JBIOGRITech
Journal of Biopesticides and Agriculture Technology
JBIOGRITech 3(2): 17–46
ISSN 3048-3921

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

A review on insect pheromones of crop pests and its future applications

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Received Date: March 3, 2026 Revised Date: May 31, 2026 Accepted Date: June 2, 2026

ABSTRACT
Background: Crop failure due to pest infestation can devastate local communities in agrarian economies across the world. However, the overuse of insecticides has led to the development of resistant pests and pollution of the groundwater through run-off, which also impacts rural settings. Thus, Integrated Pest Management systems must be put in place for targeted prevention of crop pests. **Methods:** A systematic literature search was conducted using Google Scholar, PubMed, and Scopus to identify English-language, peer-reviewed articles published between 1920 and 2026 using keywords related to insect pheromones, insects, and resistant plants. **Findings:** Five major pests of South Indian crops (*Helopeltis antonii*, *Scirtothrips dorsalis*, *Longitarsus nigripennis*, *Liriomyza trifolii*, and *Rhizoglyphus echinopus*) still have unidentified pheromones. Each was paired with a related species whose pheromone is known, such as *H. theivora*, *Frankliniella occidentalis*, *Phyllotreta striolata*, *Agromyza frontella*, and *Tetranychus urticae*. The methods used for these relatives (GC-MS, GC-EAD, and wind-tunnel and olfactometer bioassays) can guide pheromone identification and trap deployment for the unsolved pests. **Conclusion:** It highlights crucial crops where Integrated Pest Management is yet to be deployed against the major insect pests, and shows how the discovery of mating, aggregation or alarm pheromones in evolutionary related insects, or those with a similar habitat, can aid identification of the key components of unexplored pheromone systems. **Novelty/Originality of the article:** Synthesis and dispersal of these pheromones is discussed, with the types of traps that work best for the insect. Also, other methods of pest control and resistant cultivars are mentioned for holistic crop development.

KEYWORDS: insects; pests; pheromone; plants.

1. Introduction

A major determinant of crop yield is the effect of insect pests. The economic damage that ensues from the same has led to different methods of control, most involving pesticides that cause degradation of soil quality and poisoned water run-off, along with human health diseases due to the toxic compounds. There is a decrease in beneficial insects such as pollinators and natural predators because of non-specific pesticides. Many pest species have also gained tolerance to the pesticides used and are now a greater threat to croplands. Integrated pest management strives to use novel techniques to combat insects while ensuring environmental safety. Organic insecticides use naturally derived chemicals or concoctions which are repellent to pests. The classic example is of neem, *Azadirachta indica*, the seeds of which contains azadirachtin, a powerful limonoid triterpene (Isman & Akhtar,

Cite This Article:
Mascarenhas, R., & Sheikh, S. (2026). A review on insect pheromones of crop pests and its future applications. *Journal of Biopesticides and Agriculture Technology, 3*(2), 17-46. https://doi.org/10.61511/jbiogritech.v3i2.2026.3610

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2007), functions as a powerful antifeedant for *Schistocerca gregaria*, the desert locust, and some Noctuidae caterpillars. Although not every insect is affected, it interferes with the neuroendocrine system of insects, disrupting molting and metamorphosis, causing anorexia and eventually blocking reproduction. The latest in pesticides involves the use of Engineered nanoparticles (ENPs) for targeted delivery of active ingredients and their controlled release. This involves encapsulating the components or using oil or water emulsions to increase effectiveness, although run-off from these systems has also raised concerns on human exposure (Verma et al., 2026). For instance, in berry farming, introduction of natural predators and parasitoids of pests, such as predatory mites, nematodes, baculoviruses and entomopathogenic fungi goes a long way to ensuring healthy crop land (Gutiérrez-Cárdenas et al., 2026). Likewise, essential oils of aromatic plants are especially powerful when concentrated. A combination of essential oils from plants such as *Eucalyptus camaldulensis*, *E. lehmannii*, *Cymbopogon citratus*, *Salvia Rosmarinus,* and *Thymus vulgaris* displayed insecticidal properties against *Aphis fabae* through a synergistic effect. The key effective components identified were thymol, geranial, eucalyptol, acorenone B and caryophyllene, which may function through disruption of neurophysiological, developmental and reproductive systems and behaviours (Hamdeni et al., 2026).

Experiments on three members of the lemon grass family have been tested for ability to protect stored products from beetle pests (Ricardo et al., 2015). *Cymbopogon nardus* repelled *Oryzaephilus surinamensis*, the sawtoothed grain beetle, most, followed by *Cymbopogon citratus,* and *Cymbopogon martini*. When tested against *Sitophilus zeamais*, the maize weevil, *C. nardus* and *C. martini* essential oils worked best, showing that different insects perceive the variety of useful chemicals differently. Oils of the Myrtaceae plants have terpenic derivatives such as limonene, 1.8-cineole, terpineol, myrcene, linalool, thymol and α-pinene which are good pesticides (Asgar, 2013). Saponins are broad spectrum insecticides which cause digestion issues, defective insect molting and cellular toxicity, leading to loss of appetite and weight, development retardation, decreased reproduction and death (Ellen et al., 2007). Caffeine, an alkaloid of the xanthine family, is effective against *Drosophila melanogaster* and *Hypothenemus hampei* when emulsified in oleate, with a lethal time of 17-23 min (Araque et al., 2007). Even bacteria aids the farmer. *Bacillus thuringiensis* (Bt) can synthesize parasporal crystal proteins which are δ-endotoxins (Cry) that prove toxic to Lepidoptera, Coleoptera, and Diptera (Salehi Jouzani et al., 2008a, 2008b). It is host specific, consequently safe for beneficial insects. It can be formulated as spray-able bacterial pesticides (Lacey et al., 2015). It's even made its way into genetically modified plants, which is very effective for the cotton crop, although the pink bollworm is slowly gaining resistance to it. A revolution in management of pests is required, using methods of natural predator control, mixed cropping and other cultural practices. The use of sex pheromones traps to control insects is gaining popularity because it is highly species specific. The review article stresses upon the plausible exploration of pheromone. The following figure 1 shows few of the South Indian Crop Pests for which Integrated Pest Management can be explored.

2. Methods

The present review was written in the form of structured literature review. However, comprehensive Meta analyses and PRISMA guidelines were not applied in the current study. A structured literature search was retrieved using several electronic databases including primary tools such as google scholar, PubMed and Scopus.

Inclusion criteria for the articles published from 1920- 2026 were explored using custom date range function from peer reviewed articles principally in English as the language tool. The abstracts, titles, research findings on pheromones and various insects life cycle were screened to select articles for the current review study. The reference list also contained secondary literature such as theses, technical reports, annual reports and web pages only when peer-reviewed data were not available. The basic keywords alongside Boolean combinations and/or were used that included for instance, pheromone and resistant crop plants, insects and pheromones, resistant plants and compounds,

pheromones or synthetic compounds, insects or resistant plants, function and production of insect pheromones. The screening of relevant sources included titles, abstract in the initial stage and then full text was selectively reviewed. Following rigorous screening a total of 197 sources were included in review.

The exclusion criteria comprised other parameters for study that focused on non-chemical-based pest management papers, articles not written in English, non-peer reviewed articles, research findings irrelevant to insect pheromone, conference abstracts and grey literature.

3. Results and Discussion

Each insect can emit its own mixture of pheromones recognising the right one by the ratio of the components. There are three kinds of sex pheromones components by structure (Ando et al., 2004; Löfstedt et al., 2016). Type 1 is most abundant (75%) and includes straight chain of 10-18 Carbon atoms that are unsaturated aliphatic compounds, usually with carbonyl groups including aldehydes and acetate, or alcohols. Second is Type 2 (15% abundance), with straight chains of 17-23 carbons long separating 1-3 double bonds in cis conformation, along with up to 2 epoxide functions (Ando et al., 2004; Millar, 2000). The final Type 3 are miscellaneous compounds comprising 10% of sex pheromones components. Hand in hand with the pheromones are their pheromone-binding proteins (PBPs), the function of which is to solubilize and transport them through the sensillar lymph to olfactory receptors for detection. Knowledge of these has also contributed to environmentally conscious pest control (Ray & Mohanty, 2025).

3.1 Functions of pheromones

Pheromones have evolved indirectly from completely diverse functions. The anti-desiccant Cuticular hydrocarbons (CHCs) eventually were used for pheromone signalling (Chung & Carroll, 2015), now encoding information is related to conspecifics (e.g., Shahandeh et al., 2017), social rank (e.g., Honorio et al., 2019), reproductive parameters like sex (e.g., Luo et al. 2019), status (e.g., Smith & Liebig, 2017), and age (e.g., Heuskin et al., 2014). CHCs in Drosophila melanogaster have clear sexual dimorphism. Alongside, males emit 11-cis-vaccenyl acetate (cVA), which prevents males courting each other but causes aggression (Wang & Anderson, 2009). It is also attractive to virgin females, but repels them after mating (Clyne et al.,1999). Female fruit flies produce 7,11- heptacosadiene (HD) which activates the male's neurons responsible for courtship behaviour (Kohatsu et al., 2011). Pheromones are used in recognizing mating partners, especially in cases where both parents care for offspring (Aquiloni et al., 2015). Aside from sexual functions, in social insects, nestmate recognition and defence uses volatile alarm pheromones for recruitment (Van et al., 2010; Wyatt, 2014). CHCs synthesized by individuals are transferred to nestmates (Blomquist & Bagnères 2010; Leonhardt et al., 2016). Aggregation pheromones are used for drawing the attention of conspecifics to food sources, or when male-male aggression is required before mating. The study of these volatile compounds and their Odorant binding proteins will enable the development of next-generation biosensors for real time processing of chemical information (Ventura et al., 2026).

3.2 Production of insect pheromones

The study of pheromone production in insects has led to synthetic biology approaches in engineered yeast cells for scale up of compounds for mating disruption of *Plutella xylostella*, a pest of oilseed and vegetable crops (Betsi et al., 2026). Type I components are enzymatically derived from saturated fatty acid like palmitic acid (He et al., 2017; Jurenka 2004). This takes place in female pheromone extrudable glands between the 8th and 9th

abdominal segments of Lepidoptera. Type II and CHCs are produced in oenocytes- secretory cells associated with the peripheral fat body or epidermal layer (Schal et al., 1998; Wigglesworth 1933). Type 2 components are created by dietary linoleic or linolenic acid being decarboxylated along with chain elongation in oenocytes, and then being transported to pheromone glands for epoxidation (Jurenka 2004; Jurenka, 2003; Millar 2000; Tillman et al.,1999).

Table 1. Pheromone diversity across insect orders

Order	Insect example	Pheromone	Functional Group	Molecular weight (g/mol)	Produced in	Formula	References
Collembola	*Orchesella cincta*	(*Z*)-14-tricosenol	Alcohol	338.6	Male	C23H46O	(Zizzari et al., 2017)
Dictyoptera	*Blattella germanica*	3,11-dimethyl-2-hepta cosanone	Ketone	422.8	Female	C29H58O	(Schal et al., 1991)
Phasmida	*Asceles glaber*	(2S,6R)-(−) (E)-2-methyl-1,7-dioxaspiro [5.5]undecane	Spiroketals	170.22	Defensive spray	C10H18O2	(Dossey et al., 2012)
.Isoptera	*Zootermops nevadensis*	(5*E*)-2,6,10-trimethyl undeca-5,9-dienal	Aldehyde	208.34	Female	C14H24O	(Bordereau et al., 2010)
Dermaptera	*Forficula auricularia*	Ethyl-1,4-benzoquinone	Quinone	136.15	In frass	C8H8O2	(Walker et al 1993)
Thysanopter	*Frankliniell occidentalis*	Neryl (S)-2-methyl butanoate, (R)-lavandulyl acetate	Acetates	238.37 and 196.29	Male	C15H26O2 and C12H20O2	(Dublon, 2009)
Hemiptera	*Helopeltis theivora*	(Z)-3 Hexenyl acetate, (E)-2-hexenol	Acetate and Alcohol	142.2 and 100.16	Female	C8H14O2 and C6H12O	(Sachin et al., 2008)
Coleoptera	*Phyllotreta striolata*	(+)-(6R,7S)-himachala-9,11-diene, AITC	Fused rings, diene and Allyl isothio cyanate	204.35 And 99.16	Male + Herbivore-induced plant volatiles (HIPVs)	C15H24 and C4H5NS	(Beran et al., 2010)
Lepidoptera	*Helicoverpa armigera*	(*Z*)-11-hexadecenal, (*Z*)-9-hexadecenal	Aldehydes	238.41	Female	C16H30O	(Wang & Anderson, 2009)
Hymenopter	*Cephus cinctus*	9-oxononyl acetate	Ester	200.27	Male and Female	C11H20O3	(Cossé et al., 2002)
Diptera	*Agromyza frontella*	3,7-dimethyl nonadecane	Alkane	296.6	Female	C21H44	(Carriere et al., 1988)

With regards to Cuticular hydrocarbon synthesis, ecdysteroid hormones and juvenile hormone regulate it (Bilen et al., 2013; Wicker & Jallon 1995). The fundamental biosynthetic pathway is highly conserved as it is linked to fatty acid biosynthesis (Blomquist and Bagnères, 2010). There are several genes involved, such as Acetyl-CoA carboxylase (ACC) which is the rate limiting step, Fatty acid synthase (FAS), Desaturase (Desat), Elongase (ELO) enzyme complex, Fatty acyl-CoA reductase (FAR), Cytochrome P450 decarbonylase

(CYP4G) etc. This involves elongation of fatty acyl-Coenzyme A units, producing very-long-chain fatty acids (VLCFs) which upon subducting the carboxyl group, get converted to hydrocarbons (Blomquist and Bagnères, 2010; Howard & Blomquist, 2005; Nelson and Blomquist 1995;). Very little of the dietary hydrocarbons are incorporated into the epicuticle (Blomquist & Jackson, 1973), unlike Type 2 components. New pheromones are created by genetic switches changing the enzymatic pathways. More the genes, more the diversity in blends. The environmental factors that come into play are high humidity, which impairs production and sensing, decreasing the diversity as well (Royer & McNeil, 1993). Drosophila melanogaster of lower latitudes have a greater ratio of C25:C23 carbon chain CHCs (Rouault et al., 2004) to avoid desiccation. As climate change can have myriad effects on the ecology of croplands, studies have been conducted to determine the effect of increased temperature on insect pheromone detection. Wildfire impacts bees by the smoke disrupting olfaction and suppressing the alarm pheromones released (Liu et al., 2022).

3.3 Organs of production and emission

Alarm pheromone components of adult bees are synthetized in the Koschevnikov gland, close to the stinger, and in particular, the levels of the component isoamyl acetate differs according to worker age (Noël et al., 2023). Insects emit their pheromones from varied organs that function as exocrine glands. For example, in Hymenoptera, the stinging apparatus consists of the poison gland and Dufour's gland (Mitra, 2013). The Dufour's gland secretes long chain hydrocarbons, both saturated and unsaturated. In the chalcid wasps Brachymeria lasus and Brachymeria intermedia, the gland region elicits a male courtship behaviour (Simser & Coppel, 1980). In other eusocial colonies, the extracts of the mandibular gland or cuticular washes of the queen have an inhibitory effect called queen pheromone which prevents mating in other females.

Table 2. Important synthetic pheromones

Order	Scientific Name	Common Name	Synthetic Sex Pheromone	Attractive to sex	References
Lepidoptera	*Tuta absoluta* (Meyrick)	South American tomato pinworm	(3E,8Z,11Z)-3,8,11-tetradecatrienyl acetate (TDTA)	Males	(Ferrara et al., 2001)
	Sitotroga cerealella (Olivier)	Angoumois Grain Moth	(*Z,E*)-7,11-hexadecadien-1-ol acetate	Males	(Vick et al., 1978)
	Plodia interpunctella	Indianmeal moth	(Z,E)-9,12-tetradecadien-l-ol acetate	Males	(Sower et al., 1975)
	Choristoneura fumiferana	Eastern spruce budworm	97:3 mixture of E- and Z-1 l-tetradecenal	Both	(Palaniswamy & Seabrook, 1985)
	Plutella xylostella	Diamondback moth	70:30 mixture of (Z)-11-hexadecenal and (Z)-11-hexadecenyl acetate	Males	(Schroeder et al., 2000)
Coleoptera	*Ips confusus*	Pinyon pine beetle	10,11-epoxy-farnesenic acid methyl ester	Females	(Borden et al., 1969)
	Cylas formicarius	Sweet potato weevil	Z-3-dodecenol-E-2-butenoate	Males	(Pillai et al., 1993)
Diptera	*Lutzomyia longipalpis*	Sandfly	(±)-9-methylgermacrene-B	Both	(Bray et al., 2014)

	Ceratitis capitata	Mediterranean Fruit Fly	linaloo 1,2,3-dimethylpyrazine,2, 5-dimethylpyrazine, or geranyl acetate.	Females	(Baker et al., 1990)
	Bactrocera oleae	Olive fruit fly	1,7-dioxaspiro[5.5] undecane	Males	(Mazomenos & Haniotakis, 1985)
Hemiptera	*Sahlbergella singularis*	Cocoa mirid	hexyl (R)-3-((E)-2-butenoyloxy)-butyrate and hexyl (R)- 3-hydroxybutyrate)	Males	(Mahob et al., 2011)

The queen spreads it over herself by grooming (Roseler & Van Honk, 1990). In Diptera, salivary and anal glands of Tephritid flies produce pheromones (Jacquin-Joly & Groot, 2018). In Isoptera, the tergal or the posterior hypertrophied sternal glands of the females produce the sex pheromones required for post-flight behaviour during reproduction (Costa-Leonardo et al., 2009). These are the same as trail following pheromones but are emitted in larger quantities to denote the reproductive function (Pasteels & Bordereau., 1998). In an Aenictus species of army ants, the single pheromone produced is stored in a postpygidial gland (Oldham et al., 1994). In Coleoptera, Trypodendron lineatum, the striped ambrosia beetle, females produce pheromones from the posterior ileum and anterior rectum via a layer of secretory cells (Schneider & Rudinsky, 1969).

3.4 Detection of pheromones

Insects have different ways of detecting the pheromones as well. Volatile chemicals like ketones are detected by olfactory receptors of the antennae and maxillary palps, which are covered by sensilla containing olfactory receptor neurons (ORNs) (Suh et al., 2014). Olfactory receptors are divided into two families. Or genes code for those that detect volatile pheromones (Clyne et al., 1999; Vosshall et al., 2000) and Ionotropic receptors (Irs) detect volatile ligands (Benton et al., 2009). The molecules adsorb onto the antennae and diffuse through cuticle microscopic pores into the sensilla interior. To transport lipophilic compounds to the chemosensory membranes, they are combined with pheromone-binding proteins (PBPs) and moved into the hydrophilic sensillum lymph. It can then interact with its specific receptor protein, transducing a chemical message to an electric signal, which is then amplified by a second messenger system (Ujváry, 2001). Odorant-binding proteins (OBPs) and chemosensory proteins (CSPs) are odour and sex pheromones transporters in antennal lymph (Pelosi et al., 2014; Vogt et al., 2015). Tactile methods use the gustatory sensilla containing contact chemosensory receptors on labellar and tarsal taste organs to detect long-chain CHCs which are non-volatile pheromones (Chung & Carroll, 2015). Gustatory receptor neurons (GRNs) include the gene families that code for Gustatory receptor (Gr), Ir, and Degenerin/epithelial sodium channel (DEG/ENaC). DEG/ENaC is one of the largest ion channel families in the Drosophila, called pickpocket (ppk) genes associated with mating behaviour (Lu et al., 2012; Starostina et al.,2012; Thistle et al., 2012; Toda et al., 2012;, Zelle et al., 2014). The odorant receptors of ambrosia beetles *Trypodendron lineatum*, *T. domesticum*, which attack coniferous and deciduous trees respectively, were characterized, showing high sequence identity and a specific response to lineatin, the female-produced aggregation pheromone (Andersson et al., 2025).

3.5 Role of vision in attraction

With regards to vision in insects, most have Ultraviolet (UV), blue, and green receptors with 350, 440, and 530 nm spectral specificity peaks (Briscoe, 2000; Briscoe & Chittka, 2001). This can be taken advantage of when designing coloured pheromone traps. Pests with nocturnal activity can be inhibited by use of yellow or green light, which disrupts feeding and oviposition. Plastic films that block UV-light can reduce the visibility of greenhouses to whiteflies and thrips by disrupting their orientation and host-finding behaviours (Varone et al., 2026). In Hymenoptera, the dorsal part of the eye of male *Apis mellifera* has green-absorbing visual pigments, which is an example of sexual dimorphism as they are important in mating flights (van Praagh et al., 1980). In Cladocera, the water flea, Daphnia, is attracted to green light because it indicates algal food source (Lythgoe & Partridge, 1989). In Blattodea, cockroach *Periplaneta americana* has only two types of photoreceptors that sense UV and green wavelengths (Song & Lee, 2018). Other orders have wider perceptions of colours. In Orthoptera, the grasshopper species *Acinipe marmarica* and *Glauia terrea* ovipositor valves are bright blue and red which may be for sexual communication (Morse 1920; Shumakov 1963). *Solitarius deselt* locust males are highly attracted to blue and red. Odonata and Lepidoptera usually have four types of photoreceptors, but the butterfly Papilio xuthus senses UV, blue, violet, green, and red with five (Peitsch et al., 1992). Yellow swallowtail butterfly, *P. xuthus*, has tetrachromacy, n amplified detection of colours. (Koshitaka et al., 2008). In Thysanoptera, *Scirtothrips dorsalis* is caught in larger numbers in white and yellow traps while blue is attractive to *Frankliniella occidentalis*. Black or clear traps are unattractive to thrips. The whitefly *Trialeurodes vaporariorum* of Hemiptera moves toward yellow light and away from blue light (Coombe, 1981).

3.6 Evolution of pheromones

Insect pheromones could have evolved in two ways: Small gradual componential changes, including loss, gain or change in ratio (Roelofs & Brown, 1982), results in phylogenetic conservatism. This means closely related species having similar pheromones. The genus Pogonomyrmex is of harvester ants, and all species use the same three alkylpyrazines for trail pheromones (Holldobler et al., 2001). Large sudden changes/ saltational shifts (Baker, 2002) changing the components of pheromones considerably. Dissimilar pheromones are seen in sibling species. Eg. *Yponomeuta* moths (Lofstedt et al., 1991) The following table 1 attempts to showcase pheromone diversity across insect orders: For instance, in the spruce bark beetle Ips typographus, the highly expressed odorant receptor ItypOR41 was studied and it was found to respond specifically to (4S)-cis-verbenol, which attracts both sexes to attacked trees. The closely related receptors ItypOR40 and ItypOR45 were then compared, but ItypOR40 was unresponsive and ItypOR45 showed a much broader responsivity. These receptors are present in a different clade as compared to those in other beetles, indicating multiple evolutionary origins. Practically, this receptor can be used in biosensors to detect tree infestations early on, or in silico to find small molecule antagonists that can disrupt aggregation and thereby reproduction (Biswas et al., 2024). Even if the insects change their pheromones in response to the effective traps, the method still has minimal impact on the environment and is worth pursuing. Pheromone resistant strains of insects may develop, which may change the components of their own pheromones by switching on previously dormant genes (Roelofs et al., 2002) to create more distinct components or new ratios. For example, tea leafroller moth Adoxophyes honmai obtained resistance to the traps using one component of female sex pheromone, and males evolved to detect a broader range of sex pheromone ratios (Tabata et al., 2007). The purpose of this review article is to highlight crops in South India that are heavily infected by pests whose pheromones have not yet been worked out, and

their comparison to a related species in the same genera or family that already has pheromone traps or their pheromones identified, with purpose to assist further research.

3.7 Crops and their pests explored

The following five South Indian crops have one of their major pests described along with yield loss caused by it. Finding out their pheromones would go a long way into contributing to integrated crop management. It is hoped that a comparison of the methods used for the elucidation of the above closest relatives, whose pheromones have even been deployed in field work, will serve as signposts for future researchers, highlighting the diversity of methods for working out insect pheromones.

The cashew pest *Helopeltis antonii*, commonly known as the tea mosquito bug, belongs to the kingdom Animalia, phylum Arthropoda, and class Insecta. It is placed in the order Hemiptera, family Miridae, subfamily Bryocorinae, and tribe Dicyphini, within the genus *Helopeltis*. Three color variants of this species are found, namely dark red, black, and brownish black, with their numbers decreasing in that order (Sathiamma, 1981; Sundararaju, 1996). The losses in cashew cultivation incurred due to this pest can be upto 40-50% (Saroj, 2016). The infestation begins in October-November, culminating in peak population during December-March when the cashew trees are laden with flowers and fruit, holding steady till May and rapidly declining to nil during the monsoons (Sundararaju, 2005). *H. antonii* mainly oviposits on flourishing tender shoots, peduncles and growing nuts, attacking panicles and fruits the most (Ambika & Abraham, 1985). Younger trees are affected most due to year-round flushing.

Table 3. Solved pest pheromones for comparison

Insect to Investigate	Comparison Insect	Pheromone	Emitter	Receiver
Helopeltis antonii	*Helopeltis theivora*	(Z)-3 hexenyl acetate, (E)-2-hexenol	Female	Male
Scirtothrips dorsalis	*Frankliniella occidentalis*	Neryl (S)-2-methylbutanoate, (R)-lavandulyl acetate	Male	Both
Longitarsus nigripennis	*Phyllotreta striolata*	(+)-(6R,7S)-himachala-9,11-diene, AITC	Male + HIPVs	Both
Liriomyza trifolii	i) *Liriomyza huidobrensis*	(Z)-3-hexenol, (Z)-3-hexenyl-acetate	HIPVs	Both
	ii) *Agromyza frontella*	3,7-dimethyl nonadecane	Female	Male
Rhizoglyphus echinopus	*Tetranychus urticae*	Sesquiterpene alcohols e.g. farnesol	Female	Male

Within their life cycle there are five instars of varying morphology (Ambika & Abraham, 1985) and Satapathy (1993). Nymphal development on cashew lasts for 12 days with an average of 10-41 eggs (Pillai et al., 1985). The most damaging of the stages are nymphal and adult, which feed on plant parts with sucking mouthparts, rapidly causing discoloured water-soaked necrotic lesions. Nymphs make an average of 114 lesions per day, adult females 97 and adult males 25. The labial stylets enter to a depth of at least 0.3 mm. Their salivary glands inject poly-phenoloxydase, hydrolytic enzymes (protease and lipase), oxido-reductase enzymes like catecol oxidase, catalase and peroxidase and free amino acids (Mandal, 2000). These cause phytotoxaemia and detoxify host defence chemicals (Sundararaju & Sundarababu, 1999). Symptoms are seen within a week. (Saroj, 2016). It may be useful if the pheromone traps can be deployed just before the peak population is seen, in early October after the monsoons. *H. antonii* has very less intraspecific variation as

shown by Mitochondrial Cytochrome Oxidase I and 13.14 interspecific variation between *H. antonii* and *H. theivora*. Clade l is *H. antonii*. Clade III is *H. theivora*. They co-exist with *H. bradyi* in the west coast of India (Savolainen, 2005).

The chilli pest *Scirtothrips dorsalis*, commonly known as chilli thrips, belongs to the kingdom Animalia, phylum Arthropoda, and subphylum Uniramia. It is placed in the class Insecta, order Thysanoptera, and family Thripidae, within the genus *Scirtothrips*. Of the roughly 8,800 known species of thrips, only about 1% of this order are serious pests (Grimaldi et al., 2004). India's stake in global production of chilli (*Capsicum annum* L.) is 36% (Government of India, 2010). According to a survey by the Asian Vegetable Research and Development Committee, S. dorsalis is the greatest constraint on growth, its contribution to yield loss being 61 to 74% (Hosamani 2007, Patel et al., 2009). Thrips attack the juvenile leaves, buds, and stems by puncturing tissues with their stylets, producing 'sandy paper lines' on the epidermis, leading to its dessication, traditionally called "Murda" disease, because it causes plant death. (Kulkarni, 1922). *S. dorsalis* also vectors seven plant viruses including chilli leaf curl virus (CLC), peanut necrosis virus (PBNV), peanut yellow spot virus (PYSV), tobacco streak virus (TSV), watermelon silver mottle virus (WsMoV), capsicum chlorosis virus (CaCV) and melon yellow spot virus (MYSV), Tobacco Mosaic Viral Infections and Tospovirus infection (Amin, 1981; Ananthakrishnan 1993; Chiemsombat et al., 2008; Mound & Palmer, 1981; Rao et al., 2003; Satyanarayana et al., 1996).

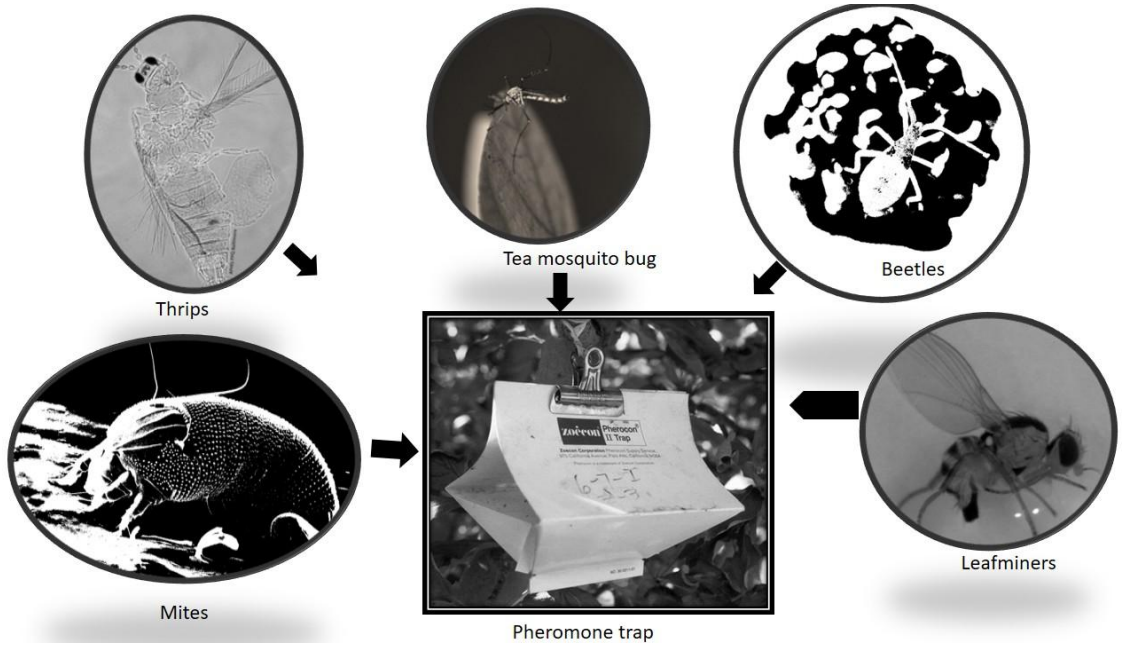


Fig. 1. South Indian crop pests that could be explored for integrated pest management

Thrips are haplodiploid and most have arrhenotokous reproduction in which fertilised eggs produce females and unfertilised eggs produce males, with Sex ratio is in favour of female progeny (Dev 1964; Kirk 2017). Growth proceeds through stages of egg, first and second instar larva lasting 8-10 days, prepupa, pupa and adult. Lifespan depends upon the plant host. Eggs are laid within aerial plant tissue and hatch in a week. Larvae and adults feed near the mid-vein or borders of the damaged portion of leaf tissues. Pupae are in the leaf litter, leaf axils or under the calyx. Temperature requirements range from 9.7 °C to 33.0 °C, with egg to egg is 281-degree days and egg to adult is 265-degree days (Holtz, 2006). They are multivoltine with 18 generations per year during prolonged dry conditions and 2 to 6 generations per crop cycle (Nietschke et al., 2008). The highest population level comes alongside flowering, decreasing at senescence (Palomo et al., 2015). Thrips gather on the chilli three weeks after planting, and are maximum during the eight weeks at full flowering and fruiting. Adult thrips feed on nectar for production of eggs. Nymphs develop by feeding

on pollen (Johari, 2016). Rainfall entirely suppresses the population. The best time to deploy pheromone traps would possibly be just before the flowering of the crop. It is unnecessary during the rains. S. dorsalis is found to prefer to infest strawberry plants that have not been preyed upon previously, and the herbivore-induced plant volatile (Z)-3-hexenyl acetate can prevent this behaviour (Kaur et al., 2026).

The pepper pest *Longitarsus nigripennis*, commonly known as the pollu beetle, belongs to the kingdom Animalia, phylum Arthropoda, and subphylum Uniramia. It is placed in the class Insecta, order Coleoptera, and family Chrysomelidae, within the genus *Longitarsus*. The beetle is distributed along the west coast of India, and its sole host is pepper. It peaks during flushing season with oviposition in July, ending in December when the berries are mature and population falls from February onwards. Adult is a bluish yellow shining flea beetle. The grubs bore into the berries and can eat 3-30 berries each, also damaging tender leaves and spikes, along with the vascular system of the spike axis while moving. The infested berries turn dark and dry, becoming hollow and crumble when pressed, lending the disease its name "POLLU" (Empty). Life Cycle: One generation lasts up to 50 days, with four overlapping generations in a year. The adults lay 1 or 2 eggs in shallow elliptical holes they dig in the pepper berries which hatch in a week; the larval stage lasts for almost a month. Pupation in the soil is at a depth of 5 - 7.5 cm, for a week, but the adults remain encased for 2-3 days until the integument is hardened (Ramachandra Rao et al., 1927). The pheromone traps could be deployed during the length of the monsoons, and just before the flowering of the vines.

The cucumber pest *Liriomyza trifolii*, commonly known as the American serpentine leafminer, belongs to the kingdom Animalia, phylum Arthropoda, and subphylum Uniramia. It is placed in the class Insecta, order Diptera, and family Agromyzidae, within the genus *Liriomyza*. This leafminer is native to America and was introduced to India in 1991 during the import of chrysanthemum (Anon., 1991), and it has acquired major pest status since 1995 (Srinivasan et al., 1995). Persistence on seedlings causes crop failures due to drying of leaves, which are a haven for invading bacterial and fungal plant pathogens (Capinera, 2001; Durairaj et al. 2007). It is a generalist pest, having many hosts. The males cannot puncture leaves and feed so they live only 2-3 days, while females survive for a week, with more activity around noon. It is a polyandrous species, with females mating several times in their life span to maximize fecundity (Kaspi & Parrella, 2008). The losses in cucumber can be extreme and the price is driven up due to the necessity of continuously applying insecticide.

Within their life cycle, 3-4 overlapping generations per year of leafminers is seen as 30-40 days is required for the insect to grow to maturity. This is hastened in tropical climates up to 30 °C. Depending on whether the crop they infest is *zaid* or *rabi*, the adult flies of leafminers can overwinter as pupae and after 9 days emerge from the soil in spring between April and May, or will be noticed from October onwards, culminating in the highest peak in January and then declining (Variya & Patel, 2013). After mating, females puncture the mature leaves with their ovipositor and lay tiny white eggs either singly or in clusters just below the epidermis on the abaxial side's tip and margins, giving a stippled appearance (Parrella et al., 1985). 35 to 39 eggs are laid per day, giving rise to 200 to 400 eggs in total. In 3 days the larvae, on hatching, mine the leaves in an irregular, blotch-like pattern and destroy the mesophyll. These activities greatly decrease photosynthesis, and premature leaf drop causes sun scalding of fruit. Since leafminers are found throughout the growing season of the crop, and the infestation only gets worse as crop maturation progresses, continuous monitoring of the leaf miner population dynamics is required and traps should be renewed constantly, with varying methods of integrated pest management so as to not develop resistant varieties altogether. The field must be cleared of excess weeds that the flies could breed in, and only after the first round of pheromones is deployed, should a minimum of chemical insecticides be used. Parasitic wasps can be introduced when there is no chance of them being lost due to the spraying of the chemical insecticides. Wolbachia-induced cytoplasmic incompatibility is seen in *Liriomyza trifolii* and can be integrated into pest management strategies (Tagami et al., 2006).

The onion pest *Rhizoglyphus echinopus*, commonly known as the bulb mite, belongs to the kingdom Animalia, phylum Arthropoda, and subphylum Chelicerata. It is placed in the class Arachnida, order Astigmata, and family Acaridae, within the genus *Rhizoglyphus*. This species is cosmopolitan, meaning it is found in many regions of the world (Fan & Zhang, 2003). Bulb mites, orig inally discovered in Europe, are found in large colonies. The smallest injury to a bulb leads to infestation and rotten pulp, or gives rise to defective, off colour, stunted new growth with serious losses, along with pathogenic fungi, obtained from North Carolina State University (NCSU). Mites of the genus Rhizoglyphus have hosts with bulbs, corms and tubers (Fan & Zhang, 2003). The yield loss caused by mites can exceed 30% of the crop. It can be expected that mite populations will increase when irrigation or the rain season begins, so deployment of traps like the *Bacillus thuringiensis* (BT) trap with suitable food or pheromone lure could be done then. *Rhizoglyphus echinopus* assesses population density through pheromone levels, and this can affect the size of the insects that grow from nymphal stages (Lymbery et al., 2021).

Their life cycle goes through stages, from egg to larva, protonymph, hypopus, tritonymph and adult. A generation lasts up to 121 days, fecundity and lifespan depending on the host bulb, optimum temperature range between the extremes of 11.8 °C-35 °C, and relative humidity. The number of eggs laid is up to 700 eggs per female, with a male: female ratio of less than 2:1; eggs mature in 5- 27 days, the males living twice as long as females. A hypopal stage is produced due to overpopulation, or decay of substrate. The hypopi stage fixes itself to visiting insects and are transported to new bulbs. Hypopi have no head so do not feed and are resistant to starvation and desiccation, obtained from North Carolina State University (NCSU). The following are pests whose pheromones have already been worked out. The process of identifying the pheromones has been briefly outlined for comparison in methodology. It endeavours to expand upon those features listed in the introduction of pheromone production, detection, response and function in courtship for 6 species which could be signposts to look out for when solving for similar crop pests. Bioassays involving wind tunnel, olfactometer, gas chromatography-mass spectrometry (GC-MS), gas chromatography-electroantennographic detection (GC-EAD), gas chromatography-flame ionization detection (GC-FID), headspace solid-phase microextraction (HS-SPME), and high-performance liquid chromatography (HPLC) conducted are described in short to highlight the diverse techniques used to determine the pheromone and to understand the behaviour of the insect when presented its pheromone in different scenarios or when kept as similar as possible to its natural surroundings, as well as to show in what conditions it cannot detect the pheromone due to environment, solvent or lack of a visual stimulant. A knowledge of the behavioural specifics of these closest relatives would help work out the unsolved insects.

3.8 Comparison insects

The female sex pheromone of *Helopeltis theivora*, commonly known as the tea mosquito bug, is discussed in this section. Taxonomically, the insect belongs to the kingdom Animalia, phylum Arthropoda, and class Insecta. It is placed in the order Hemiptera, family Miridae, subfamily Bryocorinae, and tribe Dicyphini, within the genus Helopeltis and the species *H. theivora*. It is a pest of tea that can be seen throughout the year, but it favors the monsoon season, which runs from June to November. Over 100 host plants have been identified. Indiscriminate use of pesticides like synthetic pyrethroids etc. resulted in resistant varieties. Mating behaviour: Upon moulting, females gain male attraction within 4-9 days when ovary development completes and oviposition commences. Spermatheca secretes the sex pheromones (Radhakrishnan & Srikumar, 2015). The following experiment of Sachin et al. (2008) describe how sex pheromones are extracted from the female tea mosquito bug and what the natural attractant ratios are. Experiment conducted

In the process of collection, after isolating the virgin insects for 4 days, the females are cut up into head, thorax and abdomen, the parts are separately soaked in dichloromethane to conduct High Performance Liquid Chromatography (HPLC) with supernatant

concentrated to 50 microliters. For identification, compounds identified via Gas chromatography–mass spectrometry (GC-MS) are (Z)-3 hexenyl acetate, (Z)-3 hexenyl butanoate, (E)-2 hexenyl pentanoate, 2,4 dimethyl pentanal, and (E)-2-hexenol. In Wind tunnel, it is found that male tea mosquito bugs are most attracted to female thorax supernatant. Male Response to Female Pheromone includes antennal movements, rapid walking, and climbing to the source. Regarding Ideal Ratios, for Compounds (Z)-3 hexenyl acetate and (E)-2-hexenol in the natural range ratios of 1:1 to 1:7 the response was exaggerated with males mounting other males, seen maximally at 1:5 ratio. (E)-2-hexenol increases attraction, but increase in (Z)-3 hexenyl acetate decreases attraction. Presence of related chemicals is found in Heteroptera. Female Response was none for either sex's extract. For Pheromone Dispersal, plywood block dispensers are highly effective and long lasting from 7-10 days depending on climate. 10 to 12 traps per hectare. UPASI and TRF supply traps free of cost (Radhakrishnan & Srikumar, 2015). Antenna sensilla distribution differs between sexes in the adults of *H. theivora*, with SB-II and SM sensilla present only observed in males, which could be used to detect the female sex pheromone for mating (Li et al., 2025).

Frankliniella occidentalis, male sex aggregation pheromone. The common name is Western flower thrips. For classification, the kingdom is Animalia; the phylum is Arthropoda; the subphylum is Uniramia; the class is Insecta; the order is Thysanoptera; the family is Thripidae; the genus is Frankliniella; and the species is *Frankliniella occidentalis.* The western flower thrips are polyphagous pests and virus vectors (Dublon, 2009). The following experiment of William D. J. Kirk et al. (2017) understand how the male of the species produces aggregation pheromones which attract both sexes. Mating behaviour: They release a male sex pheromone from the pore plates of sternal glands for aggregation, where one sex attracts both sexes. It is highly species specific, proven by Y-tube olfactometer test, with species differentiating the pheromones by ratio of individual components (Zhu et al., 2012). Aggregation causes fighting among males (Kirk, 1996; Terry & Gardner, 1990).An adult-male-produced contact pheromone is also present but it is difficult to integrate into pest management due to the need for contact first. A larval alarm pheromone present enhances the effectiveness of insecticides. Experiment conducted Process of Collection: Aggregation pheromones are collected by solid-phase microextraction (SPME) (Hamilton et al., 2005) due to their volatile nature. Males produced 0.1- 0.3 ng of compound per hour, estimated by Headspace solid phase microextraction (HS-SPME) combined with gas chromatography-flame ionisation detection (GC-FID) (Dublon, 2009). Compounds identified: Neryl (S)-2-methylbutanoate and (R)-lavandulyl acetate, which have proven to increase trap catches in trials. They are found to be monoterpenoid esters of 5-carbon acids. The enantiomers of these chiral compounds are separated on a chiral column by GC. Ideal Ratios: In trials, sole application of (R)-lavandulyl acetate unexpectedly reduced trap catch. A 50-50 blend has no difference from solely neryl (S)-2-methylbutanoate in trap catches. Enantiomer-specific response is seen as racemic mixtures catch fewer insects.

(R)-lavandulyl acetate affects adult male and females differently, implying it is a mating pheromone. Aggregation behaviour of Frankliniella occidentalis males involves bouts of abdominal flicking at each other (sparring), and one will manage to climb over and grab his opponent. Females will mate with the first available male that they encounter in an aggregation (Terry & Gardner, 1990). Pheromone Dispersal: Bioline Agrosciences Ltd sells the pheromone in sachets of 10 lures as ThriplineTM ams and by Biobest Belgium N.V. as ThriPher. 30 μg is inserted in a rubber septum or just in the plain trap. If the trap is set 30 minutes before insecticide application, a 30% greater reduction in thrips is seen. But increased spread of plant viruses is possible due to travel between plants. Females show response upon contacting filter discs with the two compounds. Black or clear traps are unattractive (Sampson et al., 2012), implying a connection between the olfactory and visual response, as natural aggregations are on brightly colored surfaces. Host plant volatiles could also be contributing to this. Blue sticky roller traps lower thrips numbers per flower by 73% and fruit damage by 68%. The use of p-Menth-8-en-2-one as bait in white sticky traps has

been seen to be the most effective in capturing *Frankliniella occidentalis* at canopy height (Luo et al., 2026). Other Species: Anti-aphrodisiac pheromones in Echinothrips americanus Morgan (Krueger et al., 2016) are useful for mating disruption.

Phyllotreta striolata, commonly known as the striped flea beetle, is discussed here in terms of the interaction between its male sex pheromone and host plant volatiles. Its classification is as follows: the kingdom is Animalia; the phylum is Arthropoda; the subphylum is Uniramia; the class is Insecta; the order is Coleoptera; the superfamily is Chrysomeloidea; the family is Chrysomelidae; the genus is *Phyllotreta*; and the species is *Phyllotreta striolata.* The following experiment of Franziska Beran et al. (2010) show how plant volatiles play a role in synergy with the insect sex pheromone for aggregation and subsequent mating. *Phyllotreta striolata* is a pest of Brassicaceae. Males release pheromonal compounds only while feeding on the host leaves, causing shotgun feeding damage. Experiment conducted, Process of Collection and Identification: Volatiles emitted from 30 adult *Phyllotreta striolata* males or females feeding on cut *B. juncea* leaf over one or two days are collected and filtered on activated charcoal filter traps, then are analysed with GC-MS.Compounds identified: Brassicaceae plants upon herbivory produce a secondary metabolite called allyl glucosinolate which is hydrolyzed by the plant enzyme myrosinase. The resultant blend of volatile and non-volatile products including allyl isothiocyanate (AITC) attracts more Phyllotreta insects. Other volatiles that are promising attractants for *Phyllotreta cruciferae* are the active male-specific aggregation pheromone sesquiterpene (+)-(6R,7S)-himachala-9,11-diene, 1-hexanol and ar-himachalene, proved by olfactometer bioassays and chiral stationary phase GC-MS, and also 1-pentanol, and (Z)-3-hexen-1-ol.Electroantennographic detection (GC-EAD): Female or male beetles are restrained in a cut pipette tip with one of their antennas immobilized and the tip inserted into an Ag/AgCl glass capillary electrode with Ringer solution (Kaissling, 1971) to connect to the recording unit. Volatiles of a feeding male are used as stimulus. Beetle antennae respond to plant volatiles that contains alkenyl glucosinolate hydrolysis products, such as allyl isothiocyanate (AITC), 3-butenyl isothiocyanate, and 4-pentenyl isothiocyanate, as well as (Z)-3-hexenol and 1-hexanol which are green leaf alcohols. The molecular basis of attraction for *P. striolata* to plant-derived odorants (S)-cis-verbenol and (−)-verbenone through their antenna-biased odorant receptor, PstrOR17 was determined, which can be adapted to pest management (Xu et al., 2024).

Synthetic blend using synthetic (+)-(6R,7S)-himachala-9,11-diene only. Response to Pheromones: Use solely on its own, 4 mg AITC per day per trap needs to evaporate to catch the flea beetles, which is the equivalent of 2000 freshly damaged plants. (+)-(6R,7S)-himachala-9,11-diene 1-hexanol enhances its effect, but alone it is not behaviourally active. In lab trials, beetles are attracted more by feeding males than by the synthetic stimuli. Pheromone Synthesis: (Z)-3-hexen-l-ol is synthesised via 1,4-selective hydrogenation of the conjugated diene 2,4-hexadienal in the presence of arene Cr(CO)3 or Cr(CO)6 catalysts. Simple aldol condensation of acetaldehyde with croton aldehyde in the molar ratio 5: 1 prepares the diene (Furuhata et al., 1982). (6R,7S)-(+)-himachala-9,11-diene, is synthesised by spontaneous bromination/ dehydrobromination of 2,6,6,9-tetramethylbicyclo [5.4.0]undec-8-ene (Jimenez-Alemana et al., 2012). Pheromone Dispersal: 100 µg AITC combined with 5 µg (+)-(6R,7S)-himachala-9,11-diene (36) attract the most beetles. Other Species: *P. cruciferae*, *Aphthona flava*, *A. czwalinae* (Weise), A*. cyparissiae* (Koch) and *Epitrix fuscula* males also emit some of the compounds identified for *P. striolata* (Bartelt et al., 2001). *Galerucella calmariensis* (L.) and *G. pusilla* (Duftschmidt) of the family Chrysomelidae both emit dimethylfuran lactone (Bartelt et al., 2006).

Liriomyza huidobrensis, HIPVs. The species, commonly known as the serpentine leafminer fly, is classified as follows: Kingdom Animalia, Phylum Arthropoda, Subphylum Uniramia, Class Insecta, Order Diptera, Family Agromyzidae, Genus *Liriomyza*, and Species *Liriomyza huidobrensis*. A significant amount of energy is expended in producing sex pheromones so in some species there is a functional reduction of them. There is no point in producing pheromones over vast distances, as seen in some parasitic wasps (Xu et al., 2016).

Predators may pick up on these signals and locate their prey easily, or plants may recognize the compounds and produce repellent defence chemicals and alert signals (Wyatt, 2014; Helms et al., 2012). In *L. huidobrensis*, when adult females puncture leaves in feeding and oviposition, host plants release specific blends of volatiles attractive to both sexes. The advantages of Herbivore-induced plant volatiles (HIPVs) are high attraction, low molecular weights for long distance dispersion and can synergize with the vibrational duets for sexual communication that leafminers conduct (Ge et al., 2018). The following experiment of Ge et al. (2019) devises proofs on the lack of insect based sex pheromones in the species Liriomyza huidobrensis, as well as what plant volatile is attractive. Experiment conducted, Process of Collection and Identification: Organic compounds are washed from the whole bodies of two-day-old mature virgin adult pea leafminers raised on kidney bean plants. GC–MS detected 22 Cuticular hydrocarbons (CHCs) which weren't qualitatively different in either sex, but more are produced in females because they are larger. This implies no sex pheromones. On the wind tunnel, males and females flying upwind are exposed to volatiles of the opposite sex extracted in hexane in a four-armed olfactometer, but no response was obtained.

Experiment is repeated for HIPVs produced by punctured plants and response is obtained in both sexes. On comparing volatiles of virgin females plus female-punctured leaves to only the punctured leaves, there was no significant difference as no insect-derived chemical was found in the former and both were equally attractive to males. Solid-phase microextraction (SPME) and GC-EAD: No antennal response when GC–EAD is conducted on males to the SPME volatiles and non-volatiles extract of females again proves no sex pheromones are produced. GC–EAD is conducted on both sexes exposed to Green leaf volatiles (GLVs), terpenoids and oximes. They respond to (Z)-3-hexenol and (Z)-3-hexenyl-acetate mainly, as well as (3E)-4,8-dimethyl-1,3,7-nonatriene (DMNT). In addition, females also respond to b-caryophyllene and 2-methylpropanal oxime. Response to Pheromones: When tested for visual, olfactory and control responses, a female and male pair in a cage perform vibrational duets when in the presence of female-punctured leaves and the two blends of synthetic HIPVs blend of 1050ng and GLVs blend of 580 ng. Females give a bobbing signal, and the male approaches (Ge J et al. 2019), followed by copulation. Males begin searching for mates even when exposed to the playback of female response signals. Pheromone Synthesis: (3Z)-hex-3-en-1-yl acetate is an acetate ester that can be synthesised from the condensation of acetic acid with (Z)-hex-3-en-1-ol.Pheromone Dispersal: HIPVs as chemical signals can enhance the effective space of acoustic traps. Thus for *L. huidobrensis* no sex pheromone is found. In other experiments on a different leafminer species by Carriere et al., 1988, sex pheromones were found.

Agromyza frontella, female sex pheromone:.Common name: Alfalfa blotch leafminer Classification. Kingdom: Animalia; Phylum: Arthropoda; Subphylum: Uniramia; Class: Insecta; Order: Diptera; Family: Agromyzidae; Genus: *Agromyza*; Species: *Agromyza frontellaIt* is found in North America and Europe. Experiment conducted Process of Collection and Identification: Hexane extract of alfalfa-fed 3 day old *A. frontella* adults was analysed by GC-FID and GC-MS and used for bioassays. Compounds identified: 3,7-dimethylnonadecane is a branched saturated hydrocarbon in females which attracts males. Concentration in females is about 54 ng. Pheromone synthesis can be synthesized from dodecyltriphenylphosphonium bromide. Bioassay and Response to Pheromones: Live virgin day-old males are exposed to the following cadavers glued under alfalfa leaflets: Freshly killed 3-day old virgin female Male cadavers soaked in 1) 5 microlitres of the female extract; 2) 5 microlitres of the 3,7-dimethylnonadecane in hexane; Controls: female and male cadavers soaked in hexane. All three experimental cadavers showed the same degree of response from the males regarding number of contacts and attempted copulations, frequency of wing vibration and time spent on the plant. However when black cotton knots soaked in the chemicals did not give a response, it was concluded that there is also a short-range visual component involved in mating comparison pest.

Tetranychus urticae, female sex pheromone. The species, commonly known as the twospotted spider mite, is classified as follows: Kingdom Animalia, Phylum Arthropoda, Subphylum Chelicerata, Class Arachnida, Order Prostigmata, Family Tetranychidae, Genus *Tetranychus*, and Species *Tetranychus urticae*. Arachnids play important roles in the field as predators, but certain species, especially of mites, can be very damaging. A method of pheromone control is explored: The following experiment of Reed N. Royalty et al. show whether extract solvent and time play a role in sex pheromone perception in mites. Tetranychus urticae has 150 economically important host plants. In the deutonymph stage, females become quiescent by depositing webbing on the leaf. Wandering males locate these females by short-range mechano- or chemoperception cues of the webbing (Penman & Cone, 1972). They are arrested there and guard her until ecdysis to improve their chances of being the first to mate. This need not be solely dependent on female pheromones as in natural conditions males can move around her without becoming arrested (Potter et al., 1976). Other factors that influence male guarding behaviour and inter-male fights positively are high temperature, low humidity, physiological state of the male and host plant decline (Cone et al. (1971b). This implies the pheromone only prolongs the guarding behaviour. This behaviour is similar to that of *Rhizoglyphus echinopus*. Experiment conducted Process of Collection and Identification: Tests were conducted to conclude whether the extract solvent plays a role in insect pheromones. Quiescent deutonymphs raised on Henderson lima beans are soaked in HPLC grade hexane, diethyl ether or methanol for 2 days, and for time periods from 5 min to 96 hours. The solvents have different polarities for all possible pheromone compounds to be eluted. Different parameters were considered to study the method of arrestment such as Comparison of Solvents, Effect of Different Extraction Times, Effect of Concentration and Extractions from Other Instars. Response to Pheromones: In an experiment, extract is dried in a 3-mm-diameter circle on a glass slide, and males are watched for how long they spend within it. 2 minutes are given to get used to the surroundings and arrestment ends if they leave it for more than 5 seconds. There was no difference observed in guarding behaviour due to different solvents or time.

Extracts of other instars like protonymphs, quiescent protonymphs, deutonymphs, and adults of both sexes were bioassayed, but quiescent deutonymph extract arrested males longest because it is the optimum reproductive strategy, as mating can occur with newly moulted virgin females (Helle, 1967; Potter et al., 1976; Potter & Wrensch, 1978). Wind tunnel: When testing for volatile chemoreception, Cone et al., 1971a and Penman and Cone, 1974 found that a maximum distance of 2-3 mm is required for attraction. While circling behaviour around the source was observed, orientation and arrestment were not seen, giving a conclusion that volatile perception of pheromone doesn't occur. Compounds identified: HPLC separations find four distinct active components in female sex pheromone. Sesquiterpene alcohols farnesol and nerolidol, monoterpene alcohol citronellol were identified by Regev and Cone (Regev & Cone, 1976). Female fertility is increased with farnesol applied topically. A conclusion was drawn that host plants with greater content of farnesol are more susceptible to *T. urticae* because of its gonadotropic effect. Male response to the above synthetic compounds was not seen however, but activity is noticed when the most polar components are not present. Pheromone Dispersal: The BT Trap is a robust adjustable housing containing a mixed food base lure. This could be swapped out for farnesol. Within 4 days the laboratory trials showed a mean minimal capture rate of 62% (Thind 2005). Since there is no volatile perception of pheromone, traps used for this insect may have to be modified according to vision or with food bait.Pheromone Synthesis: Farnesol is synthesized from nerylacetone or geranylacetone (Yu et al. 2005).

3.9 Synthetic pheromones

Nature has always given the basic structural formulae for designing the most effective synthetic insecticides. From chrysanthemum flowers, a neurotoxic but not photostable insecticidal chemical Pyrethrin is obtained, which was converted to synthetic pyrethroids

with better properties, although insoluble in water (Ananenka 2018). These have been widely used in agriculture and new research is required to find less toxic chemicals to humans and beneficial insects. In this way, the basic structure of the elucidated sex pheromones of insects is modified to be more user friendly for application or stability. The major sex pheromone of moth species that infest stored products is (Z,E)-9,12-tetradecadienyl acetate (ZETA), and it is used for detection, mating disruption and trapping of the insects. Through mining of the pheromone gland transcriptome data of the almond moth, Ephestia (Cadra) cautella (Walker), the gene for E12 fatty acyl desaturase was found and a pathway for ZETA bioproduction was established in expressed in Saccharomyces cerevisiae (Ding et al., 2021).The following table 2 consists of a short list of some important synthetic pheromones: A summary of the solved pest pheromones for comparison while investigating the above crop pests is given in the table 3.

3.10 Other methods of control

Aside from these, cultural, chemical and biological methods have been used to rid fields of the pests. While chemical methods have immediate effects, they do give rise to superbugs. Cultural methods have traditionally been reliable but with the rise of monocultures, pests may be able to dominate. Biological methods are by far the most cost saving and environmentally friendly option as it relies on promoting a healthy ecosystem. The following are methods for control of insect pests:

Helopeltis antonii biological controls includes egg parasitoids including *Telenomus cuspis* (Rajmohana et al., 2013) and *E. helopeltidis* (Devasahayam, 1989), nymph parasites such as Leiophron (Sundararaju, 2002), spider predators such as *E. inornatus* can eat 20 *H. antonii* per day (Devasahayam & Nair 1986), assasin bug predator such as *Rihirbus trochantericus* Stal var which is cultured using wax moth larvae as food (Bhat et al., 2013); predatory mite such as Leptus latches onto the mouth parts of *H. antonii*. The latest technology is using drones to shower mites across crops for ease of distribution as they don't travel far. For chemical control, natural chemical such as oil of Pongamia and Calophyllum kernel (NRCC 1993, Satapathy 1993). Meanwhile artificial chemical such as DDT sprayed twice in 15 days (Damodaran and Nair (1969)), spray in the early morning and afternoon, when new shoots start to grow and at the onset of fruiting and *H. antonii* is active (Babu et al. 1983, Pillai 1987). Apply synthetic pyrethroids by fogging (Tuck,1987). Carbaryl dust works best but is damaging to beneficial insects like bees (Bakthavatsalam et al., 1993). Application of fipronil 5% SC (2ml/l) was the most effective in reduction of tea Mosquito bug population followed by profenofos 50% EC (2 ml/l) and lambda cyhalothrin 5% EC (1.5ml/l).

Scirtothrips dorsalis, pesticides are not much use against thrips due to their ability to hide in tight places and development of resistance to insecticides (Gao et al., 2012). Biological control including mites such as *Amblyseius swirskii* and Cucumeris work best (Dogramaci et al., 2011; Arthurs et al., 2009), minute pirate bug such as Orius, parasitic nematodes such as *Steinernema feltiae* for thrips pupae. For chemical control, Dichlorvos is a pesticide that can be put in different coloured CC trap, although white and yellow ones work better than blue (Chu et al.,2006). Vapona® dispensers work five times better and have been tested in Taiwan (Chu et al., 2005).

Longitarsus nigripennis can be controlled chemically using several techniques. To kill pupae, rake the soil with quinalphos, carbaryl and endosulfan. Spraying of dimethoate and quinalphos must be done when formation of spikes begins (June-July) and when berries are maturing (September-October).

Liriomyza trifolii biological control includes parasitic wasps belonging to Braconidae, Eulophidae and Pteromalidae work well when pesticides aren't used. For chemical control, Acephate, dichlorvos, phosalone and triazophos are used (Chunilal, 2006). Broadleaf weeds and remnants of older crops encourage the breeding of leafminers, so cultural control

involves removing them. So these must be cleared off in due time, weeds must be removed and deep ploughing must be done to bury the insects.

Rhizoglyphus echinopus biological control includes predatory mites: *Hypoaspis aculeifer* and *Cosmolaelaps claviger* belong to the order Mesostigmata feed on juvenile *R. echinopus*. The predators can be showered on the field using drones for even dispersion. Mites are also attacked by viruses, bacteria, protozoans and nematodes. Hirsutella fungi infect mites (Gerson et al., 1979). For chemical control, Acaricides are widely used, although mites develop a tolerance for them quickly. They have active oxidases, esterases, and transferases for detoxification. 100 ppm of citral mixed with miticide can control mites. Cultural control involves keeping bulbs dry during storage, because bulb mites are not drought tolerant and cannot harm dry, stored bulbs.

3.11 Resistance

A few plants have been identified which show greater ability to tolerate pests:Cashew: Accessions VTH 153, Kunthur 24, Goa 11/6, VTH 153/ 1, VTH 9/78 and 51 others in Karnataka, accession No. 665 in Kerala and BLA-39-4 in West Bengal (Ghosh & Chatterjee 1987, NRCC 1988, Uthaiah et al., 1994, Hiremath,1991, Sundararaju & John 1993). They have more phenols, but cannot completely fend against detoxification enzymes. Chilli: Genotypes DCC-3, 185, 109 and 89. They have high trichome density, chlorophyll and total phenol content (Latha S et al., 2018). Cucumber: Gorgan, Sanandaj and Roodbar are resistant and acquire lesser leafminer stings and mines (Basij et al., 2011).

4. Conclusions

Jevons Paradox states that when the efficiency of using a resource is increased, so does the consumption of it. We have been trying to fix the problems of agriculture by adding as much chemical as we can to the ground, in the form of fertilizers and pesticides. There are several policies that have supported practices in agriculture that while having increased our immediate yields, depleted the soil and thus now require additional inputs, leading to salinity and poisoned runoff. This has created a cycle which is difficult to escape from. The arms race between insects and pesticides will only continue if unique methods for dealing with pests are not devised. But by combining efforts in pest management many of these problems can be solved, and perhaps even more efficiently. Less can be more, with judicious use of insect pheromones and cultural pest management, we will not leave behind resistant superbugs that can only be cleared with ever more powerful and dangerous chemicals and antibiotics. Growing a healthy ecosystem means we have to stop the one-size-fits all strategy in insecticides, and further research in pheromones can provide us with smarter and regenerative solutions to the pest management problems.

Acknowledgement

The authors would like to thank all parties who contributed to the completion of this research, particularly those who provided valuable support, feedback, and assistance during the research and manuscript preparation process.

Author Contribution

R.M. and S.S.; Conceptualization; Methodology; Investigation; Formal analysis; Writing–original draft; Writing–review & editing. Both authors read and approved the final version of the manuscript.

Funding

This research received no external funding.

Ethical Review Board Statement
Not available.

Informed Consent Statement
Not available.

Data Availability Statement
Not available.

Conflicts of Interest
The authors declare no conflict of interest.

Declaration of Generative AI Use
During the preparation of this work, the authors used Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. After using this tool, the authors reviewed and edited the content as needed and took full responsibility for the content of the publication.

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