalerate (0.07% + 0.005%) were highly effective against *L. orbonalis* that recorded only 13.3 percent damage as compared to 69.8 percent in control.

The combination of compatible tactics was always superior. Any single option, such as sole mechanical control, schedule spray of Carbosulfan at 7 days interval or sole sex pheromone trap was inferior to any of other combined options and the combinations of options resulted lowest damage shoot/fruit compare to control. Thus, combination of three options produced with the highest yield of healthy fruits as well as maximum BCR (Rahman *et al.*, 2009).

The model of IPM having shoot clipping with alternate spraying of Multineem and Trizophos plus Deltamethrin was given by Bhushan *et al.* (2011) with minimum shoot and fruit damage and maximum yield. Sharma *et al.* (2012) reported that the treatment including pesticides and botanicals combined with cultural method lowered shoot/fruit damage and increased fruit yield.

In addition, Latif *et al.* (2009) used the potash in IPM module suggesting that the application of flubendiamide at 5 percent level of fruit infestation in combination with mechanical control + potash @ 100 kg/ha + field sanitation for the management of *L. orbonalis*.

Although various IPM strategies have been developed and promoted for vegetables, adoption remains low due to IPM's limited effectiveness in managing insect pests compared with chemical pesticides. Moreover, IPM has been promoted as a combination of techniques without giving due consideration to the compatibility of each component (Srinivasan, 2012).

Conclusions

A practically monophagous key pest of eggplant, *Leucinodes orbonalis* Guenee distributed throughout the tropics but most important and first ranked pest of South-East Asia. The boring nature as well as short life cycle of the pest made it worst in this region. The various integrated pest management practices are suggested. The use of resistant varieties are regarded as first line of defense, however no resistant varieties with appreciable level of resistance have been developed so far. Mass trapping of pest can be done by use of lucin-lure, installing 65 numbers per hectare starting from 15 days after transplanting till final harvest. In addition, the plant condition can be improved by cultural and mechanical practices like intercropping, periodic pruning of infested twigs and branches, removal of alternate host, adopting net barriers or net height etc.

Oil and extract of different plant, like Neem, Pungam, Iluppai etc. found to be effective against the pest. The microbial *Bacillus thuringiensis* var. *Kurstaki* were also found to be effective. The egg parasitoid, *Trichogramma chilonis* Ishii and larval parasitoid, *Trathala flavo-orbitalis* (Cameron) can be utilized as means of potential parasitoids of this pest. To escape from development of pest resistance, the newer molecule of pesticides like, Spinosad, Emamectin benzoate, Abamectin would be better if above practices of non-chemical means of pest management do not keep the pest population below economic threshold level. To protect environment and public health, the compatible use of above practices as means of IPM in community level would be better than that of any single method.

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