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Safe Management of Borers in Vegetables

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Borer pests cause significant yield losses and are one of the most serious production constraints in tropical vegetable production. For instance, eggplant fruit and shoot borer (EFSB), *Leucinodes orbonalis* Guenée (Lepidoptera: Pyralidae) reduces yield as much as 70% (Dhandapani *et al.,* 2003). Tomato fruit borer, *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae) causes about 5 to 55% loss in almost all the tomato producing areas in the world (Kashyap and Batra, 1987). Up to 80% yield losses have been reported in various vegetable and grain legumes due to legume pod borer (LPB), *Maruca vitrata* F. (Lepidoptera: Pyralidae) damage (Singh *et al.,* 1990; Sharma, 1998; Gressel *et al.,* 2004; Hammig *et al.,* 2008; Zahid *et al.,* 2008). Due to higher yield losses, growers tend to apply extremely high quantities of chemical pesticides to control borer pests on vegetable crops. Because the borer larvae are exposed on external plant parts only for a brief time after hatching, the window for effective pesticide application is very brief; vegetable farmers spray throughout the growing season, but without satisfactory results. A 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 (SUSVEGAsia, 2007). Pesticide application often exceeded 50 sprays per tomato crop season in south India (Nagaraju *et al.,* 2002). In Bangladesh, country bean (*Lablab* *purpureus*) is being sprayed at weekly or biweekly intervals—sometimes every day—to control LPB (Hoque *et al.,* 2001). On average, farmers used 10-24 kg/ha of pesticides in cabbage and cauliflower in India to manage the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae) and other pests (Weinberger and Srinivasan, 2009).

Excessive pesticide use adversely affects human health and increases the cost of production, making vegetables expensive for consumers. For instance, the share of pesticides to total material input costs was 55% for eggplant, followed by tomato (31%) and cabbage (49%) in the Philippines (Orden *et al.,* 1994). It was 40-50% on eggplant in Bangladesh (SUSVEGAsia, 2007). It is unlikely that any single method of pest management such as chemical pesticides can achieve a level of borer pest control acceptable to vegetable producers. Therefore, integrated pest management strategies have been developed and are being promoted among growers in South and Southeast Asia. This chapter aims to compile simple, affordable, safe and environmentally sound control technologies for the management of key borer pests on tropical vegetable crops.

1. Eggplant Fruit and Shoot Borer, *Leucinodes Orbonalis* Guenée (Lepidoptera: Pyralidae)

Eggplant fruit and shoot borer is mostly monophagous, although sometimes it feeds on tomato, potato, *Solanum indicum* L., *S. xanthocarpum* **Schrad**. & Wendl., *S. torvum* Swartz., and *S. nigrum* L. (David 2001; Alam *et al.*, 2003). During the early vegetative phase of the crop, the larva feeds inside the tender shoots, which results in wilting of young shoots, followed by drying and drop-off. The pest prefers to feed on the fruit during the fruiting stage of the crop; damaged fruit exhibits boreholes on the surface that often are sealed with excreta, rendering the fruit unfit for marketing and consumption.

Management

1.1. Cultural practices

As EFSB is practically a monophagous insect on eggplant, discontinuation of eggplant cultivation in a community for a few seasons will significantly reduce populations of this pest. Eggplant seedlings should not be grown near fields with previous or existing crops, or near dried eggplant heaps (Alam *et al.,* 2003). If seedlings must be grown in those areas, the seedling beds should be covered with 30-mesh nylon net to prevent the entry of EFSB moths and thus egg laying.

1.2. Host plant resistance

Planting resistant or moderately resistant cultivars can deter EFSB. For instance, accessions or varieties such as EG058, Pusa Purple Long, Pusa Purple Cluster, Pusa Purple Round, Banaras Long Purple, Arka Kesav, Arka Kusmakar, Punjab Barsati, Punjab Chamkila, and Kalyanpur-2 have been reported to be tolerant or resistant (Parker *et al.*, 1995; Alam *et al.,* 2003; Shivalingaswamy and Satpathy 2007). Except for EG058, which is an AVRDC accession, most of the varieties noted originated in India.

1.3. Mechanical control

Prompt removal and destruction of infested shoots and fruit at regular intervals until final harvest significantly reduces EFSB damage (Alam *et al.,* 2003). However, growers sometimes leave the culled shoots and fruit in or around the field, where the discarded plant material may serve as a source for future infestation. Pruning and destroying infested material is most effective when a whole community in a particular region follows the practice, rather than only an individual grower. Pruning does not adversely affect the plant growth or yield (Srinivasan and Huang, 2009).

1.4. Biological control

Parasitoids such as *Trathala flavoorbitalis* (Cameron), *Eriborus sinicus* Holmgren, and *Pristomerus testaceus* Morley are commonly found occurring on EFSB larvae (AVRDC, 1996a; Alam *et al.,* 2003). Reduced use of synthetic pesticides enhances the activities of these natural enemies. In addition, weekly releases of egg parasitoid *Trichogramma chilonis* Ishii @ 1g parasitized eggs/ha/week, and larval parasitoid *Bracon hebetor* Say @ 800-1000 adults/ha/week are effective in reducing EFSB (Alam *et al.,* 2006).

EFSB sex pheromone lures in traps can be installed at the rate of 100 traps per hectare (Cork *et al.,* 2003) to reduce fruit damage and increase yield. Traps should be placed either at canopy level or at slightly above the canopy level for effective attraction (Alam *et al.,* 2003).

2. Tomato Fruit Borer, *Helicoverpa Armigera* Hub. (Lepidotera: Noctuidae)

The tomato fruit borer is a polyphagous and highly mobile insect. It is a serious pest, causing significant yield losses in agricultural and horticultural crops. It has been recorded as a damaging pest on 181 cultivated and wild plant species in at least 45 families (Venette *et al.,* 2003; Srivastava *et al.,* 2010). The older larvae prefer to feed on flowers and young fruits. The larvae make holes and feed by thrusting their heads inside. The holes are circular and often surrounded by fecal pellets.

2.1. Cultural practices

Crop rotation with non-host crops is effective in managing the tomato fruit borer, because the insects emerging from pupae in the soil in the present season (especially in locations where *H. armigera* diapause during winter) which pupated during the previous crop cycle pose a serious threat. African marigold (*Tagetes erecta* L.) can be planted as a trap crop to reduce the incidence of *H. armigera* (Srinivasan *et al.*,1994). It is important to synchronize transplanting of both crops so that flowering coincides, which attracts *H. armigera* female adults. Tropical soda apple (*Solanum viarum* Dunal) also can be used as an effective trap crop to manage *H. armigera* (AVRDC, 2000; 2001).

2.2. Host plant resistance

Although resistant tomato cultivars can reduce pest damage, commercial cultivars with appreciable levels of resistance are not yet available. Germplasm screening at AVRDC – The World Vegetable Center revealed the presence of high levels of fruit borer resistance only in the wild *Solanum* species, particularly *S. habrochaites* and *S. pennellii*. Efforts to introgress resistance from the wild species into cultivated tomato resulted in small-fruited resistant accessions (Talekar *et al.,* 2006).

2.3. Biological control

H. armigera sex pheromone traps can be used to monitor, mass-trap, or disrupt the mating of male moths. Although sex pheromone traps baited with *H. armigera* pheromone lures can be used to trap more males, this method is less effective for polyphagous insects like *H. armigera.* Polyphagous populations are always higher due to the availability of multiple host plants in the tropics and two population parameters *viz.,* density and polymorphism, are important factors that affect the trap catches of *H. armigera* males (Kumar and Shivakumara, 2003). Placing a high concentration of sex pheromone (all or one component of the multi-component pheromone) in a slow-release formulation on a 5- and 10-m grid in the field results in a drastic reduction in male moths, which adversely affects mating in *H. armigera* (AVRDC 1988).

Egg parasitoids (*T. pretiosum* Riley and *T. chilonis*) and larval parasitoids (*Campoletis chlorideae* Uchida) can be conserved and/or released in tomato fields at regular intervals to check the build-up of *H. armigera* (Ballal and Singh, 2003; Gupta *et al.,* 2004). In addition, commercially available biopesticides based on *Bacillus thuringiensis*, *Helicoverpa armigera* nucleopolyhedrovirus (HaNPV) and neem (*Azadirachta indica* A. Juss.) can be used against *H. armigera*.

2.4. Chemical control

Chemical pesticides are widely used against this pest and they are effective against the early larval stages, before the larvae enter into the floral buds or fruit. Pesticide spraying should be scheduled soon after noticing the eggs or during early larval stages. It is advisable to follow a proper pesticide rotation. Before application, it is important to check the effectiveness of chemical pesticides in the region and their registration status for tomato.

3. Legume Pod Borer, *Maruca vitrata* F. (Lepidoptera: Pyralidae)

Legume pod borer is considered the most serious pest of vegetable and grain legumes in tropical Asia and Africa (Sharma, 1998). LPB larvae feed on floral buds, flowers, and pods by webbing. They occasionally feed on the peduncle and stems (Taylor, 1967). A total of 39 host plants of LPB, including two non-leguminous hosts (Rathore and Lal, 1998), have been reported. Although two other species, *M. amboinalis* and *M. nigroapicalis,* were observed in the Indo-Malaysian and Tonkin area, *M. vitrata* is believed to be the predominant species causing severe economic losses in food legumes.

3.1. Host plant resistance

Although *M. vitrata* is an economically important pest on several food legume crops, it is quite important in mungbean, yard-long bean and cowpea. Only 12 mungbean accessions were identified as resistant to *M. vitrata* in a germplasm screening of more than 6000 accessions

(AVRDC, 1993a; 1994; 1996a). V 1649, V 1857, V 3274, V 3276 and V 3279 are some of the highly resistant accessions. Similarly, intensive research on *M. vitrata*-resistant cowpea has been carried out at the International Institute of Tropical Agriculture in Nigeria, where more than 8000 accessions were screened (Brink and Belay, 2006). Although a few *Vigna vexillata* accessions and the wild cowpea cultivar TVu 946 have good resistance to *M. vitrata*, the crosses between *V. vexillata* accessions and cultivated lines were not successful (Fatokun 2002), and the crosses of cultivated lines with TVu 946 had produced progeny with unacceptable agronomic characters and an inadequate level of resistance (Singh, 1985). Thus, there is virtually no cultivar available with demonstrable resistance against *M. vitrata* (Machuka, 2002).

3.2. Biological control

Sex pheromone compounds already have been identified in *M. vitrata*, consisting of one major compound and two minor compounds. When the major and minor compounds were formulated in a ratio of 100:5:5 for lures, they attracted large numbers of male moths in Benin and Ghana; however, the major compound alone attracted a significantly higher number of moths in Burkina Faso, compared to the lures based on major and minor compounds (Downham *et al.,* 2004). The major compound either alone or combined with (E)-10-hexadecenol in 90:10 ratio [(E)-10-hexadecenol was not reported from *M. vitrata*] attracted a significantly higher number of male moths in Andhra Pradesh, southern India (Hassan, 2007). Pheromone traps could be used against *M. vitrata*, but the traps need some refinement to be suitable to a specific local environment.

Although a substantial number of parasitoid species have been reported to attack *M. vitrata* in tropical Asia and Africa, a few selected candidates are quite promising. A strain of *Apanteles taragamae*, a solitary braconid endoparasitoid, parasitized as high as 63% of *M. vitrata* in Taiwan (Huang *et al.,* 2003). Another braconid wasp, *Bassus asper,* was the most prevalent parasitoid with parasitism rates up to 17.1%; it was found in all cropping periods in the Philippines (Ulrichs *et al.,* 2001). *Phanerotoma leucobasis,* the predominant braconid wasp, inflicted about 30% parasitism in Benin (Arodokoun *et al.,* 2006). Recently, *P. philippinensis* was found to be the most effective egg-larval parasitoid of *M. vitrata* in Thailand (Yule and Srinivasan, 2012). In addition, *Therophilus marucae* (Braconidae) was found to occur widely in Vietnam, Lao PDR and Taiwan (Srinivasan *et al.,* 2012). Hence, conserving and/ or releasing these candidates in food legume fields at regular intervals could contain the build-up of *M. vitrata*.

Biopesticide formulations could effectively reduce the incidences of *M. vitrata*. Several isolates of *Beauveria bassiana* and *Metarhizium anisopliae* were highly pathogenic to the eggs (achieving 89–100% mortality) and larvae (94–100% mortality) of *M. vitrata* (Ekesi *et al.,* 2002). *Maruca vitrata* multiple nucleopolyhedrovirus (MaviMNPV), discovered and characterized at AVRDC (Lee *et al.,* 2007) is effective in managing *M. vitrata* either alone or in combination with other biopesticides and natural enemies (Srinivasan *et al.,* 2009; Tamo *et al.,* 2010). Formulations based on *B. thuringiensis* subsp. *kurstaki* and *B. thuringiensis* subsp. *aizawai* were highly effective in reducing damage of *M. vitrata* on vegetable legumes (AVRDC, 1996a; 1997), as the larvae are highly susceptible to different *B. thuringiensis* toxins such as Cry1Ab and Cry1Ca (Srinivasan, 2008). Thus, different biopesticides could be used to manage *M. vitrata* on food legumes.

3.3. Chemical control

Chemical pesticides are widely used against *M. vitrata*. Although pesticides are effective against early larval stages especially before the larvae enter the floral buds or pods, indiscriminate use leads to the development of pest resistance (Ekesi *et al.,* 1999). A proper pesticide rotation must be followed. Before application, it is important to check the effectiveness of chemical pesticides in the region and their registration status for vegetable legumes.

4. Bean Flies, *Ophiomyia* spp. and *Melanagromyza sojae* (Diptera: Agromyzidae)

Three species of bean flies *viz*., *Ophiomyia phaseoli, O. centrosematis* and *Melanagromyza sojae* are important pests of food legumes including soybean and mungbean in tropical and subtropical Asia. The larvae attack young plants, especially in the first three to four weeks after germination, and complete destruction of the crop is common. Swollen and cracked stems, wilted or dead seedlings are common symptoms of bean fly attacks; the leaves of older plants under attack may be yellow and stunted. Although they occur throughout the year, bean flies only cause severe damage in dry seasons, especially during the fall (Talekar and Chen, 1983).

4.1. Host plant resistance

AVRDC has identified sources of resistance to bean flies in selected vegetable legumes. About 9000 soybean accessions were tested against bean flies; however, only ten *Glycine soja* and two *Neonotonia wightii* accessions proved to be resistant to *M. sojae* (Chiang and Talekar, 1980; AVRDC, 1987). Two *G. max* accessions (PI 227687 and PI 171444) were found to be moderately resistant to *O. phaseoli* (Talekar and Tangkano, 1993). More than 3700 mungbean accessions were screened against bean flies; however, only three accessions (V 2396, V 3495 and V 4281) were consistently resistant to bean flies in Taiwan (Chiang and Talekar, 1980). Since V 4281 was the most resistant accession, it was crossed with a susceptible, but high yielding accession, V 2184. Five breeding lines from this cross, *viz.,* VC 2839-56, VC 2839-70, VC 2839-71, VC 2839-75 and VC 2839-89 in the F_8 generation were selected because of their higher yield potential and level of resistance comparable to V 4281 (Talekar, 1987). Sources of resistance to *O. phaseoli* exist in common bean and cowpea (Talekar, 1990). However, concerted efforts are required to develop agromyzid resistant vegetable legumes.

4.2. Cultural control

Various cultural practices such as ridging of young plants, planting of vegetable legumes after a green manure crop, crop rotation, and mulching with rice straw enhance plant growth and induce tolerance to bean fly damage. Late plantings should be avoided, since infestations of bean fly are heavier then (Parker *et al.,* 1995).

4.3. Biological control

About 26 eulophid and four braconid parasitoids were reported to attack the agromyzid bean flies (Konishi, 2004). However, these parasitoids may not play any significant role in checking the bean fly population because the concealed immature stages such as larvae and pupae of bean flies reduce the effectiveness of most natural enemies.

4.4. Chemical control

Treating seed with systemic chemical pesticides before sowing, or applying pesticides to the soil when seed is sown, can provide adequate control of bean flies for two to three weeks (Parker *et al.,* 1995; Rahaman and Prodhan, 2007). One or two additional foliar sprayings may be necessary to protect the crop.

5. Diamondback Moth, *Plutella xylostella* (Lepidoptera: Plutellidae)

Diamondback moth (DBM) is a cosmopolitan and destructive insect pest of vegetable brassicas. The larvae feed and create holes in the leaves; however, severe damage is caused when the larvae tunnel into the heads of crops like cabbage, sometimes causing almost 100% crop loss. Hence, pesticides still occupy the predominant role in managing DBM. Due to extensive and inappropriate pesticide use, DBM has developed resistance to almost every class of insecticide that has been used against it, including novel insecticides such as chlorantraniliprole and flubendiamide (Sukonthabhirom *et al.,* 2011) and biopesticides such as *B. thuringiensis* (Tabashnik *et al.,* 1990). A recent conservative estimate of total costs associated with DBM management is about US$4-5 billion (Zalucki *et al.,* 2012).

5.1. Cultural control

Trap cropping with Indian mustard (*Brassica juncea*) is an effective way of reducing DBM damage. Growing of two rows of mustard between every 25 rows of cabbage as a trap crop is suggested. One row of mustard should be sown 15 days before cabbage planting, so that mustard attains a height of about 6-8 cm and provides thick and bushy foliage to help attract early DBM arrivals. Mustard starts flowering about 40 days after sowing and stops producing new foliage. This results in onset of senescence and leaves become unsuitable for larval feeding. To maintain continuous foliage, a second sowing is recommended in the adjacent ridge on the 25th day after planting cabbage (Srinivasan and Krishnamoorthy 1992). This method is commonly known as sequential trap cropping (Shelton and Badenes-Pérez, 2006). The first and last row of plots also should be planted with the trap crop. The DBM colonize on the trap crop, averting damage on the main cabbage crop. The trap crop should be sprayed with chemical pesticide.

Yellow rocket, *Barbarea vulgaris* var. *arcuata* can be used as a dead-end trap crop for the DBM. Yellow rocket is highly attractive to DBM, but DBM offspring cannot survive on it. Dead-end trap crops do not require any pesticide treatment to prevent pest populations from moving onto the main crop. The dead-end trap crop should be planted in field borders where it can intercept DBM adults and thus reduce damage on the main crop (Shelton and Badenes-Pérez, 2006).

5.2. Mechanical control

Brassica seedling production can be carried out under 32-mesh nylon net to reduce DBM infestation early in the season. Growers can thus reduce the amount of chemical pesticides used at the beginning of the crop cycle, which will help to protect natural enemies. In peri-urban areas where the brassicas are grown on smaller farms, plots can be confined with 32-mesh nylon net barriers on all four sides using a 2-m high net barrier (AVRDC, 2000; 2001).

5.3. Biological control

Traps baited with female sex pheromone lures can be placed at the rate of 50 per hectare randomly in the field, and replaced twice during the season (AVRDC, 1991). A recent study has shown that sex pheromone traps installed at the rate of 30-45 traps/ha were effective for controlling DBM in the field, and reduced insecticide use by 30% per planting season in southwestern China (Zhao *et al.,* 2011). It must be noted that different DBM populations may react differently to the same sex pheromone lure (Feng *et al.,* 2011). Hence, the pheromone lures should be validated in a new region before using them as a pest management tool.

Releasing the egg parasitoid, *Trichogrammatoidea bactrae,* once a week for six weeks starting within a week after transplanting brassicas is a recommended method to manage DBM (AVRDC, 1991). Release of a larval parasitoid (*Diadegma semiclausum*) and the pupal parasitoid (*Diadromus collaris*) significantly reduced damage from DBM in highland areas. The larval parasitoid *Cotesia plutellae* is well-adapted to manage DBM in lowlands. Unlike the egg parasitoid, augmentative releases for the larval and pupal parasitoids at regular intervals are not necessary. These larval and pupal parasitoids already have been introduced into several countries in Asia (AVRDC, 1993b; 1996b).

Although DBM was the first insect to develop resistance to Bt toxins in open field conditions (Tabashnik *et al.,* 1998), diligent deployment of *B. thuringiensis* biopesticides still offers significant protection of brassica crops from DBM damage. For example, the toxins Cry1Ac, Cry1Aa and Cry1Ca were equally toxic to the DBM population in southern Taiwan (Srinivasan and Hsu, 2008). Cry1Ba2 was more toxic to larvae of *DBM* than Cry1Ca4 (Shelton *et al.,* 2009). Hence, for effective treatment, it is important to choose *B. thuringiensis* formulations based on the most sensitive Bt toxin. Because *B. thuringiensis* biopesticides are not harmful to DBM parasitoids, both these components synergistically reduce DBM damage. Strains of entomopathogenic fungi such as *Metarhizium anisopliae* were also effective against DBM (AVRDC, 1999). Improved formulations of *Beauveria bassiana* showed promising prolonged impact in suppressing DBM populations in field conditions (Ghosh *et al.*, 2011). Biological control is an integral component in the sustainable management of DBM.

5.4. Chemical control

Pesticide misuse can accelerate the development of resistance in pests such as DBM. Utmost care should be taken when selecting chemical pesticides to use against DBM. For instance, use of broad-spectrum chemical pesticides early in the season often disrupts the control exerted by natural enemies (Talekar and Shelton, 1993). For effective integration of chemical pesticides with other DBM pest management components, countries should have a national DBM integrated pest management program that involves various stakeholders in different states or provinces. For example, based on pesticide use patterns and pest population pressure, the year was divided into two relatively equal periods (windows) in Australia; different pesticides registered for DBM control on vegetable brassicas were allocated to one of the two windows (Baker, 2011). However, because of the differences in the crucifer pest complex, timing of the peak periods of DBM pressure, and consequent pesticide use patterns in different regions, three different regional versions of the strategy, each with different calendar dates for the two window periods were devised (Baker, 2011; Ridland and Endersby, 2011). The rotation and windows approach for pesticide application can effectively manage DBM on vegetable brassicas.

6. Cabbage Head Caterpillar, *Crocidolomia binotalis* (Lepidoptera: Pyralidae)

It is interesting to note that cabbage head caterpillar (*C. binotalis*, CHC) was the most destructive insect pest on vegetable brassicas in the Old World before the use of chemical pesticides (Smyth *et al.*, 2003a). However, CHC may resurge as a serious pest due to the lack of effective bio-control agents and pesticide resistance, especially when DBM is brought under reasonable control by a guild of parasitoids. The early instar larvae migrate toward the growing center of vegetable brassicas such as cabbage, where they conceal themselves in webbing. Subsequent feeding can damage the plant's apical meristem and thus destroy the entire crop (Smyth *et al.*, 2003b).

6.1. Cultural control

Trap cropping with Indian mustard is effective against CHC (Srinivasan and Krishnamoorthy 1992). Clean cultivation is recommended, because CHC can feed and develop on certain indigenous vegetables such as African cabbage (*Cleome gynandra*), or other *Cleome* spp. that often grow as weeds.

6.2. Mechanical control

Erecting nylon net barriers around vegetable brassica plots prevents the entry of CHC adults and thus reduces larval damage. A 2.3-m high nylon net should be attached to a 2-m high framework with a 30-cm lip extending outward and downward at an angle of 80-85° to the walls (AVRDC, 1999). However, a barrier net alone is not adequate to achieve satisfactory control and it should be integrated with other compatible pest management components.

6.3. Biological control

Although male CHC moths responded to sex pheromone lures in the laboratory, the lures did not attract the pests in the field in Taiwan (AVRDC, 1996a). However, traps baited with a 10:1 mixture of (*Z*)-11-hexadecenyl acetate and (*Z*)-9-tetradecenyl acetate attracted significantly high numbers of male moths in vegetable brassica fields in Indonesia (Adati *et al.*, 2007). It is possible that pheromone lures can be developed as a monitoring and/or mass-trapping tool in CHC management.

A generalist egg parasitoid, *T. chilonis,* was found to efficiently parasitize egg masses of CHC in Samoa (Uelese *et al.,* 2011). Although further detailed studies of CHC biology and ecology and its potential host range are required before further recommendations can be made, there exists evidence for the development of *T. chilonis* as a biological control agent of CHC. Although the polyphagous pentatomid bug, *Eocanthecona furcellata,* predates more than 70% of the third instar CHC larvae, the searching ability in the field decreases (AVRDC, 1996a). Because there is no species-specific efficient parasitoid available for CHC, the potential of *T. chilonis* and *E. furcellata* can be studied in detail in further experiments.

B. thuringiensis-based biopesticides are an effective tool against CHC. This pest is quite susceptible to most of the Cry1A toxins such as Cry1Aa, Cry1Ab, and Cry1Ac (Srinivasan and Hsu, 2008) and to *B. thuringiensis* subsp. *kurstaki*- based formulations (Ooi, 1980; Sastrosiswojo and Setiawati, 1992; Malathi and Sriramulu, 2000), in which the Cry1A toxins are the major components. A recent study has shown that CHC is susceptible to Cry1Ba and Cry1Ca (Shelton *et al.*, 2009). *B. thuringiensis* subsp. *aizawai*- based formulations, in which the Cry1C toxin is the major component, could also be used.

6.4. Chemical Control

Proper selection and judicious use of chemical pesticides targeting DBM should also control CHC on vegetable brassicas, as CHC also was found to be susceptible to newer pesticides such as emamectin benzoate, spinosad and indoxacarb (Kannan *et al.*, 2011). Chemical controls should be carefully monitored at the regional or national level to effectively contain DBM and secondary lepidopterans such as CHC.

7. Cabbage Webworm, *Hellula undalis* (Lepidoptera: Pyralidae)

The cabbage webworm (CWW) is a serious pest of vegetable brassicas because of its preferential feeding on the young terminal bud and the unopened leaves (Sivapragasam and Chua, 1997). Outbreaks with yield losses up to 100% have been reported in Asia, Africa and the Pacific (Kalbfleisch, 2006). CWW has been reported as a major pest in lowland production systems (Sivapragasam and Chua, 1997) and in summer (AVRDC, 1978).

7.1. Cultural control

Clean cultivation is recommended for CWW because it feeds and develops on certain weeds such as *Cleome rutidosperma* and *C. viscose*, on which infestations may reach up to 60%. Both species are widespread and play a possible key role as alternate hosts for CWW larvae during the off-season in South and Southeast Asia (Sivapragasam and Chua, 1997; Kalbfleisch, 2006).

7.2. Biological control

Wing traps baited with female sex pheromone (E,E-11,13-hexadecadienal @ 10 μg per trap) can be placed at a height of 0.5 m above ground at a distance of 15 m, and replaced every two to six weeks depending on the trap catches (Kalbfleisch, 2006).

Release of an egg parasitoid, *T. bactrae,* once in a week for five weeks starting within a week after transplanting the brassicas is recommended to manage CWW (Sivapragasam, 1996). In addition, a few larval parasitoids such as *Bassus* sp., *T. flavoorbitalis*, *Chelonus* sp. and *Phanerotoma* sp. have been reported to infest CWW in Malaysia. Although they were reported to play an insignificant role in regulating the CWW larvae (Sivapragasam and Chua, 1997), it is important to confirm the identity of the various species and to check whether they are species-specific parasitoids of CWW.

CWW was highly sensitive to Cry1Ca, but less susceptible to Cry1A toxins (Srinivasan and Hsu, 2008). Shelton *et al.*(2009) also confirmed that CWW was susceptible to Cry1Ba and Cry1Ca. This was further confirmed by the high susceptibility of CWW to *B. thuringiensis* subsp. *aizawai* based formulations (Srinivasan and Hsu, 2008), but not for the *B. thuringiensis* subsp. *kurstaki* based formulations in Taiwan (AVRDC, 1987). However, the latter was shown to be effective in the Philippines (Ulrichs and Mewis 2003) and India (Singh *et al.,* 2000). Hence, after local validation, *B. thuringiensis* formulations can be used to manage CWW. In addition, CWW can be controlled by deploying biopesticides that focus specifically on the shoot tips. Shoot-tip treatment using *B. thuringiensis* once in a week until head formation was highly effective (Sivapragasam and Aziz, 1992).

7.3. Chemical control

The chemical control strategy suggested for DBM and CHC should also contain CWW. However, an improved mode of pesticide application via brassica shoot treatment is suggested (Sivapragasam, 1996) as this method minimizes the adverse effects of chemical pesticides on the natural enemies present in brassica production systems.

8. Melon Fly, *Bactrocera eucurbitae* (Diptera: Tephritidae)

The melon fly is widely distributed in temperate, tropical and subtropical regions of the world. It has been recorded as a damaging pest on 81 host plants in several plant families, but predominantly in Cucurbitaceae. The extent of losses varies between 30 to 100%, depending on the plant species and the season (Dhillon *et al.,* 2005). Maggots feed inside the fruit, leading to distortion or rotting.

8.1. Host plant resistance

Although sources of resistance to melon fly have been identified in pumpkin, bottle gourd, sponge gourd, ridge gourd and round melon (Nath, 1966; Mahajan *et al.,* 1997), intensive screening was carried out in *Momordica* sp. (Pal *et al.,* 1984: Srinivasan, 1991; Thakur *et al.,* 1992, 1994 & 1996; Tewatia *et al.,* 1997; Dhillon *et al.,* 2005a; Gogi *et al.,* 2010). Resistance was not stable across locations. For instance, varieties such as Faisalabad-long and Col-II, reported as the most resistant in Pakistan (Gogi *et al.,* 2010) were highly susceptible to melon fly in Taiwan.

8.2. Cultural control

The collection and destruction of melon fly-infested fruit will reduce subsequent population build-up. If field sanitation is adopted at the community level, it will significantly reduce the melon fly population. Burying infested fruit 15-45 cm deep in the soil reduces the survival rate of melon fly maggots and prevents adult fly emergence (Klungness *et al.,* 2005; Kumar *et al.,* 2011).

8.3. Mechanical control

Bagging fruit soon after formation prevents adult female melon flies from laying eggs (Kumar *et al.,* 2011) and reduces subsequent damage. Akhtaruzzaman *et al.*(1999) suggested cucumber fruits should be bagged 3 days after anthesis, and the bags should be retained for 5 days for effective control.

8.4. Biological control

Kairomonal attractant cue-lure [4-(p-acetoxyphenyl)-2-butanone] traps are highly effective for monitoring and mass-trapping of *B. cucurbitae* in bitter gourd and other crops (Pawar *et al.,* 1991; Vargas *et al.,* 2000). Similarly, protein baits are highly attractive to female melon flies (Kumar *et al.,* 2011). Protein baits mainly consist of proteins and sugars, which are essential food for the flies to survive and reproductively mature. Protein bait lures and protein bait sprays are commercially available.

Although the larval – pupal parasitoid, *Psyttalia* (=*Opius*) *fletcheri* was reported to be the predominant parasitoid of melon fly in India (Srinivasan, 1994), the parasitism of melon fly by this parasitoid was less than 5% (Wong *et al.,* 1989; Nishida, 1963). An egg – pupal parasitoid, *Fopius arisanus,* is believed to have high potential in reducing the melon fly and it has been introduced into Hawaii and Mexico (Bautis,ta *et al.*, 2004; Zenil *et al.,* 2004).

8.5. Chemical control

Spraying chemical pesticides against melon fly is not advisable because of the ineffectiveness of pesticides as well as resistance issues. However, attractants can be combined with small quantities of pesticides to develop an 'attract and kill' system. For example, protein bait sprays mixed with chemical pesticides can be spot-sprayed on the roosting host plants of melon fly. Crops like maize, cassava, sorghum and castor should be planted around the main crop (bitter gourd, water melon, etc). These roosting host plants can be spot-sprayed with protein bait sprays once a week (or more often during the wet season) to kill the newly emerged flies before they mature (Vargas *et al.,* 2008; Mcquate, 2011). The combined application of cue lure and a toxicant is the most effective way to contain male flies (Vargas *et al.,* 2008).

Conclusions

Cultural practices such as crop rotation, clean cultivation and trap cropping are effective in reducing overall populations of borer pests. Although resistant sources have been identified, varieties with appreciable levels of pest resistance as well as acceptable horticultural traits are scarce. With the advent of biotechnological tools, breeding barriers may be overcome to develop borer resistant vegetable varieties. Although protected cultivation such as net-houses is a high-input technology, it could be adopted in peri-urban vegetable production systems where vegetable production is a highly profitable business due to readily available markets. Egg parasitoids such as *T. chilonis*, *T. pretiosum* or *T. bactrae* can be released against their target pests at regular intervals. Inoculative releases of parasitoids such as *D. semiclausum* and *T. marucae* can be made in newer regions where they are not present. Withholding of broad-spectrum chemical pesticides could augment the performance of generalist parasitoids such as *T. flavo-orbitalis* or *A. taragamae*. Commercially available biopesticides based on *B. thuringiensis*, nucleopolyhedrovirus, entomopathogenic fungi, and neem could be applied either alone or in combination to manage borer pests on vegetable crops. However, biopesticides should be applied when pests are in early larval stages, which often occur on the plant surface. Sex pheromone traps are highly useful as monitoring or mass-trapping tools in managing lepidopteran borer pests. Chemical pesticides can be integrated with other components of pest management in vegetable crops; however, it is important to choose selective pesticides, and follow a mode of action rotation with a windows approach to effectively curtail development of resistance. The effectiveness of chemical pesticides in the region and their registration status for the target crop should be checked before using.

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