

Insect Pests Management of Vegetable Seed Crops

Kashinath Chiluwal

National Entomology Research Center, Khumaltar, Lalitpur

Corresponding Author: knchilu@gmail.com

Abstract

Vegetable seed production is a complex among the entrepreneurs warranting the attack of an array of insect pests including the most primitive one Lucerne flea *Sminthurus viridis* (Collembola: Sminthuridae) to the most evolved hymenopteran pest, the mustard saw fly *Athalia lugens* (Hymenoptera: Tenthredinidae). Much homogeneous crops required for vegetable seed production along with an intensive use of agro-chemicals and the compounding effects of global climate change have accelerated the resistance, resurgence, outbreaks and trans-boundary invasions of insect pests. Yet, the option is an integrated pest management (IPM) to settle the pest population below economic threshold. This article reviews the major field and storage pest insects associated with vegetable seed production in Nepal.

Keywords: Insect pests, Pest invasion, Pest management, Vegetable seeds

Background Information

Fresh vegetable production has boomed as an economically viable enterprise in Nepal as illustrated by its leading contribution of 13.44% to Agricultural Gross Domestic Production (MoALD, 2023). Though the area under vegetable production has slightly increased, production per acreage has continuously increased pertaining to the availability of high yielding varieties and the technical know-how among the entrepreneurs (Fig. 1).

The national seed production system, despite a tremendous increment in productivity of fresh vegetables, is not sufficient to satisfy the national seed demand as illustrated in Fig. 2 (Source: SQCC, 2024). Accordingly, the major vegetable seed market is dominated by the imported and registered hybrid varieties. The proportion of the imported open pollinated varieties is also comparable to those of domestic seed production (Fig. 2) leaving a crystal-clear message to all players; especially the research, education, and extension systems, of agricultural innovation systems of Nepal to facilitate the seed production entrepreneurs.

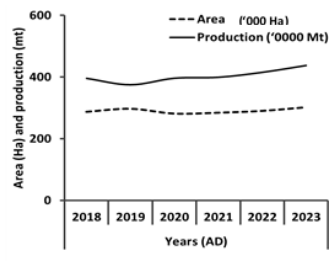


Figure 1. Area and production of fresh vegetable in Nepal (Source: Krishi Diary (2023), MoALD, Nepal)

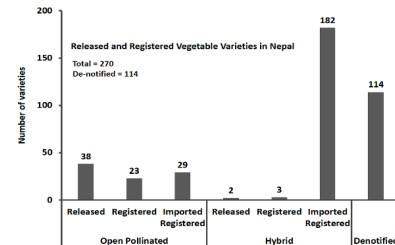


Figure 2. Released and registered vegetable varieties in Nepal (Source: SQCC, retrieved on 2024 October 22)

Vegetable seed production is a much sophisticated enterprise as it requires more time to reach maturity, has to face natural calamities like irregular rains, hailstorms, insect and non-insect pest problems. Additionally, vegetable seeds require extra time and cost compared to fresh vegetables. Amongst the bottlenecks of vegetable seed production, insect pest problem is a major one. In addition to causing direct damage to the vegetable seed crops, many insect pests vector the devastating plant diseases both persistently and non-persistently aggravating the problem much further. Insect pest management recommendations both for commercial vegetable and their seed production are primarily based upon the calendar sprays of chemical insecticides.

In recent years, owing to the shift in cropping pattern from hetero to homogeneity, ecosystem and habitat manipulation, global climate change, global trade liberalization and because of the heavy reliance on agro-chemical based intensive farming, many insect pests have switched their hosts, have developed mutagenic resistance to broad-spectrum insecticides and the minor pests have changed into the major ones. Despite all these, integrated management of the insect pest menace in vegetable seed production system is a sole alternative. This paper has highlighted the scientific evidence for the insect pest management of vegetable seed production in Nepal there by suggesting a policy-support for the vegetable seed producers.

Management of Major Insect Pests of Vegetable Seed Production

1. Tomato pin worm

Tomato pinworm (TPW) *Tuta absoluta* Meyrick (Lepidoptera: Gelechiidae) is a serious oligophagous holometabolous (Fig. 3) pests of solanaceous vegetable crops in many countries.

It is among the highly invasive ones and colonizing the world very fast. It has been reported that TPW alone can threaten 87% of the world tomato production and has already colonized majority of tomato pockets of Asia, Africa and America (Santana Junior et al., 2019). Since its invasion report in Nepal in 2016, it has colonized almost all the East-West tomato belt (Bhat and Bajracharya, 2024).



Figure 3. The developmental stages of the tomato pin worm *Tuta absoluta*: (a) egg, (b) larva, (c) pupae, and (d) adult [Source: Uygun & Ozguven (2024)]

Larvae are the mesophyll feeding agents making irregular mines which negatively affect the photosynthesis and can cause a total tomato yield loss (Shiberu and Getu, 2017). It is expected to permanently infest major tomato growing world including Nepal as depicted by Ecoclimatic Index (EI) > 50 in Fig. 4 (Santana Junior et al., 2019). Similarly, it poses a high degree of Establishment Risk Index (ERI) (Azrag et al., 2023). Accordingly, ERI will increase by 0.05 points by 2050 and by 0.1 points by 2070. Both EI and ERI indices point out that the TPW is permanently establishing in Nepal warranting an integrated approach of management.

Following could be the IPM approach for TPW management.

- Collection and composting of TPW-infested leaves, growing tips and fruits to check the next-crop population hike
- Application of balanced fertilizers. Tomato and other host plants grown with dose of N-fertilizers become much susceptible to the pests.
- Plastic mulching both in open and protected cultivation of tomato and alike crops to block the underground pupation of TPW.
- Crop rotation with non-solanaceous crops and removal of alternate solanaceous hosts/ weeds help to dampen the next season TPW population down
- A hectare of land is monitored either with 4-5 yellow delta traps or with Wota-T traps baited with female-produced pheromone lures. Major TPW-activity could be observed in March-April in mid-hilly Nepal condition (Bhat and Bajracharya, 2024).
- Combining two eco-friendly tactics; bio-control with ethological control is more effective. In a review report of Colmenárez et al., (2022), larval parasitoid *Apanteles gelechiivoris* Marsh (Hymenoptera: Braconidae) when combined with ethological approach of using sex pheromone traps results into larval parasitism rate of 68.75%. Similarly *Trichogramma brassicae* Bezdenko (Hymenoptera: Trichogrammatidae) has been found an effective bio-control to suppress PTW population (Sadidi and Raeesi, 2021).
- Chemical control trail conducted by NERC identified chlorantraniliprole (an anthranilic diamide insecticide), and spinosad (a macrolide insecticide) most effective against TPW. NERC suggests to use these insecticides in rotation to avoid resistance development (Bajracharya et al., 2017).
- An IPM package of using microbial insecticides (*B. thuringiensis* var *kurstaki*, *B. bassiana*), Azadirachtin-based neem insecticides and safer chemical chlorantraniliprole significantly reduces the TPW population even reducing the crop protection cost by 50% (Buragohain et al., 2021).

2. Cabbage butterfly

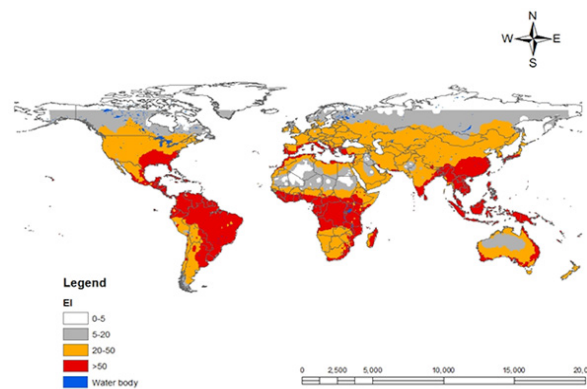


Figure 4. The Ecoclimatic Index (EI) for Tomato Pin Worm (0-5 = unsuitable, 5-20 = less suitable, 20-50 = moderately suitable and >50 = highly suitable) [Source: Santana Junior et al., (2019)]

Cabbage butterflies *Pieris brassicae* (L.) (Lepidoptera: Pieridae) and *Pieris rapae* (L.) (Lepidoptera: Pieridae) are the major constraints of vegetable seed production in Nepal hills. It may cause up to 40% yield loss of cruciferous vegetables (Hasan et al. 2008). *Pieris* larvae can feed up on all the plant parts of glucosinolate-releasing brassicas (Hopkins et al., 2009), especially cabbage, cauliflower, mustard and radish, and can attack both vegetative and reproductive parts eventually leading into a total kill of the host plants (Hasan and Ansari, 2010). Scanning of crucifer field just above crop canopies for the fluttering flight of the butterfly during onset of spring (after completion of pupal-overwinter) when flowering season of the brassicas starts, is key to know its existence and call for its management practices. Another method of scouting is sample search of ventral leaf surface of crucifers for the presence of light-yellowish cluster of 50-70 eggs in batch. Like other pests, the following integrated approach could be adopted for the management of cabbage butterfly:

- In small scale vegetable seed production field, aerial sweeping and catching of fluttering adults and smashing of the egg clusters is possible. However, for larger fields, it demands the use of repeated sprays.
- Predators like mantis, birds and others do not perform well because of the glucosinolate-sequestration by the larvae
- Pakistani strain of *Heterorhabditis* nematode exhibited increased compatibility when tested in combination with Azadirachtin-based formulation in opposite to the chemical combination (Askary and Ahmad, 2020).
- Bhandari et al., (2019) in a field trial proved spinosad as the most effective insecticide followed by emamectin benzoate. Biopesticides *Btk* and *B. bassiana* and other botanicals performed much better compared to control.
- Giri et al., (2020), among the tested soft chemical insecticides, identified spinosad and cypermethrin as the most effective among others suggesting them as the last resort to protect cabbage cauliflower crops from cabbage butterfly.

3. Tomato fruit borer (*Helicoverpa armigera*)

Tomato fruit borer *Helicoverpa armigera* (Hubner), corn earworm *Helicoverpa zea* (Boddie) and tobacco budworm *Heliothis virescens* (Fabricius) are major global challenges of heliothine noctuid pest complex. Among these, *H. armigera* is the most dominating one (Fig. 5, Kriticos et al., 2021) and can complete its life cycle in more than 180 plant species (Tay et al., 2013). Accordingly, Nepal is *H. armigera*'s country. It also inflicts potential damage to vegetable crops like tomatoes, beans, peas and other legume crops, if unattained, total collapse of the crop with no seed production possibilities. Diverse host range (Tay et al., 2013), high rate of reproduction (per female 773 eggs on chickpea and 557 eggs on tomato) (Fitt, 1989; Kumar et al., 2017), capability of long distance migration (Jones et al., 2019; Feng et al., 2004) and hybridization possibility with *H. zea* (Corderio et al., 2020) developing a newer mega-pest (Anderson et al., 2018) are some biological characters for which *H. armigera* are taken difficult to deal pest. Integrated control is thus should be a part of husbandry and the following management practices are recommended.

- Monitoring is the foremost step towards IPM of any pest. *H. armigera* is also monitored with traps baited with synthetic analogs of female-produced sex pheromone lures (Loganatham and Uthamasamy, 1998). Since the Heliiothines are noctuid moths, they can also be monitored with light traps.
- Cultural methods like deeper summer plowing to expose out the pupae to prey and predators, application of balanced fertilizers with ample amendment of organic sources of fertilizers like farmyard manure and compost, inter- and mix-cropping with non-preferred crops like onion and garlics, removal of crop residues
- Pest exclusion netting of tomato polyhouses in Kavre and Lalitpur assisted in significantly reducing *H. armigera* population (Singh et al., 2018).
- Development of Bt crops has been a major host plant resistance (HPR) strategy in many developed countries. However, it is regulated on its use in Nepal. HPR is yet to be an explored field of research in Nepal.
- Egg parasitoid *Trichogramma* has been identified as a successful bio-control agent against many noctuid

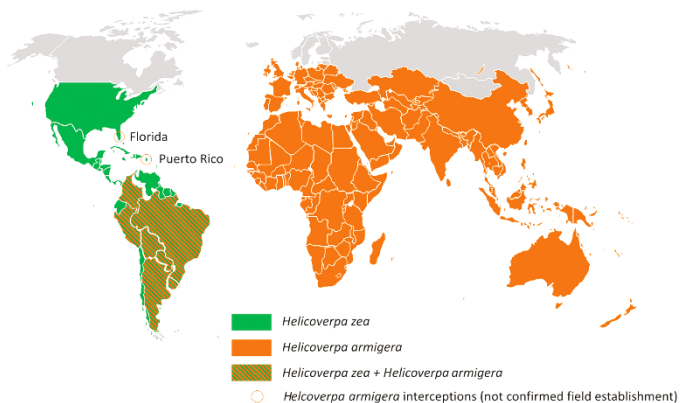


Figure 5. Global distribution of *H. armigera* and *H. zea* as economically important pests (source: Kriticos et al., 2021)

moths including *H. armigera*. National Maize Research Program (HMRP), Rampur, NERC, Khumaltar and other NARC stations across the country are rearing, testing and releasing locally available highly effective *Trichogramma*.

- The most infective viral strain HaNPV is also successfully used against *H. armigera* in many parts of the world (Luo et al., 2014).
- The lowest number of fruit damage (8.41%) in a flubendiamide followed by cocktail of chlorpyrifos + cypermethrin (15.70%) and emamectin benzoate (20.82%) was reported by Regmi et al. (2018). Ghimire et al. (2022) very recently reported the reduction of *H. armigera* larvae population on tomato by 66.52 and 68.85% after the 1st and 2nd spray of spinosad. Carneiro et al. (2014) while testing with different groups of insecticides observed the acute contact and ingestion toxicities of spinosad and chlorpyrifos followed by acephate, Bt, dimethoate, flubendiamide. Abamectin, chlorantraniliprole and methomyl also acted satisfactorily. Similar efficacy of spinosad and methomyl was also reported by Badshah et al. (2011). High degree of efficacy of spinetoram against this pest was reported by Hanafy and El-Sayed (2013). However, the pest has already developed resistance to synthetic insecticides and Bt-based HPR (as reviewed by Haile et al., 2021). For responsible product stewardship, deploying alternate use of different groups of insecticides against *H. armigera* thereby to block and break resistance development is equally important.

4. Cut worms

Holometabolous noctuid moths' caterpillars, the cut worms' cut-off vegetable seedlings of tomato, pepper, cabbage, peas, beans, squash and others, and so are regarded as polyphagous. They are problematic during hot and dry summers (recited after Bowden et al., 1983) and can increase by 10-folds of their general equilibrium population during havoc. Larvae are also night dwellers and are the only destructive stage especially to vegetable seedlings of early season plantings mainly because of a strong migration habit of adult moths (Sindhu et al., 2019). Paneru and Giri, (2011) highlighted on the two major cutworm species; greasy cutworm *Agrotis ipsilon* (Hufnagel) and *Agrotis segetum* (Dennis and Schiffermuller). The eco-climatic zones of Nepal are highly favorable for the cutworms as illustrated from CLIMEX model by Hayat et al. (2021).

Cutworms are difficult to deal with pests. However, these can be managed with the integrated management approach as follows.

- Monitoring with light and pheromone traps are successful (Raina and Khan, 2007; Sachan and Gangwar, 1990). Blue green lights are found more attractive to the cut worms (Veda and Vaishampayan, 1993). Buleza et al. (1988) found that 80 ug of 1:3:4 of female sex pheromone components [(z)-5-decen-1-ol acetate, (z)-7-decen-1-ol acetate and (z)-9-tetradecenyl acetate] per trap is the most appropriate proportion and dose. Monitoring data could be summarized to set economic thresholds and to follow the management options.
- The pest shelters and breeds on refuge crops and on the early season weeds. So, their removal along with the mulching of the main crop to provide shelter for natural enemies is beneficial.
- Plowing at least or half months ahead of plantation exposes hiding larvae and pupae to the generalist's predators like birds
- Higher seed rate in endemic areas to compensate for the crop losses can be practiced.
- Collection and mechanical disruption of the curled-up larvae near the base of young plants
- Irrigating the field very frequently to force the hidden larvae to come out to be exposed to the predators and scorching sunlight
- Shelter-baits with weed trashes or crop remnants attract the caterpillars to hide from day light which could be killed manually. Similarly, Bt- and other synthetic chemical admixed baits can be deployed in varying mode of applications like spot application to attract and kill, broadcasting before planting vegetable seedlings, and also after presence of the caterpillars (Bhattacharya et al., 2014).
- Egg parasitoids like *Trichogramma* spp and *Telenomus* spp (Pal and Katiyar, 2010), and endo-larval parasitoid like *Cotesia* spp are effective bio-control agents of the cutworms (Patil et al., 2016).
- Micro-insecticides containing NPV, Bt, granulosis virus, entomopathogenic nematodes (*Steinernema*, *Heterorhabditis*), fungi (*M. anisopliae* and *B. bassiana*) are found plenty effective to suppress the pest below economic level (Yuksel and Canhilal, 2018; Wennmann et al., 2015; Pandey, 2013; Chandel et al., 2009; Prater et al., 2006; Boughton et al., 2001). Spray or bait-broadcasting after admixing the commercial/ locally manufactured formula with grain brans could be much more effective.

- Vegetable seed crops could be protected from the cut-worms with a precise selection and timely application of chemical insecticides. Chlorpyrifos, cypermethrin, triazophos, imidachlopid, emamectin benzoate and thiamethoxam are popular both for foliage spray and for bait-broadcasting with grain substrates (Chandel et al., 2022; Joshi et al., 2020). However, alternate application of insecticides with different modes of actions are imperative for the no and delay resistance development among the worms.

5. Brinjal fruit and shoot borer

Brinjal fruit and shoot borer (BFSB), *Leucinodes orbonalis* (Guenee) (Lepidoptera: Pyralidae) is widely distributed across Asian countries (Fig. 6, Bragard et al., 2023) and is one of the major impediments to brinjal fruit and seed production in Nepal. Expert knowledge elicitation and pathway modeling by the European Food Safety Authority (EFSA) panel confirmed 3-670 (with 90% CR, certainty range) BFSB infested brinjal enter Europe with a possible impact of 0.67-13% on brinjal production if no specific action taken (Bragard et al., 2023). This holometabolous and monophagous pest can inflict a total crop failure if left unmanaged. Nursery seedlings, growing tips of the field crops and the brinjal fruits are attacked by the borer rendering the fresh vegetable unsuitable for market and further impairing the seed production processes.

Mainly the ventral surface of flush leaves and the floral parts are the preferred oviposition sites for a very high fecund female (80-260 eggs) (Alpuerto, 1994) singly or in a batch of 6-7. Initially creamy eggs turn reddish during hatching releasing whitish larvae in an incubation period of a week (as reviewed by Mainali, 2014). After completing 5 (sometimes 6) larval instars in different parts (newly hatched on tender floral parts, mid-staged larvae on shoot tips and matured ones on the brinjal fruits), they drop on the ground and go for pupation in a grey boat-shaped cocoon (Pannusamy et al., 2021). Under harsh winter, pupae go for overwinter rest. However, under favorable seasonal conditions, it lasts for 8-9 d (Van Hung et al., 2020). Adults live for <7 d and oviposition period is also very short (<3 d) (Laichattiwat et al., 2017). So, short life and high fecundity are the major reasons behind its havoc in brinjal farms. It thus demands an integrated and area-wide approach for management.

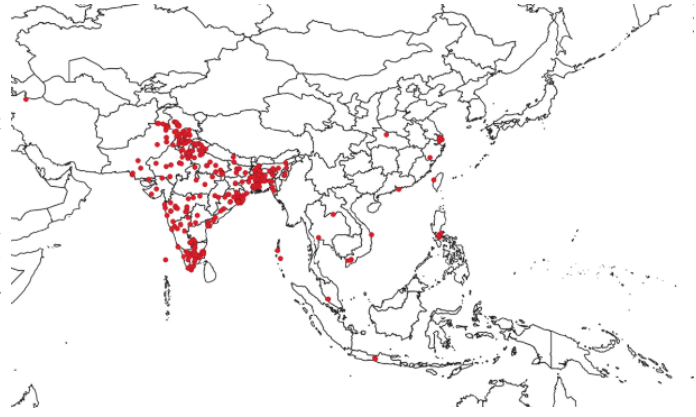


Figure 6. Point distribution of *Leucinodes orbonalis* in Asian countries based on systematic literature search [Source: Bragard et al., 2023]

- Some cultural practices like early planting, plucking the infested shoot tips, flowers and fruits, and collection of remnants of the preceding brinjal crop and destruction help to check the population buildup of BFSB.
- Captive growing of brinjal nursery checks the migration of BFSB to the main vegetable and seed growing field. Similarly, barrier crops like maize around the brinjal field, clean cultivation and crop rotation with non-preferred crops are advantageous to limit BFSB population.
- Growing resistant varieties is the most compatible IPM approach against the pests. However, Nepalese brinjal varieties are not absolutely tolerant to the BFSB infestation. Only moderately tolerant varieties (oblong-long in shape like Pusa Long, Pusa Kranti, Lurki, Pokhara Nurki, etc.) are available. Roundish varieties are much susceptible to the borer (recited from Paneru and Giri, 2011).
- Like in other moth pests, BFSB eggs are also well parasitized by *T. chilonis*. Saleh et al. (2024), out of 60 identified hymenopteran parasitoids of BFSB in brinjal field, identified *Apanteles hemara* (N.) (Hymenoptera: Braconidae) as the most potential one. The parasitoid *A. hemara* has also been reported to work efficiently against amaranth leaf webbers; *Spoladea recurvalis* and *Udea ferrugalis* (Lepidoptera: Crambidae) (Othim et al., 2017). So, in Nepalese conditions too, they could be tested to identify the best one for which further research initiatives are required.
- Pheromone traps impregnated with leucine lure are widely used both for monitoring, and mass trapping and disruption of male BFSB moths. Cork et al., (2001) confirmed E11-16: Ac as the major female sex pheromone component of BFSB. Addition of 1% of its related compound, E11-16: OH improved the trap efficacy compared to E11-16: Ac alone. Loading 3mg of the 100:1 of E11-16: Ac + E11-16: OH in a rubber septum (black or white) and deploying in a funnel trap resulted into a significantly higher BFSB attraction than those deploying E11-16: Ac alone. Delta, water pan and funnel traps can effectively be used. Denser installation of the traps (100/ ha) with leucine lures can achieve a significant control over the pest (Cork et al., 2007).

- Bt brinjal varieties are also available in the international market. Nepal has imposed regulation on those varieties. However, Bt-based insecticidal formulations are available which can be incorporated in IPM against BFSB.
- Botanical-based insecticides like neem oil and azadirachtin are effective against early larval instars and also act as antifeedant and oviposition deterrence against the foliage pests like BFSB.
- Chemical control has been widely practiced among the brinjal growers. Spinosad followed by emamectin benzoate, thiacloprid, chlorantraniliprole and flubendiamide performed well to control the field brinjal infestation (Jat and Shrivastava, 2022). Almost similar efficacy of the chemical insecticides was reported by Sowmya and Rajnikant, (2023). Percent field damage of brinjal by the BFSB was markedly lower when spinosad, flubendiamide, chlorantraniliprole, and emamectin benzoate were tested against the pest. Neem oil and *B. bassiana* also acted significantly compared to control. So, these insecticides with different mode of actions could be suggested to incorporate in IPM against BFSB in rotational basis so as to weaken the chances of resistance development.

6. Diamond back moth

Billions of dollars are annually invested for the management of global diamond back moth (DBM), *Plutella xylostella* (L.) (Lepidoptera: Plutellidae) management programs in cruciferous vegetables (Zalucki et al., 2012). Though Kfir (1998) believed that DBM originated either in the Mediterranean region or in the Southern Africa, mtDNA based study by Juric et al. (2016) also could not absolutely prove their claim. Later You et al. in 2020 by evaluating (nuclear and mitochondrial genomes, and *COI* sequencing) 532 DBM genomes representing 114 populations across the world confirmed that South America as the place of origin of DBM from where it expanded via three distinct directions; towards North America, Europe and Africa. European expansion further expanded to Asian countries and to Australia too (Fig. 7). Now, DBM is considered as the most widely distributed amongst the butterfly and moth species on the Earth (Furlong et al., 2013).

The DBM is multivoltine (4-20 generations a year) pest. Highly fecund female (~200 eggs/ female) prefers to oviposit on dorsal leaf surface (Justus et al., 2000). Tiny light yellow to pale green neonate larvae mine through the spongy mesophyll from ventral leaf surface. Remaining three instars are voracious feeders and become darker as they mature. Larval period lasts for 2-3 wk. Second-fourth instars feed on green layers of leaves, floral parts, siliques and growing grains. When disturbed, larvae exhibit a backward wriggle moves and spin down on a silken thread. Pre-pupal larvae go for pupation under a silken cocoon formed on the leaves of host plant and emerge as adults after 5-15 d (Capinera, 2001). The insect is named DBM for its light colored diamond-marks with a creamy or light-colored band at the back when at rest, which is much clearer in males. As reviewed by Philips et al. ,(2014), adults live long (up to 8 wk and 2 wk in an average) and reproductively active at least for 10 d.

- Crucifer seed production demands a heavy invest on inputs and time. So, insect pest menace is anticipated.

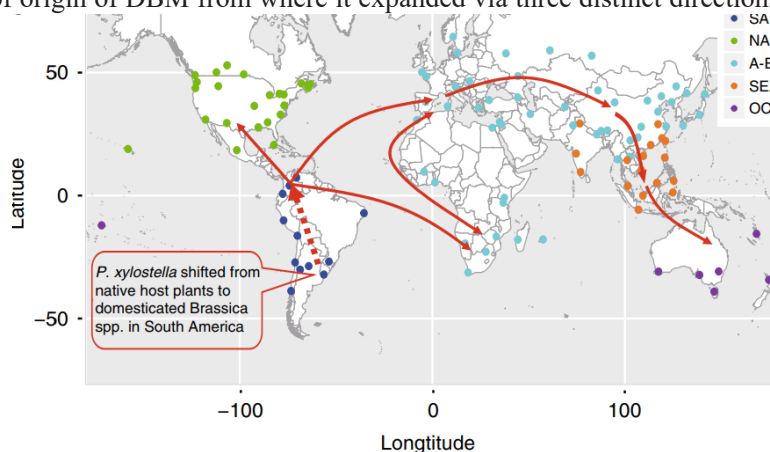


Figure 7. A proposed route of global colonization of the DBM populations [Source: You et al., 2020] SA - South America, NA - North America, A-E - Africa-Europe, SEA - South and East Asia, OC - Oceania.



Figure 8. Biological stages of DBM (Upper left -Eggs, right - Larva, Lower right - Pupa and left- Adult) [source: different web materials]

Though Bt-crops, resistant to many herbivore insects are developed, our regulation on their use and recent resistance development by the pests have challenged their cultivation. HPR with other morpho-physiological features are not sought feasible.

- Crop rotation with non-crucifer crops and clean cultivation dampen the DBM population down for the next season crop (Talekar and Shelton, 1993).
- Overhead irrigation like sprinkler irrigation dislodge the DBM early instar larvae from plant surface or drown them to die there by reducing the DBM injury to the crops (Talekar et al., 1986).
- Intercropping with non-hosts reduces the DBM attack on cabbage. Asare-Bediako et al., (2010) when evaluating intercropping cabbage with non-hosts (tomato, pepper and onion), the least damage holes on cabbage heads and average yields were obtained in cabbage+tomato intercrop. Onion and pepper intercropping were also at par with chlorpyrifos sprays.
- Trap cropping is practiced in many developed countries. Collards and Indian mustard are popularly used for trap cropping of DBM (Shelton and Nault, 2004). Badenes-Perez et al., (2004) demonstrated a 300 times greater oviposition by DBM in collard trap crops than in cabbage crop.
- Mating disruption using female sex pheromone component's lures has been sought as an effective IPM tool, both for monitoring and mass disruption. However, due attention to be paid on the geographic variation on the pheromone blends of DBM strains (Miluch et al, 2014). Altogether four components of the blends are identified; Z11-16: Ac, Z11-16:Ald, Z11-16: OH and Z9-14: Ac. Variation in amount (ug) ratio (or proportion) of 3:7:1:0 in Chinese, 1:3:2 in American, 50:50:1 in Indian and 30:70:1:0.1 in Canadian and 6:4 in Japanese strains suggests for the prior information on the local blends to assure the higher efficacy of the lures and traps. Addition of green leaf volatile (Z-3-hexenyl acetate) significantly increases the attractiveness of lures to the male moths (Miulch et al., 2014). Though non-significant, higher number of moths were captured when pan traps were not painted except dull white and were installed at a plant height (Miulch et al., 2014).
- As in the cases of other pest insects, bio-control of DBM is also a first line tactic of IPM (Fig. 9). In a review paper by Sarfraz et al., (2005), almost 130 parasitoid species are identified to attack biological stages of DBM. Amongst all, ichneumonids (genus *Diadegma* and *Diadromus*), braconids (genus *Microplitis* and *Cotesia*) and the eulophid (genus *Oomyzus*) are the most effective larval parasitoids. *Cotesia plutellae* shows a preference for non-parasitized DBM larvae over parasitized one. Moreover, *C. plutellae* is also champion in developing resistance to pyrethroids. Liu et al., (2003) recorded resistance to pyrethroids by resistance factor 13.6 after 13 selections of highly resistant DBM host showing good prospect of using it as a bio-control agent. This is also supported by the report of abundance of *C. plutellae* in a South African field which was repeatedly treated with pyrethroids (as reviewed by Sarfraz et al., 2005). The generalist egg parasitoid *Trichogramma brassicae* Bezdenko is also popularly used, but with a high risk of non-target parasitism (Babendreier, et al., 2003).
- Bt-based formulations characterized by species-specific toxicity, compatible to the genetic engineering technique and little or no harm to non-target organisms including humans (Bauer, 1995). However, Tabashnik et al., (1990, 1993) and Tabashnik (1994) evaluated the resistance of DBM to a number of insecticidal crystal proteins like Cry1A series (Cry1Aa, Cry1Ab, Cry1Ac) and so newer protein crystals are added in the list which show greater efficacies during initially and subsequently the pests develop resistance mainly due to the interference with any of the steps in mode of action of Bt Cry proteins (Tabashnik, 1994).
- Vandenberg et al., (1998) screened 54 entomopathogenic fungi (EPF) including the most popular and effective *B. bassiana* and *M. anisopliae*. Works on EPFs are regular in NERC, Khumaltar. However, commercialization is yet to be a part of research in Nepal.
- Granuloviruses (PxGV), nucleopolyhedrovirus (PxMNPV) and cypovirus (PxCPV) strains infecting different strains of DBM from different parts of the world are found to have differences in LC₅₀ and LC₉₉ values (Cherry et al., 2004; Grzywacz et al., 2004; Lu et al., 2004; Woodward et al., 2004; Kariuki and McIntosh, 1999) thereby providing an opportunity to select the most virulent one.
- Though chemical measures are sought as an easy and effective options to size DBM population down to the economic level, instant resistance development by the DBM strains from across the world is a serious concern. The 2020 Arthropod Pesticide Resistance Database documented 877 global cases of DBM resistance to all major classes of insecticides, outnumbering to all the pests in the world. Wang et al. (2021) demonstrated the resistance level of different Chinese population of DBM to spinetoram, beta-cypermethrin, indoxacarb, chlorantraniliprole, abamectin, chlorfenapyr, chlorfluzuron, and even to the Bt-pesticides suggesting for

the wise selection of an IPM tactic against the pest. Opoloioiu et al., (2023) demonstrated that the resistance of DBM to emamectin benzoate is inherited as an autosomal, recessive trait conferred by a single or few closely linked loci. Surprisingly, emamectin benzoate resistant strain also exhibited multi-resistance profile to popular insecticides (chlorantraniliprole, lambda-cyhalothrin, fipronil, indoxacarb, spinetoram, abamectin, and others).

- To effectively circumvent the global DBM problem, recent molecular advances can be a newer avenue. Philips et al., (2014) summarizes that the informations achieved so far, especially in the part of insecticide-resistance in DBM (by chemosensory proteins, proteinase activities in the mid-gut, sodium channel genes, cytochrome P450 gene and bacterial symbionts, and molecular mechanisms related to detoxification of glucosinolates and insecticides) for the further improvement necessities. RNAi technology has been proved to knock out the cytochrome P450 gene, target acetylcholine esterase genes successfully and to target the suppression of the receptor gene of pheromone biosynthesis (Plx-PBANr) on female DBMs resulting in reduced male attractiveness. Dead-end trap crops as above could be another technology to tackle DBM havoc. DNA-based prey-detection approach has provided an excellent option to understand the specific and generalist predators' role in DBM control (as reviewed by Schmidt et al., 2021). The basic idea is to field collect predators and conduct PCR to identify pest's DNA in their stomach.
- To sum up, development of new insecticidal formulas with novel modes of action aided with the RNAi technology to suppress the resistance genes and mechanisms, trap cropping and crop resistance breeding, regular monitoring of insecticide resistance, improvement of current bi-control and cultural practices, pheromone-based behavioral management including suppression of receptor genes are some newer interventions to be commercialized for successful global DBM control program.

7. Fruit flies

Fruit flies are a complex of cucurbit cropping system in Nepal. So far, 27 tephritid species are reported in Nepal (Sapkota et al., 2024). However, only a couple of the flies are posing serious threat to the cucurbit industry in Nepal. Notably, *Bactrocera tau* Walker, *Bactrocera dorsalis* (Hendel) and *Bactrocera cucurbitae* (Coquillett) are among the most destructive ones. *Bactrocera scutellaris* (Bezzi) and *Bactrocera diversa* (Coquillett) are also frequently encountered, their level is not crossing the economic level. These authors have recently reported eight fruit fly species [*B. tau*, *B. cucurbitae*, *B. dorsalis*, *B. diversus*, *B. scutellaris* Wiedemann, *Bactrocera. correcta* (Bezzi), *Bactrocera zonata* (Saunders) and *Dacus longicornis* Wiedemann) in cucurbit cropping system in Gandaki Province (Chiluwal et al., 2022). It was also declared from the trap (baited either with cue lure, or methyl eugenol or their mixtures) collection of fruit flies from nine cucurbit pockets of seven districts of Gandaki and Bagmati province that the most dominant was *B. tau* with a dominance index of 0.55 (Chiluwal et al., 2024). Interestingly, the fruit flies, one at the least are pest of concern in every nation in the world. So, possibility of invasion and pattern of dominance seems to be changed periodically. Probably, the dominance of *B. tau* as reported by Chiluwal et al., (2024) could be of the reasons. Interspecific competition (as reported by Ma et al.,

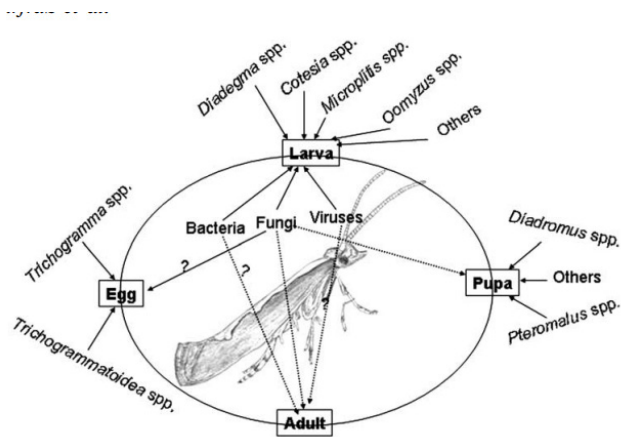


Figure 9. Principal bio-control agents of *Plutella xylostella* (L.) [Source: Sarfraz et al., 2005].

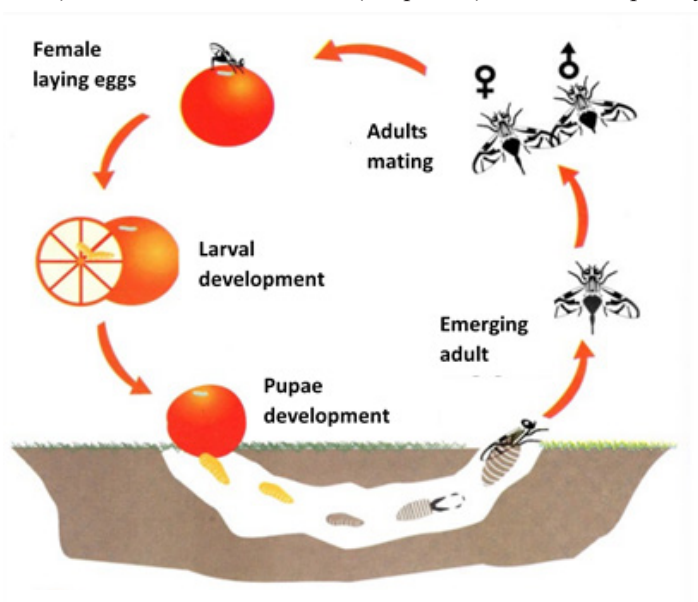


Figure 10. Typical fruit fly life-cycle [Source: FAO/IAEA, 2023].

2009) between previously assumed dominant *B. cucurbitae* and currently dominating *B. tau*, probably after its invasion in Nepal could be the reason behind the interspecific substitution. However, it would be too early to declare before nation-wide cue-mediated survey and surveillance. Furthermore, invasion possibility of highly aggressive tephritid fruit flies like *Anastrepha grandis* (Diptera: Tephritidae) in Nepal is very high as reported by Teixeira et al., (2021) using Maxent algorithm.

These holometabolous cucurbit pests with their biological stages having different nutritional guilds and habitat; eggs and larvae inside fruits, pupation under soil and aerial adults (Fig. 10) are also difficult to deal pest enforcing farmers to replace cucurbits from their farming system. Many seed producing farms are unable to produce enough seeds of cucumbers to meet national demand. So, a systematic approach of fruit fly management involving multiple tactics should be adopted to safe-gourd the cucurbit vegetable crops and their seed production program. Monitoring, identification and behavioral control: In the cucurbit ecosystem in Nepal, both cue lure-sensitive (like *B. cucurbitae*, *B. scutellaris*, *B. tau*, *B. diversus*) and methyl eugenol - sensitive species (*B. dorsalis*, *B. zonata*) are much encountered. *Bactrocera cucurbitae* and *B. tau* are much devastating to cucurbits causing fruit damage before maturity. So, monitoring and identification are most important. Cue-baited trapping and mass disruption is the widely used fruit fly control measures. Ahmad et al. (2023) found the most appropriate methyl eugenol: cue lure 60: 40 for *B. dorsalis* and 10:90 for *B. cucurbitae*. We also found an appropriate trapping height of the traps baited with cues (cue-lure or methyl eugenol) and found that “lower the trap height, higher the trap catches” in the case of fruit flies (Fig. 11). This happened mainly due to the energy saving strategy in the flies to approach to the shortest distance of the cues.

- Food baits attract both male and female flies in the principle that flies need sugar and protein for growth and development of eggs and sex organs. Protein baits such as hydrolyzed protein or bacterial fermentation broth are found effective (as reviewed by He et al., 2023).
- Mulching (especially with black plastic) of the open field cucurbit crops and at protected structures are popular and are beneficial in reducing the fruit fly population as they disrupt the lifecycle by not allowing the proper pupation of the dropped fruits/larvae to the soil.
- Bagging and netting is considered the safest idea to produce cucurbit seeds effectively with a healthy crop stand. Paper/ plastic/ cloth bagging or netting the production area or use of insect exclusion net in plastic houses are widely practiced to safe-gourd the crops.
- Natural enemies like *Fopius arisanus* and *Diachasmimorpha longicaudata* (Hymenoptera: Braconidae) are popularly used parasitoid wasps (Ndlela et al., 2020; Rousse et al., 2006) to control different tephritid species across the world. In Nepal, studies related to parasitism of the fly biological stages are not conducted yet. However, we can have benefit of adaptation research from those reported in other countries.
- Instead of adopting curative approach, sanitation of the cucurbit farms is an effective measure to reduce the fruit fly population. Addition on sanitation could be an augmentorium (Jang et al., 2007; Klungers et al., 2005) based on a principle of “pests in parasitoids out”. Augmentorium is simply a tent like structure where in fruit fly infested fruits are piled up facilitating the easy escape of parasitoids out to the field and containing the emerged flies in (Fig. 12). Collection and composting of the fallen infested mandarin fruits in the case of closely related *Bactrocera minax* caused >70% reduction in pupal density per unit area (Chiluwal et al., 2023) supporting the importance of sanitation and augmentorium method of pest management.
- Irradiation-mediated sterile insect technique (SIT) has become the choice of fruit fly control tactics, especially for quarantine purpose and for the area-wide control programs in the field. Generic doses of irradiation (mainly gamma- and X- ray) are proposed for many fruit fly species (Barnes, 2016; Shelly and McInnis, 2016) with an ease of pupal-irradiation. Male pupae reared under laboratory condition are irradiated with the proposed generic doses and released to compete with the wild ones. The male and sperm-competitiveness in many irradiation male insects are already proven and applied in many parts of the world.

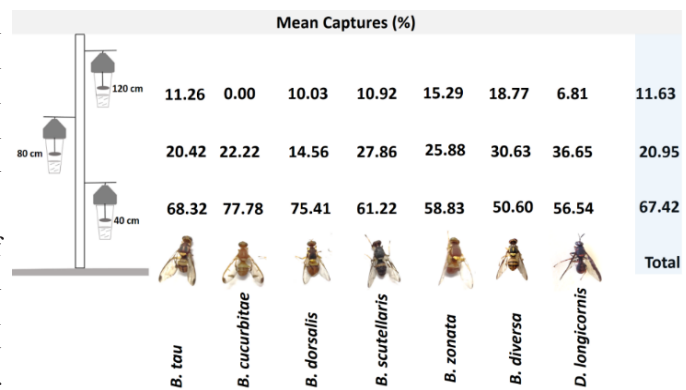


Figure 11. Effect of trap-installation height on the attractiveness of male fruit flies to cue-lure or methyl eugenol baited transparent bucket traps at cucumber field of DoAR, Lumle during 2021-2022.



Figure 12. Different augmentorium structures used widely across the world to enhance augmentorium-based biological control of fruit flies. [Source: Klungness et al. (2005)]

- Though less priorities are given to insecticidal fruit fly management, a few are evaluated for their efficacies (Lekha and Swami, 2007). Azadirachtin for its repelling action and spinosad for interfering the acetylcholinesterase activity. The differential efficacies of imidacloprid, chlorpyrifos, thiacloprid, beta-cypermethrin, fipronil, malathion, spinosad and others are reported (Arouri et al., 2015; Harter et al., 2015; Yee and Alston, 2006). Similarly, bio-insecticides containing fungus (*leucanicillium*, *Beauverria*, *Metarrhizium*) bacteria (*Bti*) and nematodes (*Steinernema* and *Heterorhabditis*) are also practiced in some parts of the world (as reviewed by Dias et al., 2018).
- Strict quarantine to block the introduction of highly invasive quarantine flies like *A. grandis* and *C. capitata* should be in practice as Nepal stands third for the likelihood of invasion of globally invasive pests.
- The area-wide multi-year control program could be the major tactic to size the fruit fly population down the economic level. However, priorities could be given for the pheromone-mediated behavioral, augmentorial sanitation and physical (bagging, netting) methods of management. To adopt an effective management strategy, components of agricultural innovation systems; research, education and advisory services should have a good knowledge of the fruit fly species and their species- and site-specific management strategies.

8. Leaf miner fly

A pest native to South America, the leaf miner fly [*Liriomyza huidobrensis* (Blanchard) (Diptera: Agromyzidae)] has now become the economic pest both in native and invaded regions of the world. Chavez and Raman (1987) reported it to be the classical example of secondary pest outbreak, as a result of the selection pressure after heavy insecticide use against the regular pest (*Tuta absoluta*) in 1970s in South America. The polyphagous pest resistant to many conventional insecticides was then carried to other parts of the globe with an ever-increasing trend of global trades and movements (Meyerson and Mooney, 2007). Scheffer et al. (2024) used phylogeographic analysis of >2 kb of mitochondrial cytochrome oxidase I and II sequence data from >400 field-collected *L. huidobrensis* specimens from both native and invaded populations and confirmed that it has spread to at least 30 countries on five continents (Fig. 13). Chiluwal et al. (2012) assessed foliage damage by *L. huidobrensis* on potato and concluded that the lower geographical altitudes and the lower plant canopy face much damage by the pest. Weintraub et al. (2017) recorded 365 host plant species from 49 plant families for *L. huidobrensis*. Seed production of many vegetable crops like tomato, pea, broad bean, four-season beans, bell pepper and other in both field and protected structures are constrained by this pest in Nepal. The adults of this holometabolous (Fig. 14.) dipterous pest are blackish with yellow spots on the head and thorax. Females puncture the leaf tissues both for feeding (by both adults) and oviposition. The translucent eggs then hatch into maggots and tunnel through the parenchymatous leaf tissue. After completing three instars, the pupation takes place in the ground and emerge as adults for repeating the regeneration (Pirtle and Severi, 2020). High intrinsic rate of increase with several generations a season are the reasons for their rapid growth, crop losses and the insecticide resistance. Based on control costs and tomato production value as a function of *L. huidobrensis* density, Lopes et al. (2019) calculated economic injury level (EIL) when 3.24 maggots exist per tomato leaf. Based on $EIL = 3.24$, the sequential sampling plan for *L. huidobrensis* has been developed (Fig. 15). In Fig. 16,

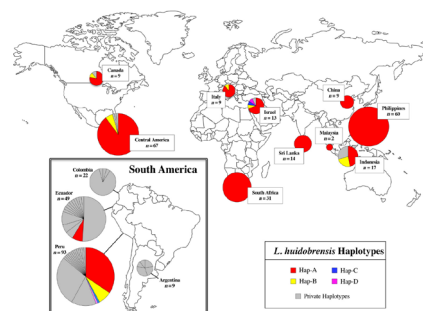


Figure 13. Global distribution of collection sites and haplotype composition of populations of *Liriomyza huidobrensis*. Each circle represents pooled samples for each country. Sample sizes are shown within boxes; in addition, circles are approximately scaled for population size. Slices within each circle represent haplotypes present in that particular location and indicate relative abundance. All private haplotypes (those found only in a single country) are shown in grey. Haplotypes shared between two or more countries are indicated in color. [Source: Scheffer et al. (2024)]

the three maggots per leaf (a) and more than three per leaf (b) are shown showing for the importance of EIL and sequential sampling plan. Accordingly, the action to limit the *L. huidobrensis* population to reach EIL should be started well ahead of the situation Fig. 16 (a) and we may incur a huge loss when we reach situation at Fig. 16 (b).

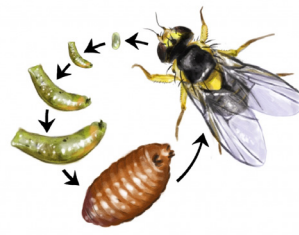


Figure 14. Life cycle of leaf miner fly [Source: Pirtle & Severi (2020)]

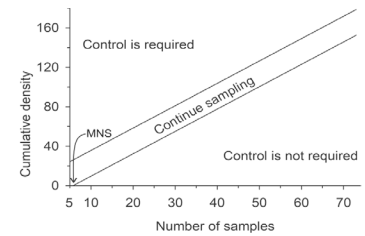


Figure 15. Decision-making limits of the sequential sampling plan for *Liriomyza huidobrensis* in tomato fields [Source: Lopes et al. (2019)]

Since the pest has acquired a global status, an IPM approach is only a relevant idea to suppress its population below economic level. Monitoring and management with yellow sticky traps in small scale tomato seed producing farms is feasible. For a larger area, movable yellow sticky boards could be beneficial by not-spraying insecticides and by reducing related expenses, and reduce killing natural enemies (Chavez and Raman, 1987). Preference to yellow color traps were also illustrated by Hamza et al., (2023).

- Defoliation and composting of the lower leaves of tomatoes could be an another cultural practice to check the population build-up of the fly as Chiluwal et al. (2012) reported the lower leaves are preferred to be attacked by the flies compared to leaves of upper canopy.

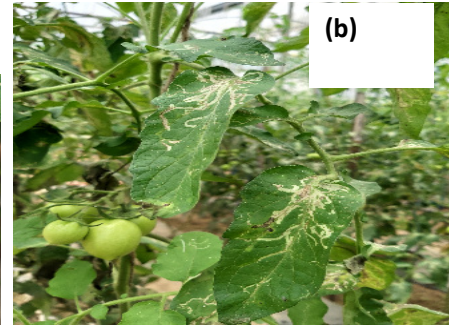
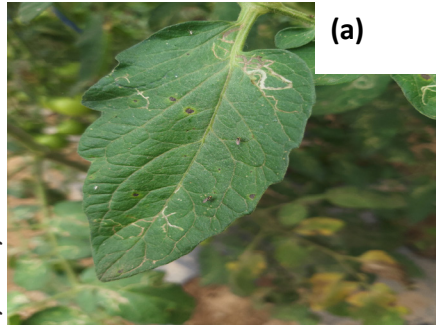


Figure 16. Situation of EIL = 3.24 maggots/tomato leaf (a) and >3.24 maggots/leaf (b) at tomato seed production block at Lumle, Kaski in 2022 (Photo by: Dr. K Chiluwal).

- Reducing dampness and more spacious planting of the crops (like tomato, peas, beans, etc.) for penetration of sunlight to the crop canopy would certainly reduce the crop infestation.
- Since the pest shows positively geotactic pupation, mulching would reduce the pupation rate resulting into a reduced subsequent generation.
- A considerable cohort of biological control agents (>80) of leaf miner species are reported (Liu et al., 2009).
- Though the exploring and using bio-control agents against leafminer flies in Nepal is not practiced, there are many entomopathogens tested globally and found effective. Among all, parasitoid *Diglyphus isaea* is found effective to control agromyzid leaf miner populations in both their native and invaded areas (Rauf et al., 2000; Chen et al., 2003). *Dacnusa sibirica* is the widely used parasitoid of leafminer under glasshouse (Leuprecht, 1992). Pathogenicity tests of entomopathogenic fungi (*Beauveria bassiana* and *Metarrhizium anisopliae*) against the leaf mining flies are carried out with pronounced efficacies (Migiro et al., 2011).
- Baker et al. (2012) suggested the phytosanitary measures to block the further introductions of *L. huidobrensis* to other potato belts of the world. However, wider host range and loopholes in the phytosanitary legislations have led the accidental introductions of the flies.
- Though we have witnessed a manifolds of resistance to conventional insecticides by *L. huidobrensis* adults, chemical measures to control are still practice across the world to size the fly population down the EIL. Botanical insecticides extracted from Neem tree *Azadirachta indica* and Bakaino *Melia azedarach* are proved to have extraordinary feeding and oviposition deterrence activity, and translaminar effects increasing pupal mortality without negatively affecting the parasitism (Bahchio et al., 2003; Weintraub and Horowitz, 1997). Similarly, systemic effect of spiosad on the larvae of *L. huidobrensis* was reported by Weintraub and Mujica (2006) where the treated larvae could not advance to next life stages. Recently, another insecticide, spinetoram has been reported to significantly reduce the fly population after sprays (Hamza et al., 2023). Yadav et al. (2024) demonstrated that the chlorantraniliprole



Figure 17. A crab spider (Tomisidae) catching and feeding on a *Liriomyza huidobrensis* adult (Source: Weintraub et al., 2017).

and emamectin benzoate were equally and highly effective against another agromyzid fly, *L. sativae*. So, we have a few insecticides in hand that are effective against the fly. However, care should be given to apply in appropriate dose, volume and frequency to mitigate the possible resistance development in the insects.

9. Aphids

Aphids, trans-literally plant lice, are pests of nearly every plant species and are also most common in Nepalese farming systems. Vegetable seed producing farms suffer more from the pest as they interfere the seed production process, especially during flowering, pod formation and maturity stages when the temperature starts to rise favoring the aphid colonization.

Table 1. Major aphid pests of vegetable seed production in Nepal, their host plants and transmitted plant diseases

Aphids	Vegetable host plants	Transmitted viral diseases
Cowpea aphid, <i>Aphis craccivora</i> Koch	Beans and peas	Leaf curl virus, bean mosaic virus, cucumber mosaic virus, rosette virus
Cabbage aphid, <i>Brevicoryne brassicae</i> L.	Brassicas like cauliflower, cabbage, broccoli and others	Cauliflower mosaic virus, Turnip mosaic virus, Cabbage black ring spot virus, beet yellow virus
Mustard aphid, <i>Lipaphis erysimi</i> (Kaltenbach)	Cauliflower, cabbage, broccoli, radish, turnip, broad-leaf mustard	Cauliflower mosaic virus, Cucumber mosaic virus, Potato Virus Y, turnip mosaic virus, bean yellow mosaic
Black bean aphid, <i>Aphis fabae</i> Scopoli	broad beans, French beans, carrots, tomatoes, sugar beet, spinach, cucurbits	Bean mosaic, bean necrosis, potato leaf roll, bean yellows, etc.
Green peach aphid, <i>Myzus persicae</i> (Sulzer)	Tomato, brassicas, cucurbits, brinjal,	Potato leaf roll, tomato mottling, beet yellow, turnip yellow, lettuce mosaic, bean leaf roll, bean mosaic, cucumber mosaic, cauliflower mosaic
Cotton aphid, <i>Aphis gossypii</i> Glover	Pumpkin, cucumber, pepper, brinjal, okra, squash	Closterovirus, mosaic virus, rosette virus

- Integrated management tactics focusing on prevention, detection and control are suggested to keep aphid population below threshold. Paneru and Giri (2011) in their intensive review based book proposed good to follow steps
- Reflective mulch in vegetable seed producing farms has been found effective to repel aphids. Stapleton and Summers (2002) demonstrated the consistently low aphid population with delayed (by 3-6 weeks) landing of aphids on the *Cucumis melo* L. var. *cantalupensis* escaping the flowering and fruit setting stage which is considered crucial for viral diseases (cucumber mosaic cucumovirus and watermelon mosaic and zucchini yellow mosaic potyvirus).
- Scouting and identification is the foremost step of any IPM programs. Aphids are also identified by scouting and survey. Visual survey with some standard transect walks along the vegetable seed producing fields are recommended for aphid monitoring and identification.
- Washing off of the aphids from vegetable crops with pressure spray of water is also effective as the aphids once lodged down cannot climb again up the plants.
- Excessive use of nitrogenous fertilizers and dense planting make plant succulent and more susceptible to the aphids. So, application of balanced fertilizer and planting in a good spacing, especially for the seed production purpose are recommended.
- Conservation of insect predators like lady beetles (*Adalia bipunctata*, *Coccinella septempunctata*), green lace wings (*Chrysoperla carnea*) and syrphid flies. NERC has developed rearing protocol for *C. carnea*.
- Yellow sticky traps are much attractive to the winged aphids. Monitoring and mass attraction both can be performed using traps fitted at the crop height.
- Dusting plant ashes or soap solution on the vegetable crops is helpful to reduce aphid infestation. Spray of cattle urine diluted @ 1:4 with water is also beneficial.
- Neem extracts, tobacco + soap water decoction, and neem-based soft insecticide sprays are also proven effective against the aphids.

- Extraction of some pesticidal plants like; *Justicia adhatoda*, *Melia azedarach*, *Artemisia vulgaris*, and others and spraying after water solution @ 1:4 has been found effective against the pest.
- Different insecticides are found to work differently on different aphid species. However, dimethoate, imidacloprid, thiomethoxam are found having lower LC₅₀ values (Halder et al., 2011). Similarly, spinosad and *Beauvaria* formulations are also found effective (Basnet et al., 2018).

10. White fly

White flies are polyphagous pests and are among the major problems in vegetable production across the world. Among the three popular white fly species (Fig. 18; Skaljac et al., 2012), *Bemisia tabaci* (Gennadius) and *Trialeurodes vaporariorum* (Westwood) are commonly found in Nepal (Paneru and Giri, 2011). *B. tabaci* is commonly a field pest and *T. vaporariorum* is destructive in poly- or green- or glass-house crops. Importantly, tomato seed production under plastic house condition is severely affected by this pest in Nepal.

These homopteran aleyrodids suck cell sap from ventral leaf surfaces and cause direct damage by turning leaves yellow, withering soft plant parts resulting into obstacles in flowering and fruiting for the seed production purpose of the crops. Most importantly, whiteflies are serious vectors of many plant diseases; yellow mosaic and leaf curl diseases. *B. tabaci* is slightly smaller than *T. vaporariorum*, and are distinctly differentiated with their wing postures at rest; *B. tabaci* wings look tent-like tilting gently either sides while in *T. vaporariorum*, they are roof like flat. Nymphal stages are more distinct than the adults (see Fig. 18). The pest with highly fecund females (~320 eggs) can achieve exceptionally the boomed population within a few generations. These factors are equally contributive to the resistance development in whitefly against any kinds of insecticidal molecules. So, whiteflies are also difficult to deal pests.

- Cultural practices like regulating fertilizer and irrigation can be modified to make the crop environment unfriendly for whiteflies.
- Yellow sticky traps installed at crop height for monitoring and mass trapping. Planting at proper crop geometry to avoid dampness and dark in the crop growing environment and thereby reducing the whitefly infestation.
- Drip irrigation is preferred over furrow and sprinkler irrigation to keep crop canopy dry and non-dampened (Abd-Rabou and Simmons, 2012).
- Sulfurous fertilizers are helpful to reduce whitefly infestation (Simmons and Abd-Rabou, 2008).
- UV reflective silver or aluminum coated plastic mulches reduces the severity of white flies in cucurbits, tomato, beans and in chilly (Simmons and Abd-Rabou, 2008;)
- Spray of sour buttermilk help to reduce infestation of sucking pests as milk has a good spreading characteristics and so wings of whiteflies due to casein protein and wetting nature of it causes them to die. Fermented cow milk also can lower whitefly population down by 60% and if sprayed in combination with chili extract, provides a systemic protection (Karthikeyan et al., 2006).
- Some botanical extracts like neem, garlic and some essential oils prevent settling and oviposition by whiteflies on tomato and other plants (Fanela et al., 2016; Castillo-Sanchez et al., 2015; Diabate et al., 2014; Barati, et al., 2013; El Shafie et al., 2012; Nzanza and Mashela, 2012).
- Lady beetles, lace wings and phytoseiid beetles, mirid bugs and predatory mites are popular bio-control agents of whiteflies in green-, glass-house condition.
- Foliar spray of dsRNA to regulate pest population exogenously without genetic alternation is popularly applied to control whitefly too (Cagliari et al., 2019; Dubrovina et al., 2019; Dalakouras et al., 2020; Gogoi et al., 2017), often aided with nanotechnologies, which is yet to be an addressed issue in Nepal.
- Management of whitefly in our condition relies highly on synthetic chemical insecticides. The most commonly used insecticides in Nepal are spiromesifen, spirotetramat, chlorantraniliprole, imidacloprid, flonicamid, nitenpyram along with the *Verticillium lecanii* and *Beauvaria*-based formulations are quiet effective. However,

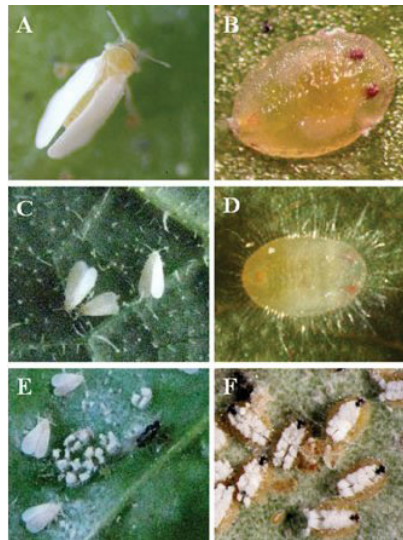


Figure 18. Phenotypical differences between three whitefly species: adults of (A) *B. tabaci*, (C) *T. vaporariorum* and (E) *S. phillyreae*; pupal stages of (B) *B. tabaci*, (D) *T. vaporariorum* and (F) *S. phillyreae* [Source: Skaljac et al., 2012].

whiteflies are also champion of resistance development against these insecticides. So, alternate use of the different groups of insecticides can be practiced.

11. Thrips

Cowpea flower thrips, *Megalurothrips sjostedti* trybom; Melon thrips, *Thrips palmi* Karny; *Frankliniella occidentalis* Pergande; onion thrips, *Thrips tabaaci* Lindeman are the major global thrips infesting many crops including vegetable crops. Scarring spots in leaves, growing buds/ flush and in fruits are the major symptom of direct damage. However, they are much popular for their vectoring efficiency for major viral diseases of crops. Besides these, two more thrips' species [bell pepper thrips, *Thrips parvispinus* Karny (Joshi et al., 2024) and chili thrips, *Scirtothrips dorsalis* Hood (Devkota and Shrestha, 2024)] are recently reported infesting vegetable crops in Nepal.

Thrips are minute and slender thysanopteran insects with fringed wings. They feed on the plant surface tissue contents causing them to die resulting silver-grey patches on the leaves and black dots for their excreta. These are the powerful vectors of many plant diseases like tomato spotted wilt virus, necrotic virus in a range of plants. Scarring on cucumber may result in the "pig-tail" like deformities. To know them, field scouting is required. Direct observation for their presence, for their signs like scarring, can be evaluated and score their presence. Secondly, tapping method can also be used. Finally, and the most conveniently sticky traps are appropriate. Blue traps are the most preferred over yellow and red sticky cards by the thrips.

- Cultural practices like avoiding dampness and dark, proper spacing, balanced soil fertilization and irrigation help to reduce thrips population.
- UV-reflective metalized mulches are efficient to repel thrips' infestation (Razzak et al., 2019)
- As in other sap-feeders like aphids and whiteflies, thrips are also controlled by proper cropping methods, physical and mechanical means.
- Chemical means are the stand-alone methods adopted by many vegetable seed growers. Popular thripicides like azadirachtin, spinosad, emamectin benzoate, thiamethoxam and others are used (Gholami and Sadeghi, 2016). Since the thrips easily develop resistance to many groups of insecticides, rotational use of the insecticides is crucial to slow or break the resistance development.

12. Pulse beetle

Pulse beetles or cow pea weevil or bruchids are oligophagous field-to-storage (and vice versa) pests of legumes including peas and beans in the tropics and sub-tropics (Tuda et al., 2005) inflicting considerable nutritional and germination deterioration (de Sa et al., 2014). It is estimated that the third world countries suffer 12-30% storage loss of the legume seeds to this pest (Proctor, 1994). In Nepal, it is the major stored product insect pest of legumes including leguminous vegetable seeds like cow pea, faba bean, broad beans, French beans, four season bean and others. Two species are globally and in Nepal also; *Callosobruchus chinensis* (L.) and *Callosobruchus maculatus* (Fabricius) are competing the similar ecological and nutritional guilds, probably creating an interspecific competition. The identical difference between two species is antennal type. *C. chinensis* is dimorphic; males have pectinate and females have serrate antennae. But, *C. maculatus* males and females both have serrate antennae. The beetles start to glue their eggs on the seed surface of stored vegetable legume seeds which is the very first indication of pest attack. Larvae, the most destructive stage, tunnel and reside in the grains (Credland and Wright, 1990). Since the pest is field-to-storage, it certainly imposes troubles in its management.

- Monitoring with female sex pheromone traps or with sweep netting can be the options to detect the pest in field. Much attractive pheromone components and synthesis methods are developed (Chiluwal et al., 2017; Shimomura et al., 2008).
- Paneru and Giri (2011) suggests to admix sweet flat (*Acorus calamus*) stolen powder or basil leaf powder @ 5 g/ Kg seeds of peas, beans or cow peas; or admixing gains with mustard oil (10mL/ kg of seeds) in storage.
- Essential oils from some pesticidal plants like star anise, wintergreen, croton and other common spices are strong repellents and oviposition deterrents against the bruchids (Chiluwal et al., 2017; Chaubey, 2013; Chaubey, 2008).
- Recent regulation on the celphos (aluminium phosphide) 3 g tablets, popular for storage safe-gourd of many post-harvest commodities, has triggered the search for safer alternatives. Ethyl formate alone and in combination with others have been sought an alternative (Chiluwal et al., 2023, 2020).
- Storage surface treatment, sun-drying of seeds before storage and metal bin or storage in super grain bags are common practice among the farmers.

- Recent experiments in NERC, Khumaltar have found plant essential oils of timur (*Zanthoxylum armatum*), clove (*Syzygium aromaticum*) and others are potential against the bruchid pests.

Keep an Eye on Invasive and Trans-Boundary Insect Pests

Though the global likelihood (0.001) of invasion is very unlikely (Williamson and Fitter, 1996), if it happens, exhibits a catastrophic situation (Venette and Hutchison, 2021). Most importantly, Nepal stands globally the third in terms of overall threat of pest invasion in contrast to its 109th position as an invasion source country (Paini et al., 2016). Every nation, especially Nepal for its invasion-prone geographical location, should keep an eye to the future possible threats of the pests. Immediate control over the pests faces challenges as the invasions are new to our ecosystem, have no natural enemies to naturally suppress their population, lack research results and the extension materials. In those instances, Venette and Hutchison (2021) suggest for prediction and prevention, early detection and rapid response, and management and mitigation. Here, some insect pests globally invading at the fastest rate and possibly invading Nepal and posing threat to vegetable seed sector are discussed.

1. Colorado potato beetle

Though name affixed with potato, Colorado Potato Beetle (CPB) *Leptinotarsa decemlineata* (Say) feeds on a range of solanaceous crops like brinjal, tomato, pepper and others causing total destruction of chlorophyllous leaves before florescence and seed set (Carson-Taylor and Tubam, 2024). These chrysomelid leaf beetle adults (Fig. 19 Left) after overwintering emergence from soil forage a week before laying their bright yellowish-orange oval eggs in cluster (10-30 eggs) on ventral of the leaves. If left untreated, both larvae and adults feed on and completely defoliate the crops. Old grubs (4th instars) are reported to cause 75% damage (Hodgson, 2024).

This prolific breeder (350 eggs per female over 3-5 weeks) because of its polygamy nature (Alyokhin et al., 2015) is of serious global quarantine concern and has already colonized global potato belts (Fig. 20) of Andes peripherals, North America, Europe and Northern Africa and Eurasian ranges and even to our northern neighbor, China (Liu et al., 2014). Moreover, the pest is champion in developing resistance and cross resistance against broad range of insecticides from not-in-use DDT to the neonicotinoids like imidacloprid, thiamethoxam (Quinton, 1955; Alyokhin et al., 2007; Mota-Sanchez et al., 2006; Rondon et al., 2021) by deploying DNA methylation, the process of epigenetic changes (= turning certain genes on and off) which is heritable down to the grandkid generations efficient to tolerate a broad range of toxins (Brevik et al., 2021). Huseth et al. (2014) proposed a new tool and strategy to CPB control by using a product rotation model thereby checking the resistance development in CPB which is an essential element of responsible product stewardship as it is increasingly difficult and costly to develop a newer insecticide in place of insect-resistant one. RNAi-based methods of pest control are marked as avenue against the CPB if some challenges; potential off-target effects, development of resistance against RNAi-technology and overall cost associated with its formulation are addressed (Timani et al., 2023). However, following recommendations of professor of Iowa State University, Hodgson (2024) could settle the CPB problems to below economic level;

- Cultural: sanitation and removal of potential food hosts for an effective starvation technique
- Degree days - based scouting and monitoring (i.e. when temperature starts to rise with spring) to detect the emergence of over-wintered adults
- For small scale cultivation, hand removal or lodging of adults, egg batches and larvae into soap-water
- Crop rotation to check population build-up



Figure 19. Colorado potato beetle adult (Left) and grubs (right) (Source: Carson-Taylor & Tubam, 2024)

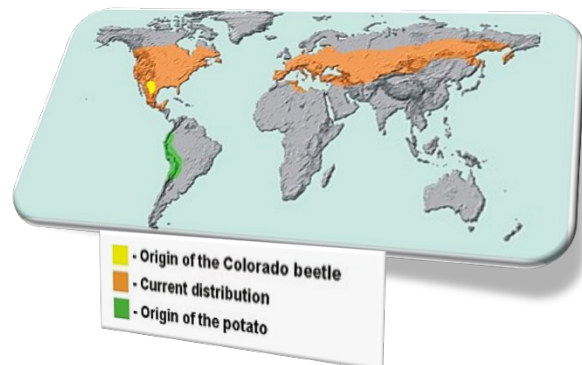


Figure 20. Global spread of Colorado beetle (Source: Venette & Hutchison, 2021)

- Deep plowing to expose over-winter adults up for encouraging predation by birds and other predators
- Early-maturing varieties to escape the CPB attack
- White muscardine fungus *Beauveria bassiana* are effective against adults and grubs
- When crosses the threshold (20-30% at vegetative stage, 5-10% at flowering and 15-20% post-flowering stage) despite above practices, management options should switch to microbials, plant derived and synthetic insecticides
- Neem oil sprays after notifying the maturing CPB eggs and early instar grubs
- Spinosad is also an effective insecticide against the CPB larval stages

2. Japanese beetle

Highly polyphagous and aggressively colonizing Japanese beetle (JB) *Popillia japonica* (Coleoptera: Scarabaeidae) hosts on >300 plants (Fleming 1972) and has attained cosmopolitan distribution (EPPO, 2016). Different feeding guilds of grubs (root zone) and adults (aerial parts) is key to its rise as a destructive pest and so the management is troublesome. In light of ongoing rapid climate change, Rocca and Milanesi (2022) model confirmed the JB colonization across the globe by 2050 (Fig. 21) and intensity of colonization would shift further north with at least 23% range expansion in Europe by this mid-century (Kistner-Thomas, 2019).

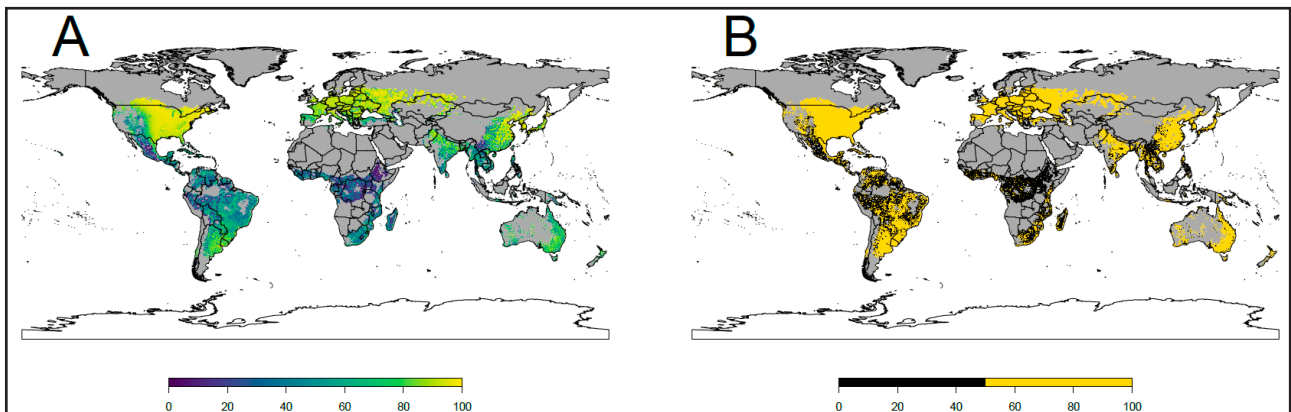


Figure 21: Distribution maps of the JB, estimated under current conditions (A) yellow–blue scale indicates higher–lower occurrence probability values, respectively, (B) areas of predicted species occurrence, presence shown in orange, while absence shown in black and those with below threshold are shown in grey (Source: Rocca and Milanesi, 2022).

Prediction Fig. 21 clearly shows Nepal will face JB problem by this mid-century and so the vegetable seed production industry will face another difficult-to-tackle problem. So, ideal and applicable management practices should at the hand to tackle the JB challenges.

- Strict quarantine and biosecurity checks (Rocca and Milanesi, 2022)
- Scouting and monitoring in much aggregation areas of field like field edges of downwind sides (Sara et al., 2012) and preferably on the most sun-lit plants of the field (Rowe and Potter, 1996; 2000)
- Small scale hand pick is possible. However, vegetable seed production blocks are larger in major. So, further management practices are warranted.
- Monitoring and management with combination of Japonilure and food-type volatile blend (Ladd and MCGovern, 1980)
- Weed management in JB control program is crucial as they shelter in weedy plants during non-host season (Szenderi and Isaacs, 2006; Rodenhouse et al., 1992) and some
- Strip intercropping with antagonist crops (Szenderi and Isaacs, 2006) like wheat/sorghum, reducing soil moisture by irrigation cut off (Potter and Held, 2002; Potter et al., 1996), addition of higher organic matter (Potter and Held, 2002; Dalthorp et al., 2000) and removal of weed shelters (like buckwheat, rye grass and clover) and crop residues (Szenderi and Isaacs, 2006) are some cultural practices to limit oviposition and larval development of JB, especially in vegetable nurseries.
- Early morning or evening drenching of entomopathogenic heterorhabditid nematodes (250,000 infective juveniles in a square meter) in fair moist content soil is as efficacious as chlorpyrifos against JB larvae (Klein

and Georgis, 1992; Shapiro-Ilan et al., 2002).

- *Tiphia vernalis* Rohwer wasp externally parasitizes the overwintering grubs following a kairomonal stimuli but, due care should be taken not to spray imidachloprid during seasonal adult flights (Rogers and Potter, 2003).
- Nepal is rich in native generalists and soil-dwelling natural enemies like ground beetles, rove beetles, ants and other carnivorous scarabs, the US and Europeans strains of which are reported to feed on eggs and grubs of scarabaeid pests like JB (Terry et al., 1993). So, the protection of these NEs could be a tactic to defend JB if invaded Nepalese seed producing vegetable farms
- Bacterial insecticide Bt to defend JB (Btj) isolated from Japanese soil has been detected as effective and applicable as soil-applied insecticides (Potter and Held, 2002).
- Though the control efficacy of 90% JB adults by *Istocheta aldrichi*, a pronotom-preferring JB-specific parasitoid fly in Japan dropped down to 20% in US (Shanovich et al., 2019), could be introduced in Nepalese vegetable seed producing farms if found synchronized with the host population in our geo-topo-climatic condition.
- As summarized by Shanovich et al. (2019), diamide insecticide chlorantraniliprole as a seed treatment protects seedlings from the grubs and adults during nursery stage. Pyrethroids popularly used in Nepal (like cyfluthrin, lambda-cyhalothrin, permethrin), neonicotinoids (acetamiprid, imidacloprid, thiamethoxam) and azadirachtin-containing neem products could be deployed against the JBs. However, the chemical tactics are to be adopted in rotation to avoid/slow down/ break resistance as JBs are reported successful insecticide-resistant.

3. Spider mites

The cosmopolitan two-spotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae) family includes ~4000 species (Domingos et al., 2014; Migeon et al., 2007). Intrinsic rate of increase (4-6 generations a season) (Laing, 1969), fastest life-cycle (8 days) in a suitable temperature range (25-30°C) (Jakubowska et al., 2018) facilitated by haplodiploidy (haploid and monogamous male, diploid and polygamous female) (Yoshioka and Yano, 2014) and expansion in territories resulted by the global warming and subsequent climate change (Ximenez-Embun et al., 2017; Meynard et al., 2013; Migeon et al., 2009) are some key facts behind the resistance development to popular miticides (Van Leeuwen et al., 2010; Osakabe et al., 2009) by the mites, their cosmopolitan distribution and their adverse effects on the crop damage, yield losses, quality deterioration and economic damage (Archer and Bynum, 1993; Grbić et al., 2011). The post-winter to full spring season temperature range characterized by the dry weather in Nepal are favorable for the magnificent increase of the mites. Vegetable crops like cucumbers, okra, tomato, eggplant and pepper are mainly attacked and their seed production is hampered in many cases and are in the verge of pandemic attack by these polyphagous, cosmopolitan and hardy to control mites. Mite management options mainly relies on chemical options. In Nepal, components like bifentazate, buprofezin, fenpyroximate, fenazaquin, hexythiazox and propargite are registered as miticides (PQPMC, 2020). However, general insecticides like abamectin, imidacloprid, azadirachtin and others are also used. So, integrated approach should be a deal.

- Foremost tactic of mite control should be scouting field in Z- or W-pattern with a hand-lens observation if suspected specks are noticed. If mites are found scattered in middle and top canopy, starts of the further management tactics are recommended (Dean and Hodgson, 2024)
- Use balanced doses of fertilizers, specially no over-application of nitrogenous fertilizers which favors increased population growth rate (r) and fecundity (Taghizadeh and Chi, 2022)
- -Overhead irrigation like sprinkling reduces mite infestation in vegetable crops (Opit et al., 2006) to facilitate easy florescence initiation and seed set. Overhead irrigation reduces mite population by creating wet surface, by dislodging the mites and by washing the dusts on plants and by creating favorable environments for predators.
- Intercropping vegetables with garlic causes 44-65% reduction in the mobile mite population and egg laying also decreases by 38-65%, the effect could be attributed to the major components (diallyl disulfide or diallyl trisulfide) in garlic (Mohammadi et al., 2021; Hata et al., 2016).
- Fungal and bacteria-based bio-pesticides have proved to be highly acaricidal. Popularly available commercial formulations of *Bacillus thuringiensis*, *Beauveria bassiana* and *Metarrhizium anisopliae* could be successfully used against the mites as many authors have reported >90% efficacy against adult and juvenile mites (Zenkova et al., 2020; Marcic, 2012; Chandler et al., 2005).
- Host plant resistance (HPR) is somehow working in international researches. HPR is mainly attributed to the physical aspects like leaf blade structure, presence of glandular and non-glandular trichomes which secrete

secondary metabolites (such as terpenoids, alkaloids, flavonoids and polyacetylenes), the defense compounds (Rattan, 2010).

- Due to those secondary metabolites, many botanical products like neem oil, extract of pesticidal plants are acaricidal (Dabrowski and Sereczynska, 2007; Rattan, 2010; Souto et al., 2021; Ebadollahi et al., 2014; Topuz et al., 2018). Interestingly, aggregation pheromone component of Japanese pine sawyer (monochamol) is also proved to be acaricidal (Chiluwal et al., 2022). However, its commercialization is an awaiting research issue.
- Nepal being rich in acaricidal plants, could be grabbed benefits of using them. Neem based insecticides work greatly in the integrated approach of the mite management. However, Prophylactic treatments before the mites reach EIL are appreciable.
- Though the mites have developed many-fold of resistance against popular miticides across the world, they could be put in rotation for the mite management so as to break or slow down the resistance development. Chemical constituent, propargite is available in Nepalese market (PQPMC, 2020) with some companions like bifentazate, buprofezin, fenpyroximate, hexythiazox. Common insecticides like dimethoate and other organophosphates could also be included in the rotational foliar sprays against the mites.

Suggestions

- Strong research on local, regional, invasive and trans-boundary pest insects
- Molecular-based phylogenesis and geographical distribution identification so as to present scientific evidence in the international communities for right to have compensation for total invasion cost to threatened countries like Nepal.
- Research on newer interventions (like RNAi,) technology in insect pest management.
- Strengthen research, education and agro-advisory systems for the efficient agricultural innovation system in Nepal with special emphasis on insect pest management of vegetable seed production.
- International ties on technology exchange to mitigate the problems of pest insects on vegetable seed production
- Provision of plant protectionists at every local bodies with full authority of pesticide inspection, pest survey-surveillance and focal person to adhere with the research bodies
- Research support from IPPO as Nepal is among the most vulnerable to invasion of pest insects
- Cross cutting issues like host plant resistance to be incorporated for varietal release and registration in Nepal

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