Chapter

Holistic Pest Management Strategies in Tropical Plant Species

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Abstract

The tropical climate shift is causing herbivores to emerge almost ceaselessly throughout the year in certain regions exhibiting homodynamic cycles and unbalanced biodiversity. Crop management and pest management are being viewed as separate activities, with recent focus on sustainability. Even though there is a great deal of information on crop loss assessment, systems analysis, systems modelling, individual pest sciences, and pest management, the Integrated Pest Management (IPM) concept is not frequently deployed. The IPM system is a multi-tactic approach to pest management in agricultural production that takes into account economic, environmental, ecological, and human health implications. This paper provides an overview of key achievements in the development of management strategies, including the transition from a specific level of pest control that focuses on the suppression of target pests to an eco-friendlier and/or systems approach to pest management that employs a variety of non-chemical options as well as the judicious use of pesticides. The agroecological protection techniques and their integration to sustainably minimise pest risks are also reviewed here and describe technological advances in tropical pest management using host resistance, semiochemicals, natural enemies, selective pesticides, ecological engineering and habitat management which promotes sustainable pest management.

Keywords: tropical crops, pest, synthetic insecticides, integrated pest management

1. Introduction

Changes in pest populations and natural enemies in the tropics are more difficult to understand and manage due to various factors such as climate change and non-judicial use of control techniques [1]. The crop health and production are thus, irreparably harmed across the world in addition to the time-worn exploitation of synthetic organic pesticides that rooted an increased chemical pressure in agroecosystems ensuring technical, environmental and health consequences [2]. As a result, there is a rising awareness of the harmful impacts of chemical pesticides, leading to the notion of integrated pest management, which is esteemed as an ecosystem-based pest control philosophy aimed at achieving protracted pest or damage prevention through a holistic approach [3]. The concept of IPM was established as an alternative to pesticides and the strategy entails a combination of techniques in a coordinated manner to keep insect populations below the threshold at which they cause significant loss [4]. The

key components of this technique include compatible cultural, mechanical, biological and chemical methods of controlling insect pests and rodents [5]. Managing the diversity of natural enemies to promote crop productivity could help minimise the usage of synthetic pesticides in agriculture [6]. Landscape management, on the other hand, has been shown to increase the prevalence of natural enemies, hence improving biological control and perhaps reducing pesticide use [7]. They are well-known for causing significant crop yield losses by reducing plant survival, growth, and reproduction. Global yield losses are estimated to be between 7.9% and 15.1% [8]. Along with the notion of Integrated Pest Management, pest control practices are divided into two categories: human input-based practices and biodiversity-based practices [9]. The IPM strategy entails using a variety of techniques in a coordinated manner to keep insect populations below the threshold at which they cause significant loss and reduces the use of chemical pesticides, minimising their negative consequences [10]. The farmers' perception is that pesticides can give a quick and certain control within a short period. They lack knowledge of other management strategies and considered them as not practical because of lack of training. In this chapter, we have briefly described the important tropical crops and their integrated management which will be useful for training personnels and researchers.

2. Integrated pest management in cereals

2.1 Rice

2.1.1 Important pests of rice

Yellow stem borer (*Scirpophaga incertulas*), Brown plant hopper (*Nilaparvata lugens*) and White backed plant hopper (*Sogatella furcifera*), Leaf folder (*Cnaphalocrocis medinalis*), Gundhi bug (*Leptocorisa acuta*), Gall midge (*Orseolia oryzae*), Termite (*Odontotermes obesus*), Rice Hispa (*Dicladispa armigera*), Climbing cutworm/Rice Ear Cutting Caterpillar/ Armyworm (*Mythimna separata*), Caseworm (*Nymphula depunctalis*), Mealy bug (*Brevennia rehi*), Black bug (*Scotinophara coaractata*).

2.1.2 Integrated pest management approach

Clipping the tops of bundled seedlings is a typical method for eliminating eggs and larvae of stem borer, hispa, thrips and leaf folder [11]. Plant hoppers, leaf hoppers, leaf folders, gall midges and cutworms are all kept at bay by keeping enough space between plants. Aquatic insects such as whorl maggot, root weevils, yellow stem borer, and case worm are suppressed when fields are drained for 1–2 days. Crop rotation is used to combat gall midge, stem borer, and termites. Infestations of white-backed plant hoppers can be controlled by planting rice crops at the proper time and synchronising transplants. Deep summer ploughing of fields reduces insect pest populations by exposing them to bird predation and parasitization. Flooding the field shortly after harvest has been mostly utilised to combat stem borer [12]. Mechanically trapping or crushing insects with a hand, tool, or machine is a traditional method to protect the rice crop from pests [11]. Pheromones were particularly effective in the control of the yellow stem borer, where they were employed for both

species monitoring and management via mating disruption or mass catching of males. The bulk of paddy pests is combated by a range of natural enemies like *Tetrastichus* spp., *Telenomos* spp., and *Trichogramma* spp. *Xanthopimpla flavolineata* was found as a prominent rice leaf folder pupal parasitoid. In various hoppers, more than 100 parasitoid species and 72 predatory species have been. Spiders are the most prevalent predators in the rice environment. The wolf spider, *Lycosa pseudoannulata*, and *Oxyopes* sp. destroyed up to 90% of 130 borer larvae in a single day. This spider was also dangerous to stem borer moths. Neem seed kernel extract (NSKE) 5% and neem oil 3% were effective against brown plant hopper, as were botanical powder formulations using NSKE, *Vitex negundo*, *Prosopis juliflora*, and *Ipomoea carnea* leaf extract 5% for earhead insect and black bug [13]. The plant-derived natural compound chrysoeriol7 can potentially thus be used to develop environmentally-friendly pesticides [14]. Chemical insecticides, such as carbofuran 3% CG or carbosulfan 6% G or carbosulfan 25% EC for gall midge, are applied based on need. Cartap hydrochloride 4% granules or cartap hydrochloride 50% SP, carbofuran 3% CG or monocrotophos 36% SL for stem borer. Carbofuran 3% CG or monocrotophos 36% SL, apply cartap hydrochloride 4% granules, cartap hydrochloride 50% SP @, monocrotophos 36% SL, or chlorpyrifos 1.5% DP for leaf folder Spray imidacloprid 70% WG or imidacloprid 30.5% m/m SC @ or ethofenoprox 10% EC or acephate 75% SP or buprofezin 25% SC @ or ethofenoprox 10% EC or acephate 75% SP or buprofezin 25% SC for brown plant hopper, WBPH and other sucking pests [15].

2.2 Maize

2.2.1 Important pests

Maize stem borer (*Chilo partellus*), Pink stem borer (*Sesamia inferens*), Shoot fly (*Atherigona spp*.), White grub (*Holotrichia consanguinea*), Cut Worm (*Agrotis ipsilon*), Hairy caterpillar (*Amsacta albistriga*), Aphid (*Rhopalosiphum maidis*), Army worm (*Mythimna separata*), Pyrilla (*Pyrilla perpusilla*), Thrips (*Anaphothrips sudanensis*), Termites (*Microtermes obesi*), Chafer beetle (*Chiloloba acuta*), Fall armyworm (*Spodoptera frugiperda*).

2.2.2 IPM approaches

To minimise pest populations, remove and destroy crop leftovers, any substitute host plants after harvest, and cut stems harbouring diapausing larvae. Growing recommended hybrids and composites and seeding with the first rain to minimise borer attack. Crop rotation with non-hosts proved highly efficient. Insects become more common as plant density increases. Insect incidence rises as plant density rises; so, the suitable plant population should be kept in the fields to prevent insect incidence. *Trichogramma* spp., a parasitic egg parasite can be used to keep stem borers away. Many spider species have been discovered in plant whorls feeding on stem borer eggs and early larval stages. Adult *Menochilus sexmaculata* Fab. and *Coccinella septumpunctata* L. coccinellid beetles feed on newly emerging stem borer larvae [16]. To control one of the annoyance pests, the fall armyworm (FAW), single cross maize hybrids were selected, as well as heavy ploughing before each crop season to open up the soil and expose FAW pupae to sunshine and predators. The FAW trap crop was sown in the form of Napier grass in the border rows. According to the researchers, seeds treated with Cyantraniliprole 19.8%

+ Thiomethoxam 19.8% @ 4 ml per kg seed offered protection for up to 2–3 weeks after germination [17] If staggered seeding is required, spray the crop with 5% NSKE or azadirachtin 1500 ppm @ 5 ml/l at weekly intervals, as in peri-urban baby corn and sweet corn cultivation. Release 50,000 *Trichogramma pretiosum* or *Telenomus remus* seeds per acre at weekly intervals beginning a week after germination and continuing until harvest. Instal 5 FAW pheromone traps per acre before or during crop germination [18]. To keep population growth under control, mass capture male moths using traps. Need-based pesticides should be used to efficiently remove the pest, viz. carbofuran 3% CG for stem borer, shoot fly and thrips, dimethoate (30% EC for Stem borer and Shoot fly), imidacloprid (48%) FS, monocrotophos (36% SL), oxydemeton (25%) EC for shoot fly, thiamethoxam 30% FS for stem fly, thiamethoxam 70% WS for shoot fly & aphids, thiamethoxam 12.6% + lambda cyhalothrin 9.5% ZC for aphid, shoot Fly, stem borer [19].

2.3 Wheat

2.3.1 Important pests

Termite (*Odontotermis obesus, Microtermes obesi*), Wheat aphid (*Sitobian avenae*), Army worm/cut worm (*Mythimna separata*), American pod borer (*Helicoverpa armigera)*, Brown mite (*Petrobia latens*), Pink stem borer: (*Sesamia inferens*), Shootfly (*Atherigona naqvii*).

2.3.2 IPM approaches

Deep summer ploughing should be done in May and June to expose nematodes, rodents, and pupating larvae to radiation and predation termite management will be facilitated by the use of well-rotten farmyard manure, while it will be lowered by planting late and treating seeds with chlorpyriphos at a rate of 4 ml per kg of seeds prior to sowing. *Trichogramma* sp. was released at a rate of 50000 per acre for 2 to 3 times to suppress lepidopteran pests [13]. Need based insecticides viz., bromadiolone 00.005% RB for Indian field mouse, field rat, carbofuran 3% CG for ear cockle nematode, cereal cyst nematode, cypermethrin 10% EC for shoot fly, fipronil 0.3% GR for termites, imidachloprid 48% FS for aphids and termites, quinalphos 25% EC for aphid, ear head caterpillar and mite, thiamethoxam 70% WS for termites & aphids, thiamethoxam 25% WG for aphids were effectively utilised [20].

3. Integrated pest management in millets

3.1 Sorghum

3.1.1 Important pests

Shoot fly (*Atherigona soccata*), Stem borer (*Chilo partellus*), Midge (*Stenodiplosis sorghicola*), White grub (*Holotrichia consanguinea*), Armyworm (*Mythimna separata*), Cutworm (*A. ipsilon*), Grasshopper (*Hieroglyphus sp*), Pyrilla (*Pyrilla perpusilla*), Shoot bug: (*Peregrinus maidis*), Earhead caterpillars (*Helicoverpa armigera*), Earhead

bug (*Calocoris angustatus*), Sugar cane aphid (*Rhophalosiphum maidis*), Spider mite (*Oligonychus indicus*).

3.1.2 IPM approaches

Sowing dates must be altered based on the population dynamics of the main pests to keep the pest population under control. Sowing the same cultivar early and consistently across large areas reduced shoot fly, midge, and head bug damage. Cultural practices such as high seed rate, balanced fertiliser treatment, field cleanliness, weeding, and intercropping with legumes reduced damage from shoot fly, stem borer, armyworm, and sorghum midge. Pest resistant cultivars should form the foundation of any sorghum pest control approach. P 311, SPV 1015, M-35-l, Swati, and CSV 14R are resistant to shoot fly and are suitable for cultivation throughout the rainy and post-rainy seasons [21]. In locations where head bugs and caterpillars are common, cultivars with loose panicles, such as ICSV 88032, can be grown. Insecticides derived from plants, such as those obtained from *Azadirachta indica* (neem), *Annona squamosa*, *Acrorus calamus*, *Catharanthus roseus*, and others, were exploited in IPM [22]. Sorghum shoot fly eggs have been parasitized by *Trichogrammatoidea bactrae* and *Trichogramma simmondsi*; *Trichogramma evanescens*, *Trichogramma kalkae*, T*richogramma chilonis* and *Trichogramma*. *australicum Aprostocetus spp*. and *Neotrichoporoides* (*Tetrastichus*) *nyemitawus* were the most important shoot fly larval parasitoids. Need-based insecticides viz., malathion 50% EC for earhead midge, Oxydemeton – methyl 25% EC for shoot fly, phenthoate 2% DP for red spider mite, pink mite, purple mite, scarlet mite, phosalone 4% DP for ear head midge, quinalphos 5% G for stem borer, quinalphos 25% EC for Mite and Shoot fly, quinalphos 1.5% DP fo earhead bug, earhead midge, thiamethoxam 30% FS for shoot fly.

3.2 Pearl millet

3.2.1 Important pests

Cutworm (*A. ipsilon*), white grub (*Holotrichia* consanguinea), shoot fly (*Atherigona soccata*), stem borer (*Chilo partellus*), grasshopper (*Hieroglyphus* spp.), white ant (*Chrotogonus* sp), grey weevil (*Myllocerus* sp), earhead bug (*Calocoris angustatus*), hairy caterpillar (*Spilosoma obliqua*), earhead worm (*Cryptoblabes gnidiella*), blister beetle (*Mylabris pustulata*), chaffer beetle (*Rhizotrogus majalis*).

3.2.2 IPM approaches

The pest management strategies recommended for sorghum might likewise be used for pearl millet. Long-term pearl millet pest control requires the development of high-yielding insect-resistant cultivars and hybrids. Among the possible sources of resistance discovered for numerous pests were MP-16, MP-19, MP-53, MP-67, MH-49, MH-52, MH-9, MH-82, MH-99 and MH-105 [16]. Shoot fly may wreak havoc on late-planted kharif crops. As a result, sowing should begin soon after the monsoon begins, or no later than 10–15 days after the first monsoon rain. Adult beetles of White grubs were gathered and exterminated immediately after the first shower in the endemic zones after mating on trees such as neem or Acacia.

4. Integrated pest management in pulses

4.1 Important pests

Pod borer (*Helicoverpa armigera*), spotted pod borer (*Maruca vitrata*), spiny pod borer (*Etiella zinckenella*), blue butterfly (*Lampides boeticus*), grass blue butterfly (*Euchrysops cnejus*), bihar hairy caterpillar (*Spilosoma obliqua*), stem fly (*Ophiomyia phaseoli*), pod weevil (*Apionam plum*), bean Aphid (*Aphis craccivora*), leaf hopper (*Empoasca kerri*), podfly (*Melanagromyza obtuse),* lab bug(*Coptosoma cribraria*), whitefly (*Bemisia tabaci*), thrips (*Megalurothrips usitatus*), blister beetle (*Mylabris spp*), stem fly (*Melanagromyza sojae*), tobacco caterpillar (*Spodoptera litura*), green semi-loopers (*Chrysodeixis acuta, Gesonia gemma and Diachrysia orichalcea*), girdle beetle (*Obereopsis brevis*), pod borer (*Helicoverpa armigera*), white fly (*B. tabaci*).

4.2 IPM approaches

Plant spacing, sowing time, intercropping, and soil activities can all be adjusted to reduce *H. armigera* harm Chickpea germplasm with low to high insect pest resistance has been established. Deep ploughing of fields in the summer and leaving the land for solarization are widespread cultural practices in black gram and green gram pre-sowing [23]. Avoiding waterlogging, judicious fertiliser usage, and other common cultural methods for stem fly, pod weevil, pod fly, blister beetle, white grub and grass butterfly management. Installing light traps in and around fields to minimise crop stress [24], enhancing parasitic activity by avoiding chemical spray collecting and destroying eggs and early-stage larvae, handpicking older, gregarious caterpillars and cocoons during early stages and using yellow/blue pan water/sticky traps @ 4–5 traps/acre [25] light traps @ 1/acre, and pheromone traps @ 4–5/acre for monitoring adult moths' activity. Cleaning of infected stubbles followed by deep summer ploughing, optimal fertiliser application, timely sowing, proper seedbed conditions and depth of sowing, optimum seeding rate and plant population, regular scouting, rogueing, and destruction of infected crop/plant parts, elimination of collateral/alternate and reservoir hosts, crop rotation and intercropping, cultivation of soybean only during the rainy season, and agronomic practices to avoid pests are all common cultural practices in soybean [26]. Collecting and eliminating girdle beetle-infested plant parts, egg masses, and gregariously feeding hairy caterpillar and tobacco caterpillar larvae should be prioritised. Ten to twelve bird perches will be installed on each acre. Pheromone traps should be used to track the spread of *S. litura* and *Helicoverpa armigera*, as well as Castor as a tobacco caterpillar trap crop and Dhaincha as a girdle beetle trap crop. It is recommended to intercrop soybean with asafoetida (early maturing variety), maize, or sorghum in a 4-row soybean with 2-row intercrop sequence. Increased biodiversity will aid natural biocontrol fauna such as coccinellid beetles, *Chrysoperla*, and others. In girdle beetle and semilooper endemic areas, intercropping with maize or sorghum should be avoided. *Campoletis chlorideae*, an ichneumonid, is the most prominent chickpea larval parasitoid of *Helicoverpa armigera* Six parasitoid species have been identified in Helicoverpa pupae collected in the field and potential biocontrol agents for *B. pisorum* have been reported *Chrysopa spp*., *Chrysoperla spp*., *Nabis spp*., *Geocoris spp*., *Orius spp*., *Polistes spp*., and species belonging to the Pentatomidae, Reduviidae, Coccinellidae, Carabidae, Formicidae, and Araneidae, respectively, are the most prevalent predators of insect pests The entomopathogenic fungus *Nomuraea*

*rileyi*caused 90–100% larval mortality, while *Beauveria bassiana* Balsamo caused only 6% chickpea damage compared to 16.33% damage in untreated control plots Spraying *Bacillus thuringiensis* (Bt) (Berliner) formulations later in the day yields greater control than spraying earlier in the day. Vegetable oils, neem oil, and karanj oil are excellent in protecting pulses from bruchid damage. For the management of *Helicoverpa armigera*, strategies for deploying Bt genes in transgenic chickpea have been devised. In order to deal with the Bihar hairy caterpillar, preventing preharvest infestation by irrigating once to forestall a prolonged mid-season drought. Dig 1-inch-deep holes between the fields and dust them to kill the larvae. To control the larvae, spray Quinalphos 25% EC 600 ml diluted in (black gram) or Phenthoate 50% EC diluted in (blackgram & greengram). Rates of sowing and seeding the ideal seed rate should be used depending on seed size. After every 15 rows, a one-row break should be provided to enable for spraying in a standing crop. Conservation of spiders, coccinellid beetles, tachinid fly, praying mantids, dragon fly, damsel fly, *Chrysoperla*, and meadow grasshoppers by limiting the use of wide-spectrum pesticides and releasing *Telenomus remus* at a rate of 50000/ha against *S. litura*. Spraying *B. thuringiensis var. kurstaki*, Serotype H-39, 3b, Strain Z-52 at a rate of for semilooper complex management (*Chrysodeixis acuta*, *Gessonia gemma*, *Diachrysia orichalcea* and *defoliators*). *Trichogramma chilonis*, *Tetrastichus*, and *Telenomus* are egg parasitoids, while *Ichneumon promissorius*, *Carcelia sp*, and *Diglyphus isaea* are larva parasitoids of *Spodoptera* and *Helicoverpa*; *Xanthopimpla flavolineata* is both a larval and a pupa parasitoid of an adult wasp; *Encarsia formosa*, *Eretmocerus sp*. Removal and destruction of damaged plant parts, as well as two applications of monocrotophos 36 WSC at one and three weeks of crop age. Need-based insecticides viz., Monocrotophos 36% SL, Chlorantraniliprole 18.5% SC, Lufenuron 5.4% EC, Thiodicarb 75% WP (*Helicoverpa* spp.) & (*Maruca* spp.), Novaluron 05.25% + Indoxacarb 04.50% SC, Azadirachtin 0.03% (300 PPM) for pod Borer, Flubendiamide 39.35% w/w SC for fruit borer, Flubendamide 20% WGfor *S. litura*, *Maruca spp*, Pod borer, Quinalphos 25% EC for Bihar hairy Caterpillar, *Beauveria bassiana* 1.0% WP for gram pod borer (*Helicoverpa armigera*), *Metarhizium anisopliae* 1.15% WP for *Heliothis armigera*, NPV OF *Helicoverpa armigera* 2.0% AS Strain for pod borer (*Helicoverpa armigera*), Bromadiolone 0.005% RB, Indian house rat, field Rat, Chlorantraniliprole 18.5% SC for green semi looper, stem fly, girdle beetle [27, 28]. Bioefficacy of flubendiamide 24% w/v + thiacloprid 24% SC w/v against shoot and fruit borer and its sucking pests and its safety to non-target organisms in brinjal was also proved.

5. Integrated pest management in oilseeds.

5.1 Groundnut

5.1.1 Important pests

Aphid (*A. craccivora*), bruchids (*Caryedon serratus*), jassid (*Empoasca kerri*), leaf miner (*Aproarema modicella*), termite (*Odontotermes spp*.), thrips (*Scirtothrips dorsalis, Thrips palmi*), tobacco caterpillar (*S. litura*), white grub (*Lachnosterna (Holotrichia) serrata* and *Lachnosterna (Holotrichia) consanguinea*), Bihar hairy caterpillar, (*Spilosoma/Diacrisia obliqua*), gram pod borer, (*Helicoverpa armigera*), jewel beetle (*Chrysochroa fulgidissima*).

5.1.2 IPM approaches

Semi loopers, capsule borers, and hairy caterpillars in groundnut can be controlled by planting one row of pigeonpea following groundnut. The following methods are used to manage *Helicoverpa armigera*: Setting up pheromone traps at a rate of 10 per hectare to monitor *Helicoverpaa armigera* / *S. liturai [29]*, When a considerable number of eggs and early instar larvae are seen, HaNPV @ 250 LE/ha or SlNPV @ 250 LE/ha or Bt. 1 kg/ha or 5% NSKE will be sprayed if not reduced [30]. Pre-monsoon planting reduces damage from white grub and bud necrosis (if protective irrigation is available). The plants' cowpea or soybean function as trap crops for leaf miner. The major predators are a wide variety of spiders, *Odynerus punctum*, *Coccinella septempunctata*, *Chrysoperla carnea*, *Rhynocoris marginatus*, reduviid bug, praying mantis, fire ants, big eyed bugs (*Geocoris* sp.), pentatomid bug (*Eocanthecona furcellata*), earwigs, ground beetles, rove beetles etc. *Ovomermis albicans*, a nematode etc. and parasitoids are *Chelonus blackburni*, *Bracon spp*, *Brchymeria spp*., *Apanteles spp*., *Goniozus spp*., *Elasmus spp*., *Stenomesius*, *Sympiesis* and *Tetrastichus*, *Trichogramma chilonis*,*Tetrastichus spp.*, *Telenomus spp., Chelonus blackburni Carcelia spp.*, *Campoletis chlorideae*, *Bracon spp*. etc. [31]. If the pest is severe, use the prescribed dosages of a safe pesticide viz., carbofuran 3% CG for pod borer and white grub, chlorpyrifos 20% EC for aphid root grub, deltamethrin 2.8% EC for leaf miner, flubendiamide 20% WG for *spodoptera litura*, imidacloprid 17.8% SL for aphid and jassid, lambda-cyhalothrin 5% EC for thrips, leaf hopper, leaf miner, methomyl 40% SP for *spodoptera litura*, methoxyfenozide 21.8% w/w SC for leaf eating caterpillar groundnut leaf minor and pod borer, oxydemeton – methyl 25% EC for aphid/ leaf minor, phenthoate 50% EC for leaf webber, quinalphos 1.5% DP for thrips, jassids and red hairy caterpillar, quinalphos 20% AF for spodoptera, quinalphos 25% EC for leaf hopper, leaf miner, thrips, thiamethoxam 75% W/W SG for termites etc. [32].

5.2 Castor

5.2.1 Important pests

Tobacco caterpillar (*S. litura*), castor semilooper (*Achaea janata*), shoot and capsule borer (*Conogethes (Dichocrocis) punctiferalis*), red headed hairy caterpillar (*Amsacta albistriga, A. mooreii*), Bihar hairy caterpillar (Spilosoma obliqua), whitefly (*Trialeurodes ricini*), thrips (*Retithrips siriacus, S. dorsalis*), hairy caterpillars (*Euproctis fraternal*), castor spiny caterpillar (*Ergolis merione*), castor slug (*Parasa lepida*).

5.2.2 IPM approaches

Summer ploughing to expose the hibernating pupae to predatory birds or hot sun [33] and selection of triple or double bloom castor cultivars viz., DCH-519, GCH-4, GCH-5, GCH-7, YRCH-1 which are tolerant to leafhopper. Springer, Cham. Castor varieties/hybrids with non-spiny capsules (Jwala) or semi-compact spike (GCH-4, GCH-7) are less damaged by capsule borer. In areas where red hairy caterpillar (RHC) is a problem, using a light trap (200-watt mercury lamp covers 10 ha area) on a community basis with the first monsoon rains to attract and kill the adult moths. In situations, where operating electric light trap is not feasible, a petromax light of 200 candle

power is also effective in attracting moths, covering 4–6 ha area [34]. Sowing cucumber along field borders preferably before sowing of castor attracts the migrating caterpillars of RHC [35]. Using vegetative twig traps (*Jatropha* or *Ipomoea* or *Calotropis*) for collection and killing of migrating larvae of red hairy caterpillars in endemic areas [36]. Sex pheromone trapinstalled for *S. litura* @ 10 traps/ha for monitoring and implementing timely control measures. Hand-picking and destruction of gregarious stages of *S. litura* and hairy caterpillars along with damaged leaves are effective for the management of defoliators in castor, which keep the defoliation level usually less [35] Manipulation of parasitoid activity by avoiding spraying of insecticides, when 1–2 cocoons of larval parasitoid (*Microplitis maculipennis*) observed per plant [37]. If the damage by the insect pests exceeds ETL any of the following insecticides could be sprayed. Dimethoate 30% EC - jassids, mites, semi looper, malathion 50% EC. jassids, mites, semi looper, *B. thuringiensis var. Kurstaki*, Serotype H-39, 3B, Strain Z-52 for hairy caterpillar, *Achea Janata* [33].

5.3 Sunflower

5.3.1 Important pests

Tobacco caterpillar (*S. litura*), head borer (Helicoverpa armigera), jassids (Amrasca biguttula), thrips (*S. dorsalis*), green semilooper: Thysanoplusia orichalcea, cabbage semilooper (*Trichoplusia ni*), Bihar hairy caterpillar (Spilosoma obliqua), cutworm (*A. ipsilon*), termite (Odontotermes obesus).

5.3.2 IPM approaches

Close spacing, particularly if the rainfall is heavy, mixed cropping of sunflower with cotton, Studies on groundnut and sunflower intercropping system. Removing nearby weeds that may serve as a host for aphids before planting sunflowers can slow or prevent a serious infestation [38]. To manage whiteflies, installing yellow sticky traps, which are coated with grease/sticky oily materials may be effective. Flooding of orchard with water in the month of October to kill the eggs, ploughing of orchard in November, raking of soil around tree trunk to expose the eggs to natural enemies and sun and removal of weeds. Fastening of alkathene sheet (400 gauge)/grease band of 25 cm wide afterwards mud plastering of trunk at 30 cm above the ground in the middle of December and in July –August destruction of fallen leaves infested with scales. Bihar hairy caterpillar could be managed by pre-monsoon deep ploughing (two to three times) which expose the hibernating pupae to sunlight and predatory birds and timely sowing and clean cultivation [39]. Use of well rotten manure, intercropping with pigeon pea at a row ratio of 2:1 is effective in reducing the insect attack. Tobacco caterpillar will be controlled by intercropping sunflower with pigeon pea and spraying 5% neem seed kernel extract preferably in the evening or spraying SlNPV @ 100LE/acre/spraying *Clerodendrum inerme* dust (25%) and plant extracts (10%) [35]. For head borer management, intercrop with pigeon pea, groundnut, finger millet and soybean along with sowing trap crops like marigold at 50 plants/acre. The use of pheromone traps (4 traps/acre) to trap the male moths and setting of light traps (1 light trap/5 acre) to know the range of pest incidence as well as to kill moths' population is also effective method [38]. Spraying dichlorvos 76% EC, thiamethoxam 30% FS for jassids and thrips, thiamethoxam 70% WS for jassids & thrips, cypermethrin 10% EC for Bihar hairy caterpillar, imidacloprid 48% FS for

jassid, whitefly, imidacloprid 70% WS for jassid and whitefly, imidacloprid 17.8% SL for aphid and jassid, malathion 50% EC for white fly.

6. Integrated pest management in commercial crops

6.1 Sugarcane

6.1.1 Important pests

Early shoot borer (*Chilo infuscatellus*), pink borer (*Sesamia inferens*), top shoot borer (*Scirpophaga excerptalis*), root borer: (*Emmalocera depressella*), internode borer (*Chilo sacchariphagus indicus*), stalk borer (*Chilo auricilius*), white woolly aphid (*Ceratovacuna lanigera*), black bug (*Cavelerius sweeti*), whitefly (*Aleurolobus barodensis*), pyrilla (*Pyrilla perpusilla*), mealybug (*Saccharicoccus sacchari*), (*Oligonychus sacchari*), termites (*Odontotermes spp*).

6.1.2 IPM approaches

Expose the grub stages by deep ploughings for predation. Destroying the termitarium present on the bunds and nearer to the field. Sugarcane woolly aphid (SWA) reduced in Paired or wider row planting. Selection of infestation free stalks and the discarding of seed stalks, and leaves left after seed preparation reduce scale insect, mealy bugs, white flies, borers, sugarcane woolly aphids [40]. Collection and destruction of beetles from neem trees during nighttime immediately after first heavy showers for white grub control. For top shoot borer, the egg masses should be destroyed and the affected canes along with pest stages will be removed [41]. Avoid excess use of N fertilisers before earthing up [42]. For *Pyrilla* releasing 1000 viable cocoons of *Epiricania* parasites per ha. is effective [43]. Syrphid fly @ 1000 larvae or cocoons per ha [44]. Internode borer will be managed by releasing *Trichogramma chilonis* parasitized eggs in suitable instalments and the use of pheromone traps. Placing of pheromone sleeve traps @ 25 per hectare for *Chilo infuscatellus* control by destroying adult males. Soil application of 10 G phorate or 2% methyl parathion dust. For Pyrilla Releasing 1000 viable cocoons of *Epiricania* parasites per ha. White grub (L) will be managed by collection and destruction of adults from sugarcane and application of 10 G phorate. At planting (January) to manage termite, shoot borer and root borer drenching of 20 EC chlorpyriphos. Drenching the sets immediately after planting in-furrow with Chloranthriniliprole 35%WG and Chloranthriniliprole 35%WG, were proved superior by recording the lowest average per cent dead hearts by early shoot borer [45]. Application of *Metarhizium anisopliae* (Metschnikoff) Sorokin (Ma-1) against sugarcane white grub, *Holotrichia serrata* (Hope) at $1x10^{13}$ conidia ha^{-1} was found next best to chlorpyriphos. Spinetoram 12 SC were significantly effective in minimising, number of termites per colony [46] For Rodents control bromadiolone cake 0.005% will be kept in rodent burrows or bait stations continuously for two days. Field evaluation of anticoagulant rodenticides, bromadiolone and difethialone in sugarcane fields of Cauvery delta. For Internode borer, Spot spraying of biopesticide like *Verticillium* Grasshopper Dusting of 2% methyl parathion dust in sugarcane and on bunds. 210–240 days after planting (August to September). Removal of 2–3 leaves containing egg and pupal stages

and spraying 0.08% DDVP or monocrotophos with addition of 2.5% N in spray solution or spraying neemark.

6.2 Tobacco

6.2.1 Important pests

Leaf eating caterpillar (*S. litura*), whitefly (*B. tabaci*), stem Borer (*Scrobipalpa heliopa*), gram pod borer/bud worm/ capsule borer (*Helicoverpa armigera*), grass hopper (*Acrida exultata, Cyrtacanthacris tartarica, Atractomorpha crenulate*).

6.2.2 IPM approaches

Deep summer ploughing, growing of castor as trap crop for oviposition, collection and destruction of egg masses and early instar larvae, removal of weeds are the common cultural practices of leaf eating caterpillar. Stem borer will be managed by removal of infested plants, use light trap. Whitefly and grass hoppers will be managed by field sanitation and rogueing of alternate hosts, planting tall border crops to reduce white fly infestations, Using yellow sticky traps or cards, Conserving the available natural enemies such as *Encarsia formosa*, *Eretmocerus spp*., *Dicyphushe sperus*, *Chrysocharis pentheus*, spiders, coccinellids, lacewings etc. *B. thuringiensis var. kurstaki*, Serotype H-3a, 3b, Strain Z-52, NPV of *S. litura* 0.5% AS (1x109 POB/ml), Release parasitoids viz., *Trichogramma chilonis*, *Tetrastichus spp*., *Telenomus spp*, Spraying NSKE 5% against eggs and first instar larva, *Ichneumon promissorius*, *Bracon sp*, *Carcelia spp*, *Chaetopthalmus*, *Campoletis chloridae*, Lissopimpla excels, *Ichneumon promissorius*, Neem extract containing 5% azadirachtin W/W [47, 48].

6.3 Cotton

6.3.1 Important pests

Leaf hopper (*Amrasca devastans*), whitefly (*B. tabaci*), thrips (*Thrips tabaci*), aphids (*Aphis gossypii*), mealybugs (*Phenacoccus solenopsis*), tobacco caterpillar (*S. litura*), pink bollworm (*Pectinophora gossypiella*), spotted and spiny bollworm (*Earias vittella*) & (*Earias insulana*), Helicoverpa bollworm (*Helicoverpa armigera*), leaf roller (*Sylepta derogata*), red cotton bug (*Dysdercus cingulatus*), dusky cotton bug (*Oxycarenus hyalipennis*), semi-looper (*Anomis flava*), stem weevil (*Pempherulus affinis*), shoot weevil (*Alcidodes affaber*).

6.3.2 IPM approaches

Summer deep ploughing is used to reveal the soil's insect population's inhabiting/resting phases. Crop rotation can help to limit the occurrence of many pests of cotton The crop should be kept weed-free for at least 8–9 weeks following sowing, or until the canopy begins to close in due to timely inter-culture. Intercropping cotton with pigeon pea, groundnut and pulse crops is encouraged, as is the use of trap/border crops such as okra (for shoot weevil), cannabis, castor, marigold, early pigeon pea, jowar, and maize crops [49]. To suppress main perennial weeds, a hoeing in between crop rows should be performed following the appearance of cotton seedlings.

Allowing animals to graze after the last picking is advised for reducing the carryover population of bollworms. Growing of *Setaria* as intercrop to serve as live bird perches and installing 8–10 bird perches per ha after 90 days of crop growth for the benefit of predatory birds Hand-picking and destruction of various insect stages viz., egg masses and gregarious larvae of *S. litura*, grown-up larva of *Helicoverpa armigera*, affected plant parts, rosetted flowers due to pink boll worm and rotted bolls. Growing maize interspersed with cowpea on border to attract predators and parasitoids [50]. Only sucking pest tolerant Bt cultivars should be used for endemic areas. For bollworm and *Spodoptera*, *Bacillus thuriengiensis var kurstaki* is recommended. [Only suitable for non-Bt cotton]. Chemical control strategies under IPM need need-based, rational, and safe pesticide use like 50WP Diafenthiuron and Diflubenzuron 25 WP for whiteflies, aphids, thrips, and jassids, diflubenzuron 25 WP for tobacco caterpillar, dinotefuran 20 SG for bollworms white flies, jassids, aphids, and Thrips, 5 SG emamectin benzoate for boll worms, pink american boll worm, spotted and spiny, fenvalerate 0.4 DP and Fipronil 5 for Aphid, Jassid, Thrips, White fly, spotted bollworm and pink bollworm, flonicamid 50 WG for boll worms aphids, jassids, thrips, and whiteflies; flubendiamide 20 WG and flubendiamide 39.35 SC for american bollworm, Fluvalinate 25 EC for bollworms (American and Spotted bollworm), imidacloprid 70 WG for aphids, jassids, red cotton bug, bollworm jassids, aphids and thrips. Avoid combining two or more pesticides in the same tank [51, 52]. Using pesticides like pyrethroids, which cause sucking bugs to resurface should be avoided.

7. Integrated pest management in vegetables

7.1 Okra

7.1.1 Important pests

Shoot and fruit borer (*Earias vitelli, E. insulana*), gram pod borer: (*Helicoverpa armigera*), jassids (*Amrasca biguttula biguttula*), aphids: (*A. gossypii*), whitefly (*B. tabaci*), red spider mite (*Tetranychus spp),* red cotton bug (*Dysdercus cingulatus*), ash/grey weevils (*Myllocerus subfaciatus*), stem fly (*Melanagromyza hibisci*).

7.1.2 IPM approaches

Growing maize/sorghum on borders as a barrier/trap crop for the entry of shoot & fruit borer adults and set up yellow sticky and delta traps for white fly etc. Erection of bird perches @ 10/acre in the field for facilitating bird predation [53]. Removal and destruction of borer affected shoots and fruits. Sprinkler irrigation to reduce the whitefly population Application of botanical insecticides. Inundative release of natural enemies such as *Trichogramma brasiliensis* against *Earias vittella* and *H. armigera* and *Chrysoperla zastrowi sillemi* for sap feeders [54] Two to three sprays of NSKE @ 5% alternating with sprays of pesticides, if needed, for leaf hopper, white fly, mites and aphids etc. [55]. Leaf hopper, if crosses ETL (5 hoppers/plant), spray imidacloprid 17.8 [56]. This will be effective in controlling other sucking pests as well. Installation of pheromone traps @ 2/ acre for monitoring of *Earias vittella* moth emergence. Replace the lures after every 15–20-day interval. Releasing egg parasitoid *Trichogramma chilonis* @ 1–1.5 lakh/ ha starting from 30 to 35 days after sowing, 4–5 times at weekly interval for shoot & fruit borer. Need based application of chemical

pesticides viz. imidacloprid 17.8 SL @ 150 ml/ha, cypermethrin 25 EC @ 200 g a.i/ha (0.005%), quinalphos 25 EC @ 0.05% or Propargite etc. 57 EC @ 0.1% for control of leaf hoppers, aphids, white flies, borers and mites.

7.2 Brinjal

7.2.1 Important pests

Fruit and shoot borer (*Leucinodes orbonalis*), jassids (*Amrasca biguttula biguttula*), hadda beetle (*Epilachna vigintioctopunctata*), whitefly (*B. tabaci*), aphids (*A. gossypii*), spider mites (*Tetranychus spp.)* grey weevils (*Myllocerus subfasciatus*), tobacco cut worm (*S. litura*), stem borer (*Euzophera perticella*), thrips (*T. palmi*), brinjal lacewing bug (*Urentius hystericellus*).

7.2.2 IPM approaches

Soil solarisation during June will help in reducing the soil-borne insects. However, care should be taken that sufficient moisture is present in the soil for its solarisation. Clipping of borer damaged shoots and collection and destruction of damaged fruits i.e., clean cultivation helps in management of borer and phomosis disease effectively. Seed of popular hybrids is sown in beds in the first week of July. Weeding should be done from time to time and infected seedlings should be rogued out from the nursery [57]. Bird perches @ 10/acre should be erected for facilitating field visits of predatory birds [58]. Blue/yellow sticky trap should be installed for hoppers, aphids, white fly etc. [59]. Give 2 to 3 sprays of 5% NSKE against sucking pests and borer. Neem oil (2%) application reduces borer infestation, though marginally. Pheromone traps @ 5/ acre should be installed for monitoring and mass trapping of shoot & fruit borer *Leucinodes orbonalis*. Replace the lures with fresh lures after every 15–20-day interval. Release egg parasitoid *T. brasiliensis* for shoot & fruit borer, 4–5 times at weekly intervals. Apply neem cake @ 250 kg/ ha (in two splits) in soil along the plant rows at 25 and 60 DAT for reducing nematodes and borer damage [60]. If the borer incidence crosses ETL (5% infestation), apply cypermethrin 25 EC (0.005%) or carbaryl 50 WP, if the incidence of leaf hopper and other sucking insect pests is still above ETL, then apply imidacloprid 17.8 SL.

7.3 Cabbage and cauliflower

7.3.1 Important pests

Diamondback moth (*Plutella xylostella*), head borer (*Hellula undalis*), leaf webber (*Crocidolomia binotalis*), cabbage aphid (*Brevicoryne brassicae*), cabbage butterfly (*Pieris brassicae*), tobacco caterpillar (*S. litura*).

Removal and destruction of plant remnants, stubbles, debris after harvest and ploughing the field. Sowing 2 rows of bold seeded mustard as a trap crop for every 25 rows of cabbage to attract moths to mustard [61]. Grow intercrops such as tomato, garlic, coriander and carrot in alternate rows with cabbage. Installing pheromone traps @ 4–5/acre for monitoring [62]. Release egg parasitoid, *T. chilonis/pretiosum* @ 20,000/acre 4–6 times at weekly interval and larval parasitoids [63], *Diadegma semiclausm* @ 1,00,000/acre (Hills – below 25–27°C) or *Cotesia plutellae* (plains) @ 20,000/acre from 20 days after planting. Fungal pathogens, for example, *Paecilomyces*

spp. and Zoophthoraradican are effective. Cabbage borers collect and destroy caterpillars mechanically in the early stages of attack. Remove and destroy the webbed leaves with caterpillars and set up light traps @ 1/acre. Conserve parasitoids such as *Cotesia crocidolomiae* etc. for managing Cabbage leaf webber. For cabbage butterfly, fine-mesh netting in nursery will stop butterflies from reaching the crop and laying eggs. Collect and destroy eggs or caterpillars mechanically by hand- usually on the underside of the leaves. Release *Trichogramma spp*. and erect bird perches. Conserve parasitoids such as *Cotesia glomeratus* (larval), *Pteromalus puparum* (larval), *Aphidius colemani* (adult and nymph), *Diaeretiella spp*. (adult and nymph), *Aphelinus spp*. (adult and nymph) and predators such wasps, green lacewings, earwigs, ground beetles, rove beetles, spiders etc. [64]. Foliar spray with dimethoate 30% EC @ 264 ml in 200–400 l of water/acre or fenvalerate 20% EC @ 120–150 ml in 240–300 l of water/acre or phosalone 35% EC @ or acetamiprid 20% SP. Foliar spray with 5% NSKE or azadirachtin 0.03% (300 ppm) neem oil-based WSP. Spraying flubendiamide 20% WG or lufenuron 5.4% EC or spinosad 2.5% SC or indoxacarb 15.8% EC @ or emamectin benzoate 5% SG or fipronil 5% SC of water/acre (Last spray should be 15 days before harvesting) [65].

7.4 Tomato

7.4.1 Important pests

Gram pod borer (*Helicoverpa armigera*), tobacco caterpillar (*S. litura*), whitefly (*B. tabaci*), serpentine leaf miner (*Liriomyza trifolii*), thrips (*T. tabaci*, *Frankliniella schultzei*), red spider mite: (*Tetranychus spp*), cutworm (*A. ipsilon*), aphids (*Myzus persicae, A. gossypii, A. craccivora*), mealybug (*Phenacoccus solenopsis*).

7.4.2 IPM approaches

For managing Serpentine leaf miner, use yellow sticky traps or cards. Erecting of bird perches @ 20/acre for encouraging predatory birds such as king crow, mynah etc. [66]. Ecological engineering of tomato with growing of ovipositional trap crops such as castor [67], For gram pod borer field sanitation, ecological engineering of tomato with growing intercrops such as cowpea, onion, maize, coriander, uradbean etc. [68] and growing sorghum or maize in 4 rows all around tomato crop as guard crop. Rotate the tomato crop with a non-host cereal crop, cucurbit, or cruciferous vegetable. Instal pheromone traps @ 4–5/acre for monitoring adult moths' activity [69], setting up of light trap @ 1/acre. Conserve parasitoids such as *Trichogramma chilonis* (egg), *Tetrastichus* spp. (egg), *Telenomus* spp. (egg), *Chelonus blackburni* (egg-larval), *Carcelia* spp. (larval-pupal), *Campoletis chlorideae* (larval), *Eriborusargentio pilosus* (larval), *Microplitis* sp. etc. Conserve predators such as lacewings, lady beetles, spiders and fire ants conserve predators such as *C. carnea*, coccinellids, King crow, common mynah, wasp, dragonfly, spider, robber fly, reduviid bug, praying mantis, fire ants, big-eyed bugs (*Geocoris* sp), pentatomid bug (*Eocanthecona furcellata*), earwigs, ground 34 beetles, rove beetles etc. Spraying NSKE 5% against eggs and first instar larva or azadirachtin 5% W/W neem extract concentrate @ [70]. spray dimethoate 30% EC. Leafhoppers, soil application of neem cake 100 kg/acre, Conserving predators such as ladybird beetles and green lacewings and parasitoids such as *Anagrus flaveolus* and *Stethynium triclavatum*. For serpentine leaf miner, spraying azadirachtin 1% (10000 ppm) neem-based EC or

azadirachtin 5% W/W neem extract concentrate [71], apply entomopathogenic nematodes (EPNs) @ 20–120 crore infective juveniles of *Steinernemafeltiae*/acre, Spray with indoxacarb 14.5% SC or flubendiamide 20% WG or flubendiamide 39.35% M/M SC or novaluron 10% EC or carbaryl 50% WP or chlorantranilioprole 18.5% SC or lambda-cyhalothrin 4.9% CS or lambda-cyhalothrin 5% EC or phosalone 35% EC or quinalphos 20% AF or quinalphos 25% EC.

8. Integrated pest management in fruits

8.1 Mango

8.1.1 Important pests

Mango hopper (*Idioscopus clypealis*, *Idioscopus niveosparsus*), mango mealy bug (*Drosicha mangiferae*), fruit fly (*Bactrocera dorsalis*), stem borer (*Batocera rufomaculata*), bark eating caterpillar (*Indarbela quadrinotata*), stone Weevil (*Sternochetus mangiferae*), shoot borer (*Chlumetia transversa*), leaf webber (*Orthaga exvinascea*), shoot gall psylla (*Apsyllaci stellate*), red ant (*Oecophylla smaragdina*), Eriophyid mite (*Aceria mangiferae*),stone weevil (*S. mangiferae*), termites (*Odontotermes obesus, Microtermes obesi*).

8.1.2 IPM approaches

Collection and destruction of crop debris, insect-damaged plant parts, removing weed plants [72], timely irrigation, organic manure, fertiliser at the recommended dose, drainage, weeding, mulching, interculture and so on are examples of cultural practices. Handpicking gregarious caterpillars and cocoons discovered on stems and destroying them in kerosene mixed water are examples of mechanical techniques. Use yellow sticky traps at a rate of 4–5 traps per acre and a light trap at 1/acre and Instal pheromone traps @ 4–5/acre for monitoring adult moth activity (replace the lures with fresh lures every 2–3 weeks) [73]. Erecting bird perches @ 25/ha for encouraging predatory birds such as King crow, common mynah, etc. [74]. Common practices such as dense orchard pruning in December, orchard and field sanitation, rogueing and the application of bio-agents such as *Metarhizium anisopliae* @ 1x 108 cfu/ml or *Beauveria bassiana* @ 108 cfu/ml on tree trunk once during toffseason and twice at 7 days intervals during the flowering season. Chemicals such as buprofezin 25% SC/ deltamethrin 2.8% EC)/ Dimethoate30% EC, imidacloprid17.8% SL, malathion 50% EC, monocrotophos 36% SL, oxydemeton–methyl 25% EC, oxydemeton–methyl 25% EC used judiciously [75].

8.2 Banana

8.2.1 Important pests

Banana rhizome weevil (*Cosmopolitus sordidus*), banana stem weevil *Odoiporus longicollis)*, banana leaf-eating caterpillar (*S. litura*), Banana aphid (*Pentalonia nigronervosa*), flower thrips (*Thrips florum*), Banana lacewing bug (*Stephanitis typicus*), hard scale (*Aspidiotus destructor*), fruit fly (*B. dorsalis*), banana scab moth (*Nacoleia octasema).*

8.2.2 IPM approaches

Maintain sanitation in the orchard for banana aphids by following clean cultural practices [76]. Deep ploughing of the field is a helpful strategy for managing white grubs because it exposes the grubs to desiccation and insectivorous bird predation. During the night hours, collect and destroy beetles in kerosene mixed water and with light traps/pheromone traps. Addition of cover crop (inclusion of fallow in rotation sequences mass trapping and use of biological control agents in insect pest suppression may prove to be beneficial as alternative IPM strategies for the Banana rhizome weevil. Pheromone traps are used in mass trapping to keep insect populations under control Individual-based models (IBMs) were examined to depict the spatial dynamics of the banana weevil in relation to the cropping system. Crop fragmentation and mass trapping were considered tools for reducing insect numbers. The results showed that altering agricultural residues in the area around each pheromone trap increased trap efficiency significantly. Traps were most efficient at catching weevils escaping the fallow in an intensive banana plantation fallow when placed at the transition zone between the banana region and the fallow. Before planting the suckers, wash them and immerse them in a Chlorpyriphos 20 EC [77]. Cleanliness in the orchard is critical. On the white grub-infested host plants, spray carbaryl at a rate of 2 ml per lit. Plants are protected from a termite infestation by using chlorpyriphos 20EC @ 400 ml/gunta with irrigation water or intermittent irrigation. Spray the pseudostem and soak the base of the tree with chlorpyriphos 20 EC. Spray Malathion 50 EC after one week. The fungus *Beauveria bassiana*, in combination with entomopathogenic nematodes (*Steinernema spp*. and *Heterorhabditis spp.*), appears to be effective in nematode control. The use of biological control agents in pseudostem traps in combination with pheromone attractants could be future development in control procedures.

8.3 Citrus

8.3.1 Important pests

Aphid (*Toxoptera aurantii*), citrus psylla (*Diaphorina citri*), fruit sucking moth (*Eudocima fullonica*, *E. maternal*), citrus/lemon butterfly (*Papilio demoleus, P. polytes*), citrus blackfly *(Aleurocanthus woglumi)*, soft scale: *Coccus hesperidium*).

8.3.2 Integrated pest management practices

Intercropping, excessive irrigation, and nitrogen application should all be avoided to control citrus psylla since they increase humidity in the orchards, which is conducive to pest growth. Pruning the impacted and dry shoots as well as modifying the canopy structure to aid in optimum light interception is recommended. Curry leaf should not be grown near citrus orchards because it can serve as a breeding ground for psylla. Each flushing season, two releases of *Mallada desjardinsi* (Navas) (=*M. boninensis* (Okamoto) @ 30 larvae/tree lower citrus psylla infestation levels Pruning of all afflicted sections throughout the winter is recommended for managing citrus leaf miner and keeping the pest population under control in extreme cases. Pruning should be avoided during active growth phases because it causes more fresh flushes, allowing the pest to have more generations. The citrus blackfly can be controlled by not planting infested seedlings. Plant the orchards at the appropriate spacing. Close spacing, excessive nitrogen application, and waterlogging should all be avoided.

Alternative hosts of the pest include guava, sapota, and pomegranate, which should not be grown near citrus groves. Clipping and destroying the afflicted shoots is recommended [78]. Avoid twig cutting before the blackfly's predicted egg-laying season. Spraying neem oil @ 100 ml or Karanja oil @ 100 ml + Teepol 10 ml during egg-laying reduces blackfly egg-laying. Fruit Sucking Moths can be controlled by getting rid of fallen fruits, which attract the moths. To avoid pest development, orchard horticulture must be kept clean. Fruit bagging on a modest scale is effective. Smoke is produced in orchards in the late evening hours, which repels the bug The adults would be attracted to light traps and poison baiting with malathion 50 EC @ 10 ml + 100 g jaggery +100 ml mandarin juice +900 ml water (two bottles of poison bait/25–30 trees). Fruit flies in citrus can be controlled by submerging wooden blocks in a 6: 4: 1 solution of ethanol, methyl eugenol, and malathion for 72 hours. In the 24th week of August, instal PAU fruit fly traps at a rate of 16 traps per square foot. If necessary, refill the traps. The collection and destruction of fallen fruits at regular intervals would limit the growth of puparia, reducing the fly population for the next year. Use male attractive fly traps baited with 0.1% methyl eugenol and 0.05% malathion 20 EC @ 25 traps/ha beginning 60 days before fruit harvest and fresh solution every 7 days to control fruit fly. Citrus aphids can be controlled with horticultural mineral oil at a concentration of 1.25% (12.5 ml I″ water) [Quinalphos 25 EC @ 1 ml or petroleum spray oil @5.9 ml or novaluron 10 EC @ 0.55 ml or imidacloprid 17.8 SL @ 0.4 ml or thiamethoxam 25 WG @ 0.32 g or acetamiprid 20 SP or neem oil @ 1–5 ml or imidacloprid 17.8 SL @ 0.5 ml can be exploited for the control of various pests in citrus [79].

9. Integrated pest management in plantation crops

9.1 Tea

9.1.1 Important pests

Tea mosquito bug (*Helopeltis theivora*), thrips (*S. dorsalis*), jassid (*Empoasca flavescens*), aphids: (*Toxoptera aurantia*), leaf eating caterpillar (*S. litura*), Red spider mite (*Oligonychus coffeae*), tea looper complex (*Buzura suppressaria, Hyposidra talaca, H. infixaria*), shot hole borer (*Euwallacea fornicates*), wood eating termite (*Microcerotermes sp.),* Scavenging termites (*Odontermes sp*).

9.1.2 IPM approaches

Routine cultural activities like as plucking rounds, adjusting pruning cycles, modifying shade trees, and timely weed treatment can all be used as effective pest control measures in tea culture. Many foliar pests, such as tea mosquito bugs, aphids, jassids, scales, and leaf folding caterpillars like flush worms and leaf rollers, are removed or reduced by this technique. On the broken ends (stalks) of plucked shoots, tea mosquito bugs lay their eggs. The more eggs, larvae, and juvenile stages of pests are removed from the bushes, the shorter the plucking rounds must be. Intensive stalk removal during plucking will help to limit the prevalence of this insect. The intensity of plucking, on the other hand, is critical; the higher the intensity, the greater the pest population reduction. During a light pruning operation, most foliar pests such as the tea mosquito bug, flushworm, aphid, jassid, thrips, red Spider Mite (RSM), scarlet mite and purple mite are eradicated. The Light Skiff assists in the removal of unproductive shoots and

Helopeltis and thrips eggs *Helopeltis* is more likely to invade densely shaded regions Because the tea mosquito bug is a negatively phototropic pest, overgrown plantations should be thinned to provide for adequate sunshine and aeration. The insect is unable to endure sunshine, resulting in a reduction in the infestation. Several caterpillar pests have alternate hosts in shade trees such as *Indigofera* and *Albizzia*. As a result, the prescription for shade control will aid in the prevention of thrips, mites, and *Helopeltis* infestations. Sanitation in the field: Field cleanliness is important in the control of a variety of pests. Weeds provide ideal hiding places for *Helopeltis* and RSM, and they also act as alternate hosts for *Helopeltis* and RSM. RSM is controlled by weed-free agriculture and prohibits cattle, goats, and other animals from straying on RSM-infested fields. A trap crop also changes the habitat of an agro-ecosystem, which can be classified as an ecological engineering strategy. Marigold, on the other hand, is an attractive plant that may be used as a red spider mite trap crop in tea Removal by hand: Lepidopteran caterpillar collection and annihilation is cost-effective and useful for both small and large plantations [80]. Manual removal of larvae and pupae can greatly reduce the population of foliage-feeding caterpillars such as the looper caterpillar, faggot worms, flush worms and leaf roller. Solarization of the soil and heat treatment: The medium in which tea plants are grown in soil. Many insects, such as eelworms, cockchafer grubs, termites, and root mealy bugs, dwell or hibernate under or near the soil surface in ideal temperature and humidity conditions. In tea plantations, a light trap is a cost-effective and environmentally friendly monitoring method for lepidopteran pests The mechanical control method for destroying termitaria appears to be a viable termite management solution [80]. In Bangladesh, the elimination of isolated termitaria is a common practice in tea plantations. In tea, *Oligota flaviceps* have been recognised as a predator of the red spider mite. The two most prevalent predators of *Acaphylla theae and Calacarus carinatus are Amblyseius herbicolus and Euseius ovalis. Anthocorids of the genera Anthocoris and Orius,* as well as predatory thrips such as *Aelothrips intermedius and Mymarothrips garuda,* are natural thrips adversaries*. C. carnea* has recently been recognised as a thrips *and Helopeltis predator*. *Caloptilia theivora*, a leaf roller, is highly parasitized by the eulophid *Sympiesis dolichogaster*. The looper caterpillar, *Buzura suppressaria*, is parasitized by *Apanteles fabiae* and *Apantelesta probanae*. *Erythmelu shelopeltidis*, an egg parasitoid, was found to be effective against the tea mosquito bug, *Helopeltis theivora* (The percentage parasitism in the field ranged from 52 to 83%, and this is the first time this species has been found attacking *H. theivora*. *B. thuringiensis* bacterial pesticides have been successfully employed to combat looper caterpillars, cutworms, flushworms, and other lepidopterous pests [81]. *Verticillium lecani*, *Paecilomyces fumosoroseus*, and *Hirsutella thompsonii*, three entomopathogenic fungi, were tested and proved to be efficient against pink, purple, and red spider mites. The possible entomopathogenic fungi for the management of *Helopeltis* in tea were discovered to be *Cladosporium sp*., *Aspergillus niger* and *Aspergillus flavus*. The most common entomopathogenic fungus, *Metarhizium anisopliae*, reduced the population of red spider mites, thrips, and live wood termites in tea *Azadirachtin*, an oxygenated triterpenoid derived from the seed kernel of the neem tree *A. indica*, is presently being tested against a variety of tea pests, including *Helopeltis*, Red spider mites, flushworm, and others. Plants suffering from root-knot nematodes, *Meloidogyne brevicauda*, were found to benefit from the application of neemcake at a rate of 2 kg/bush Furthermore, extracts from Mahogany, *Karanja*, *Datura*, Tobacco, *Bishkatali*, *Katamehedi*, *Lantana*, *Xanthium* and *Clerodendrum* may be useful against significant tea pests such as tea mosquito bugs and red spider mites. Neem and *Mahogani* cake drastically reduced the nematode population in the soil [82].

9.2 Coffee

9.2.1 Important pests

White coffee stem borer (*Xylotrechus quadripes*), coffee berry borer (*Hypothenemus hampei),* coffee root mealybug (*Planococcus citri*) Shot hole borer (*Xylosandrus compactus)*, brown scale (*Saissetia coffeae*), green scale (*Coccus viridis)*, cock chafers or white grubs (*Holotrichia spp)*, hairy caterpillars (*Eupterote spp)*, coffee bean beetle (*Araecerus fasciculatus*), red coffee borer (*Zeuzera coffeae*).

9.2.2 IPM approaches

Destroying ant nests from shade trees and promoting favorable environmental conditions for the growth of the white halo fungus are two ways to manage coffee scales (*Verticillium lecanii*). Maintain optimal shade on the estates to control the White coffee stem borer (two-tiered shade tree system). Collar prune the infested plants, uproot if the borer has entered into the root, burn the affected plants immediately and remove the loose scaly bark of the main stem and thick primaries using a coir glove or coconut husk to eliminate the cracks and crevices which are used by the female beetle to place eggs on the stem. After removing susceptible plants by tracing, use a scrubbing or 10% lime coating or stem wrapping with empty fertiliser bags in hot spot areas, such as open patches and estate borders with poorly managed estates [83]. Pheromone traps can be set up in the field at a height of 1.8 to 2 metres above ground level. The traps should be laid out in a grid of 25 traps per hectare, with a 20-meter interval between them. During the summer, the shot hole borer will be controlled by cutting the affected twigs 2.5 to 7 cm below the shot hole and burning, removing, and killing all undesired / infested suckers, as well as keeping thin shade and providing good drainage in the estate. During the early part of the flight period, between April and October each year, spray Chloropyrifos 20 EC at a dosage of 600 ml in 200 l of water, coupled with 200 ml of any wetting agent on the main stem and thick primaries. Coffeeberry borer will be controlled through the use of cultural practises and phytosanitary measures, such as fumigation with aluminium phosphide under the supervision of a pest control agency or a technical expert, timely harvest, spreading gunny bags or polythene sheets at the time of harvest to reduce gleaning, removing gleanings and leftovers, dipping infested berries in boiling water for 2–3 minutes kills all stages inside, During the drying process, traps can be placed around the drying yard [84]. Dusting quinalphos 1.5% or methyl parathion 2% on afflicted patches and spraying with 4 litres of kerosene in 22 litres of water combined with 200 ml of any agricultural wetting agent reduced coffee mealybug. Drenching with roger 30EC at 3.3 ml per litre of water in the case of young plants (2–4 years).

9.3 Coconut

9.3.1 Important pests

Rhinoceros beetle (Oryctes rhinoceros), red palm weevil (Rhynchophorus ferrugineus), black headed caterpillar (Opisina arenosella), eriophyid mite: *Aceria guerreronis* (Acari: Eriophyidae), Termite: *Odontotermes sp.*

9.3.2 IPM approaches

Rhinoceros beetle and cock chafer beetle could be controlled by collecting and eliminating the various stages of the beetle's life cycle from manure pits (the pest's breeding site) whenever manure is removed. GI hooks can be used to extract the adult beetle from the palm crown during the peak phase of population growth [85]. Pheromone traps installed and gathered away from the main plantation are effective. Set up a pheromone trap for rhinoceros beetles at a rate of one trap per 100 hectares by attaching it to the plant at a height of 0.6 to 1 m to trap and kill the beetles [86]. Avoid cutting green leaves for red palm weevil, and if necessary, cut them about 120 cm away from the stem to prevent successful inward passage of the grubs via the cut end. Set up a pheromone trap and a trap with coconut logs: Set up attractant traps (dirt pots) containing sugarcane molasses 212 kg or toddy 212 l (or pineapple or sugarcane activated with yeast or molasses) + acetic acid 5 ml + yeast 5 g + longitudinally split tender coconut stem/logs of green petiole of leaves into 30 numbers in one acre to trap adult red palm weevils in large numbers. The discharge of baculovirus oryctes injected adult rhinoceros beetles at a rate of 6 insects per acre provides biological control by reducing the beetle's leaf and crown damage. To attract and kill the adults, soak one kilogramme of castor cake in five litres of water and place it in little mud pots in the coconut gardens. In the base of the three innermost leaves in the crown, apply a mixture of neem seed powder + sand (1: 2) @ 150 g/palm or neem seed kernel powder + sand (1: 2) @ 150 g/palm. Growing intercrop (sun hemp, four crops per year) and a shelterbelt of *Casuarina* around the coconut garden to prevent additional infiltration could help manage the coconut eriophyid mite. Fenpyroximate 5% EC was used as a chemical control (spray fluid volume as required). To control the Leaf Eating Caterpillar / Black Headed Caterpillar as a preventative precaution, clip and burn the first afflicted leaves at the start of the summer season. Cut the root at an angle and place it in a 7 × 10 cm polythene bag with an insecticidal solution containing monocrotophos 36% WSC + water 10 ml [87].

10. Conclusions

The pest management in tropical food crops with special emphasis on integration of cultural, mechanical, chemical and natural enemies is discussed in this chapter which will be useful for students, farmers, researchers and also entrepreneurs for updating their knowledge for future endeavours. The judicial and selective use of management strategies described could be helpful for sustainable pest management and production of these crops

Conflict of interest

I confirm there are no conflicts of interest.

Acronyms and abbreviations

Integrated Pest Management (IPM)
Neem seed kernel extract (NSKE)

Encapsulated granule (CG)
Granule (G)
Water-soluble powder (SP)
Soluble concentrate (SL)
Dustable powder (DP)
Fall armyworm (FAW)
Emulsifiable concentrate (EC)
Parts per million (ppm)
A mixed formulation of CS en SC (ZC)
Flowable concentrate for seed treatment (FS)
Bait [ready for use] (RB)
Water dispersible powder for slurry treatment (WS)
Water-soluble granule (SG)
Red hairy caterpillar (RHC)

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