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Use of Semiochemicals for Monitoring and Controlling Agricultural Pests

[1]Moheet Kishor Bhoyar, [2]Dr. Vaibhao R. Gurve

[1]M.Sc. (Agri.) Agricultural Entomology, Department of Agricultural Entomology, College of Agriculture, Dr. B.S.K.K.V., Dapoli, Dist. Ratnagiri (Maharashtra)

[2]Subject Matter Specialist (SMS), Department of Horticulture, Krishi Vigyan Kendra, Nandurbar

Corresponding Author Mail- moheetbhoyar@gmail.com

Abstract

Semiochemicals: the language of chemical ecology that is changing agricultural practices Sustainable agriculture has been ushered in as semiochemicals form a exciting and potentially revolutionary set of tools. Its' compounds, which include pheromones, kairomones, allomones and synomones is an important factor that regulate the insect behavior on mating, aggregation hosts seeking and defense [7]. There is a particular interest in the agricultural field due to their potential use in integrated pest management (IPM) because of the resistance against chemical pesticides, environmental pollution and nontarget effects generated by these compounds. Semiochemicals provide an ecological, species-specific and efficient means of monitoring and controlling agricultural pests. Insect monitoring entails knowledge on population dynamics, seasonal occurrence, and migration of pest insects using pheromone-baited traps and lures. Such a practice facilitates the timely decision making, the economic thresholds turning point determination and decreases unnecessary pesticide spraying. Semiochemicals for pest control used in some novel approaches. The technique of Mating disruption is based on dispersion of artificial sex pheromones to confuse males, leading them not locate females in order to mate, hence reduces pest populations. Attractant baited traps can be used for mass trapping of pests, including fruit flies and moths. These push–pull strategies combine repellents (push) and attractants (pull) and provide target-specific pest control while maintaining crop safety. Also, attract and kill approaches combine semiochemical lures and toxicants for selective control of

pests with low ecological disruption. Plus, semiochemicals have various benefits including: safety towards natural enemies, no toxic residues and lower risk of resistance compared to classical insecticides. Nevertheless, the high production costs, poor field persistence and requirement of species-specific formulations have hindered their acceptance. Research is under way for improved synthesis methods, micro-encapsulation, and nano-delivery systems to overcome these limitations. In addition, there are the prospects of synergistic effects of semiochemicals with biocontrol agents and precision agriculture devices leading to improved efficacy and scalability.

Introduction

Insect pests cause crops damage, yield loss, and food insecurity. Historically, synthetic chemical insecticides have served as the standard solution to pest control. Although these chemicals serve as faster tools of control, the indiscriminate and continuous application of them has brought forth many challenges to become a hindrance such as the development of insecticide resistance, resurgence secondary pests, pollution of soil and water bodies, adverse impact on non-target organisms like pollinators and natural enemies. Rising awareness of these constraints along with developing consumer interest in pesticide-free fruit and vegetables has brought to the forefront an urgent demand for safe, eco-friendly natural pest control tools. One such promising alternative is the use of semiochemicals, i.e., natural or synthetic chemicals that elicit responses between living organisms. Etymologically, semiochemicals are derived from the Greek semeion (sign) and chemistry and they mediate insect behaviours e.g., host finding, mating, aggregation, defence. Chemical compounds in the diet of insects can be in two broad categories: pheromones, which are involved intre-specific communication, and all omone/abbemens nerve between species (including kairomones/allornones/synomones). Their high specificity, and their capacity to control insect behaviour without killing the target species makes them particularly attractive for monitoring or controlling pests.

Currently in agriculture, semiochemicals have shown promising potential as a contribution to IPM programs in order to reduce dependence on chemicals that are broad-spectrum toxic. For instance, pheromone traps are widely used for assessing pest (cotton bollworms, fruit flies etc.) population dynamics for early interventions. Likewise, pest management tactics like mating disruption, mass trapping, push–pull, and attract-and-kill strategies have shown great promise in controlling pests with respect to population reduction coupled with ecological integrity. The use of semiochemicals is also consistent with international objectives for sustainable agriculture and the preservation of the natural balance in the environment. Unlike synthetic pesticides, pheromones have no toxic residues and are safe for humans and non-targets and less likely to induce resistance by use of behavioral disruption. Nevertheless, hurdles regarding expenses, formulation stability, and farmer knowledge still exist, which currently restrict widespread applicability across most regions.

Categories of Semiochemicals in Pest Control

Semiochemical signals are chemical cues that mediate the behaviour of insects and other organisms,They have been exploited as potent tools in agricultural pest management. These chemicals can be distinguished into two broad categories: pheromones, that operate between members of the same species, and allelochemicals, which modulate interactions among individuals from different species. Both groups have been extensively used in practices of monitoring and control insect pests on crops.

Pheromones

Pheromones are intraspecific semiochemicals exploited by insects to communicate. These are the most common in pest control:

Sex pheromones: Produced by females (or occasionally males) to attract mates. Synthetic analogs are utilized in monitoring traps for population levels of pests or in massive amounts as mating disruptants. For instance the sex pheromones of moth pests, namely Helicoverpa armigera and Spodoptera litura, are being applied to cotton and vegetable cultivation.

Aggregation: Unsex pheromones, produced by males or females to attract members of the same species to a food source or refuge. These are efficient in mass trapping of insects such as bark beetles and palm weevils.

Trail pheromones: Signalling molecules employed by social insects, such as ants and termites, to create foraging trails. Although used infrequently in agriculture, they could be utilised for baiting methods

Allelochemicals represent interspecific signals that are beneficial to one or both of the participants. They are further divided into:

Kairomones: Suitable for the receiver, but detrimental to the emitter. ") For example, volatile molecules emitted by plants lure their herbivorous predators — think fruit flies and beetles. Control Insect control Synthetic kairomones are integrated into traps for the attraction of pests.

Allomones: To the advantage of the emittor while injurious to the recipient. For example, some plant volatiles serve as repellents for insect herbivores. Treatment of unconditioned flies to inhibitors can be used in push– pull strategies (i.e. repellents that push pests away from crops).

Attributes shared by synomones: Mutual benefit of the emitter and receiver. For instance, herbivore-induced plant volatiles have been shown to attract natural enemies such as parasitoids and predators for biological control.

The versatility of semiochemicals can be exploited in various types of pest management technologies such as monitoring (traps), mass trapping, attract-and-kill, mating disruption, and manipulation of natural enemies. Their selectivity renders it harmless to non-target organisms, and their compatibility with biological and cultural controls enhance the benefit of their IPM.

Semiochemicals for Pest Monitoring

Surveillance is an important part of an IPM program because it provides information about the presence, abundance, and temporal dynamics of a pest population. Particularly, semiochemicals including pheromones and kairomones have proven to be an irreplaceable part of integrated pest management (IPM), due to their high specificity, low activity threshold, and ability to detect pests with a small number of individuals. Their use for monitoring allows farmers and researchers to know when, or if, control measures are necessary in order to minimize the level of crop protection. The Pheromone-based monitoring is the most used application. Synthetic sex pheromones are introduced into dispensers and put into traps, including sticky, funnel or delta traps to lure male insects looking for females. Insects trapped served as a good indicator of the pest population dynamics and migration too. For instance traps with sex pheromones are widely applied to trap cotton bollworm (Helicoverpa armigera), pink bollworm (Pectinophora gossypiella) and rice stem borer (Scirpophaga incertulas). Pheromone traps are employed to monitor populations of codling moth (Cydia pomonella) and some fruit fly species (Bactrocera spp.) in fruit crops. Kairomone-baited traps are useful for pest monitoring as well. These compounds imitate host-plant volatiles, which lure insects. For example, methyl eugenol and cue-lure are used for population monitoring in fruit flies on mango, guava abd cucurbit crops. Ethanol-baited traps are also used in forestry to monitor bark beetles. Kairomone lures give advance warning of pest incursion and enable intervention action before damaging populations occur. Semiochemical monitoring is particularly helpful in setting economic threshold levels (ETLs). By relating trap catch to crop damage, farmers can time insecticide applications based on the intensity of pest populations and avoid unnecessary applications. In addition, the semiochemical traps enable mass monitoring over extensive areas, thus supporting pest prediction and area-wide management programmes.

Semiochemicals for Pest Control

Besides the identification of suitable monitoring tools, semiochemicals are more and more used as direct control agents in order to reduce population numbers by directingome manipulation. Unlike traditional pesticides that kill insects by toxicity, semiochemicals interfere with or otherwise modify insect behavior, such as mating, aggregation and host finding. The method is extraordinarily species selective and environmentally safe, and is compatible with other IPM strategies.

Mating Disruption

The use of semiochemicals in mating disruption is among the most successful. Males may be induced to move away from females once searching is initiated Male flying and landing patterns are also key when considering the actual success of mating. This method was applied to control lepidopteran pest codling moth (Cydia pomonella) in apple orchards, pink bollworm (Pectinophora gossypiella) in cotton and densecursors of rice stem borers. The strategy is most effective in closed, or perennial crop systems where pest populations are concentrated.

Mass Trapping

In this approach, pheromones or kairomones are formulated to lure insects into traps where they are trapped and killed. Mass trapping is effective for highly mobile pests with high attractancy to chemical lures, notably fruit flies (Bactrocera spp.) in horticultural crops and red palm weevil (Rhynchophorus ferrugineus) in coconut and date palms. Applied at high enough density of traps, pest abundance is suppressed far below economically damaging levels.

Attract-and-Kill Techniques

It is a killing system using semiochemical baits associated to a toxicant, generally an insecticide. Insects are attracted to the source by pheromones or kairomones and die on contact or by consumption of it. Attract-and-kill also reduce the amount of insecticide sprayed compared to a blanket spray, decreasing environmental contamination and non-target impacts. Push–Pull

Systems Semiochemicals are also incorporated into behavioral manipulation tactics, such as the push–pull strategy. Repellent compounds ("push") can push pests away from the main crop, and attractive compounds or trap crops ("pull") can pull them into manageable areas. In maize, this strategy has been exploited against stemborers with Desmodium as repellent and Napier grass as attractant. Semiochemicals are valuable for pest control due to their specificity and minimal impact on environment, as well as friendly relation to species enemies. But the effectiveness of this strategy depends on pest population, plant type and environmental conditions. Formulation technologies, such as microencapsulations and controlled-release dispensers, are improving field longevity and efficacy.

Advantages of Using Semiochemicals

However, semiochemicals have proven to be one of the best alternatives for insect predator because they can manipulate/influence pest action that reduces damage on crops without negative impact on environment. Semiochemicals operate as communication signals, not toxicants, in contrast to traditional pesticides.Small-scale and targeted semiochemical based approaches are safer than broad scale contact/spray applications of older generation chemicals. Their benefits are ecological, economic and social, making them more widely applicable in the IPM.

Species-Specific Action

The major advantage of semiochemicals is their high specificity. The pest behavior modifying chemicals are specific to individual pest communication systems, thereby targeting only pests of interest. This spares non-target organisms such as pollinators, predators, parasitoids and other beneficial arthropods.

Environmentally Safe

Their biodegradability and extremely small dosage ensure that no toxic residues are left on crops, in soil or water. They reduce the potential for pesticide residues in agricultural products and the environment, and thus support food safety and ecosystem soundness.

Resistance Management

As semiochemicals effect behavior modification and not direct lethality, resistance of pests is much less likely to occur than with chemical insecticides. For instance, mating disruption does not lead to reproduction and no selective pressure is exerted for resistance traits. This Confers semiochemicals an instrument for sustainable pest control.

Compatible with IPM and Biological Control

Semiochemicals can be used in combination with other IPM strategies. They increase biological control by way of attracting natural enemies with synomones, or decrease pest density to a level where predators and parasitoids can more effectively manage them. Being non-volatile, they do not affect biological agents or cultural practices.

Earliest Monitoring and Suppression The semichemicals enable surveying for a pest in the earliest stages of colonizing a region by pheromone- and kairomonesbased monitoring. This allows growers to take preventative action ahead of pests reaching harmful levels, thus helping to save on unnecessary pesticide application and associated expense.

Economic and Social Benefits

Semiochemicals also act as a chemical alternative-pesticide pathway and therefore can decrease the potential of pesticide-related health risk on the part of both farmers and consumers. They also cater to the growing consumer want for produce that is free of chemicals, which creates avenues for exports and premium sales. Lower use of pesticides can also bring savings in the future by reducing input costs and increasing farm profitability.

Limitations and Challenges

Although semiochemicals are considered as environmentally benign substitutes to traditional pesticides, a number of factors and obstacles restrict their application in large-scale agricultural production. These limitations are technical, financial and pragmatic and they impact on the efficiency with which semiochemicals can be included into pest control development.

Costly To Produce and Formulate

The semiochemicals, particularly sex pheromones are often synthesised by a long and complex chemical process. The purity required for biological activity also contributes to cost of manufacture. Furthermore, sophisticated formulation technologies like controlled-release dispensers or microencapsulation add cost, and are less affordable for smallholder and resource-poor farmers.

Limited Field Persistence

Semiochemicals in common are volatile compounds that quickly deteriorate under field conditions by the heat, sunlight, or microbial action. This short life span diminishes their potency and requires frequently replacing or reapplying them, resulting in added work effort and expenses. The development of sustained release also represents an important formulation challenge.

Species-Specificity

While species specificity is beneficial when targeting pests, it can also be a limitation. Each species of pest needs a specific semiochemical blend, which makes it challenging to control multiple pests complexes at once. This constraint limits the potential for their use in crops belonging to the same crop (pes target) at cropping systems that are under different pests attacks.

Efficacy under High Pest Pressure

Semiochemicals (e.g., mating disruption and mass trapping) are not always efficient at controlling pests that are already numerous. The best applications of these strategies are preventive actions rather than corrective actions, and necessarily involve early action and vigilant observation.

Limited Awareness and Adoption

Farmers' knowledge on the use of semiochemicals remains low in many parts of the world and more notably in developing countries. Ignorance about how to use them, maintain the traps or read monitoring data also restricts their uptake. The provision of extension services and demonstration programs is important for wider adoption.

Infrastructure and Policy Gaps

The successful utilization (at the community or regional level) of semiochemicals will usually necessitate some form of collective coordination. Their widespread adoption is handicapped by fragile supply chains, insufficient local manufacturing capacity and a lack of government backing. In addition, approval by regulatory authorities can impede time to market.

Conclusion

Semiochemicals are effective and species-specific alternatives to traditional chemical pesticides in modern agriculture, which has played an increasingly important role. Semiochemicals offer effective tools for pest monitoring and control, owing to insects' use of them in the context of natural communication. They are used in surveillance by means of monitoring and pheromone and kairomone traps, allowing for early detection of pest infestations, accurate estimation of population dynamics and timely decisions for intervention to control the pest. For direct control, methods such as mating disruption, mass trapping and attract-and-kill systems for reducing pest populations while preserving low adverse effects for beneficials and the environment are shown to have potential. Semiochemicals have several distinctive features, including safety to humans, pollinators, and natural enemies of pests; lack of toxic residues in food and NTFPs as well as in the environment; low possibility of resistance development that make semiochemicals an important component in IPM. Even more, their complementarity with biocontrol and cultural measures inspire them as good options when integrated in a synergistical approach of IPM. As the world-wide market for non-pesticide-treated products continues to increase, and the desire to reduce environmental pollution associated with over use of pesticides becomes increasingly pressing, semiochemicals emerge as an irresistible tool not only for food security but also ecological stability. Such advantages notwithstanding, semiochemicals are not universally accepted. High production cost, low field persistence, species specificity and low awareness among farmers are some of the limitation for their extensive use especially in developing countries. Addressing these issues demands sustained research in the development of low-cost synthesis strategies and for creative formulations with controlled release, integrated with other cuttingedge technologies such as nanotechnology and precision agriculture. Policy support and extension services, as well as farmer training will be key in encouraging uptake.

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