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Field Tests for Exploiting the Behavioral Control Tactics to Pest Tephritid Fruit Flies (Insecta: Diptera)

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Abstract

In the current article, it has been attempted to determine whether the exploiting of behavioral control tactics have a synergistic effect on fruit flies capture and management in orchards and farms. Worldwide, the planting and consumption of fruits and vegetables have been steadily increasing during the last many years. Fruit flies are the most notorious pests threatening the production of horticultural crops globally, and effective, cheap and economically feasible control options are highly encouraged for poor farmers. With the emphasis on environmental and health issues due to usage of insecticides for control of fruit flies, horticulturists are searching for ways to grow healthy crops to protect the ecosystem. Some of the non-chemical alternatives are in a category known as behavioral control of insect pests. Behavioral control covers an array of techniques that involves manipulation of some aspects of behavior of fruit flies so that their populations are reduced. Protein odor significantly can increase the number of fruit flies captured by traps, and fly captures by unbaited traps (visual cue only) or McPhail type traps baited with lure (olfactory cue only), are effective management tools to control prevalent harmful fly pests for a number of fruits and vegetables. Pheromones traps and dispensers disrupt mating behavior of target species by emitting chemically produced substances. Pheromone emitters inundate the pest area with these chemical signals, saturating the air and confusing the insects so that males can no long find females to reproduce. Furthermore, the useful ideas on colors, shapes and odors of host, visual and olfactory stimuli, mating behavior, oviposition behavior, timing of oviposition, emerging of adult, pupation of larva and diurnal activity of adult fruit fly, can be of immense value to those of us working in pest control efforts. Thus, a simple, practical and low cost behavioral approach is developed that has a significant potential for crop protection, long lasting residual activity, excellent efficacy and favorable safety profiles. This makes the present invention well-suited for pest fruit flies management in a variety of crops.

Keywords

Tephritids, Trapping, Behavioral Control, Pheromones, Attractants

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1. Introduction

Fruit flies attack many important fruit crops, including citrus, mango, apples, peaches, apricots as well as some vegetables (especially cucurbits), seed crops and also many wild plants. The economic implications have not only reduced production and increased control costs, but also loss of export markets and the cost of establishing and maintaining phytosanitary measures. Globalization of trade favors the dispersal of these pests to countries and regions free of the pest earlier (Sarwar et al., 2013; 2014 a; 2014 b; 2014 c). Furthermore, introduced pests are increasingly surviving in previously inhospitable areas due to a warming climate. Socioeconomic consequences are so severe that importing countries with free

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or key fruit fly pests prohibit the import of fresh produces from exporting countries where these pests are endemic or have been introduced. Unfortunately, the spread of fruit flies does not stop at country's borders. To overcome these problems a new yet simple approach is essential which should provide viable solutions in the pest management arena (Sarwar, 2014 a; 2014 b; Sarwar, 2015 a; 2015 b). The pest management practices throughout the world are increasingly leaning toward more environment friendly agriculture without disturbing the balance of the eco-system (Tilman et al., 2002). Thus, the evolution of modern organic agriculture depends on natural control agents to disrupt and control pest attacks which impart serious adverse effects on the agricultural economy (Copping and Menn, 2000).

As behavioral tactic, adult fruit flies locate hosts using visual and olfactory stimuli, and this should be taken into account in the design of bait stations. Several authors have already demonstrated of visual stimuli as one of the essential components of 'attract and kill' methods. Pinero et al., (2009) designed a novel bait station, which enhances the behavioral response of *Bactrocera dorsalis* (Hendel) adults due to the use of the visually attractive yellow color and it also provides shelter and protection against rainfall. In addition, the results of another study confirm this observation and show that yellow device is more attractive to *Bactrocera cucurbitae* (Coquillett) in field cages than white, red or transparent. It is also found that colors with high reflectance are the most attractive to *B. cucurbitae* (Camille and Jean-Philippe, 2015). Thus, to be effective, a bait station needs to integrate visual and chemical cues for the strong attraction of fruit flies compared with using one kind of stimulus alone. This article can provide scientific support to control pest fruit flies to reduce losses in fruit and vegetable productions, minimize insecticide use, and preserve biological diversity. This might result in facilitation of international trade, increase farmer's income and enhance food security.

2. Behavioral Control

Environment-friendly management of fruit flies involving behavioral control is useful in reducing the undesirable pest populations responsible for decreasing the yield and the crop quality. Behavioral control covers an array of techniques that involve manipulation of some aspects of behavior of fruit flies such that their populations are reduced. Developing lure-and-kill trap systems to detect, monitor and control populations of this insect can provide immediate economic benefits to commercial growers. One of the most successful examples of such strategies for tephritid fruit fly management is control of apple maggot fly *Rhagoletis pomonella* (Walsh), with fruit-mimicking red sphere traps baited with host fruit odor (butyl hexanoate) and food attractant (ammonium acetate) (Duan and Prokopy, 1995). The baited red sphere traps represent "supernormal" fruit stimuli and are highly attractive to both sexes of apple maggot flies. This trapping system alone not only eliminates three to four chemical sprays annually against apple maggot flies but also greatly facilitates biological control of secondary pests such as aphids and spider mites. It has become a promising component of apple orchard integrated pest management (IPM) programs (Prokopy et al., 1990 a).

Therefore, successful behavioral control of fruit flies is highly unlikely without a lure-and-kill trap effective against females. Fruit flies use both visual and olfactory cues to find essential resources (e.g., host fruit for oviposition and protein food sources for ovarian development). Prokopy et al., (1990 b) showed that mature female oriental fruit flies *Bactrocera dorsalis* (Hendel) respond positively to visual and olfactory stimuli from individual natural host fruit (kumquats *Fortunella japonica* Swingle) or models of this fruit. In subsequent field tests, Vargas et al., (1991) demonstrated that yellow or white fruit-mimicking spheres are more attractive to both sexes than orange, red, light green, dark green, blue and black spheres. The reflectance spectrum of yellow spheres in their experiments closely resembled that of ripe fruits of an important oriental fruit fly common host guava *Psidium guajava* L. Similarly, in a study by Cornelius et al., (1999), yellow spheres captured more female oriental fruit flies than spheres of other colors or than yellow rectangular blocks. Jang and Light (1991) showed that headspace odor from ripe papaya *Carica papaya* L., is attractive to sexually mature oriental fruit fly females in a wind tunnel. Also, Cornelius et al., (2000) demonstrated that the odor of orange *Citrus sinensis* (L.), puree is attractive to both mature and immature female flies in field cage experiments, whereas proteinaceous food odor is attractive to young females in the field. More females are attracted to a combination of yellow sticky spheres with ammonia-based olfactory lures than to spheres or olfactory lures alone.

In a series of further experiments, Cornelius et al., (1999) identified standard Ladd traps as a more efficient trap for capturing oriental fruit fly females than several other trap types. The Ladd trap is a combination of a flat, and yellow foliage-mimicking panel with a red fruit-mimicking sphere attached in the middle of the panel so that there is a hemisphere on each side of the panel. It is thought that female flies perceive dark spherical objects contrasted against a light yellow background as a host habitat comprising both fruit and foliage. Cornelius et al., (2000) also determined that liquid hydrolyzed proteinaceous bait (NuLure) attracted more female flies in a guava orchard than several ammonia-based olfactory lures. At the same time, few flies are attracted to the odor of orange puree under field conditions, probably because of the competition between the bait odor and the odors of fruit naturally occurring in the orchard.

3. Research Experiments on Behavioral Control

Research experiments on behavioral control affect insects by taking advantage of their natural responses to colors, odors and light.

3.1. Behavior Modifiers

Behavior modifiers may be used for the control of those fruit fly species of the genera Bactrocera and Dacus that are attracted to male lures (cuelure or methyl eugenol). Both male and female adult flies are attracted to the attractants while foraging over the leaves for food or sheltering near the tree trunk and are poisoned after feeding on the spray droplets contributing in pest control.

3.2. Intervention Strategies Using Food Attractants

The attractants cause insects to move towards their source, for instance, pheromones secreted by insect are species specific and may be used to lay trails or for aggregation, swarming, alarming or sexual attraction. Food and oviposition attractants such as NH_3, flavoring essences and protein sources attract to fruit fly, antifeedants prevent an insect from feeding and it starves, antioviposition chemicals prevent females to lay eggs, and repellents play the part to repel fly from hosts. Population control strategies using these products are based on infestation observation during the stages noted (detection trapping) and an intervention based on an economic damage threshold i.e., the number of flies captured in one or two traps per hectare. Traps are installed in the orchards (1 or 2 per hectare), such as Tephri trap containing an attractant (Methyl Eugenol, Terpenyl and Trimedlure) and insecticide mats. Treatment should be started as soon as the threshold values have been reached. If fly captures in traps continue (depending on the threshold), treatment should be renewed every 7 days. These should be renewed in the event of rainfall of over 10-15 mm and this type of treatment has very little effect on the orchard's natural enemies.

3.3. Use of Attractants

Attractants are very useful in monitoring of pest situation, and traps give an early warning system in quarantine situations and are used in crops to monitor pest intensity to indicate when to apply insecticides, and are important for direct pest control. When baits are combined with a lethal trap or insecticide, direct kill is achieved e.g., dark pots against fruit fly in orchards. Mating disruption occurs when the environment is saturated with mating pheromone so that the male is confused and cannot find a mate

Sometimes, the development of workable pheromone mixtures, traps and application methods is time consuming and costly. It requires knowledge of physiology of pest for design of traps (size, shape, material, trap opening, the density of traps required and their positional placement in the crop), development of a substrate which will release the pheromone in a controlled, consistent rate, knowledge of the active ingredients in a pheromone (the optimal concentration of each component and whether this changes over time), and financial investment (these chemicals also need to be registered, requiring lots of data). Since these chemicals cannot be patented, there is little money to be made from their commercial development and so it is usually left to government agencies.

4. Pheromones, Hormones and Kairomones

Pheromones or hormones that insects emit during mating season to attract one another are species specific and nontoxic to environment, thus these can be used for pest management needs of crops. Pheromone traps and dispensers disrupt to mating behavior of target species by emitting chemically produced pheromones. Pheromone emitters, inundate the pest area with these chemical signals, saturating the air and confusing the insects so that males can no long find females to reproduce. Kairomones are the chemicals released when plants are injured or weakened, these are used to attract pests to healthy or resilient trees, and trap them.

5. Use of Colors, Shapes and Odors

As a tool of color attractants, the advantage of insect behavioral responses to bright coolers can be taken. Red spheres coated with a non-drying adhesive combined with attractants with odors resembling ripening apples result in excellent control of the apple maggot fly (*Rhagoletis pomonela*). The need for cover and ground sprays can be virtually eliminated by considering this behavioral response. Fortunately, the tropical Dacinae fruit flies are attracted to various colors (e.g., queensland fruit fly to blue, oriental fruit fly and melon fly to yellow, and *B. xanthodes* to grey), and there seem to be immediate prospects for using this technique for control of these pests (Burrack et al., 2008).

6. Combining Visual and Olfactory Stimuli

An effective lure-and-kill trap is a potentially important instrument in monitoring and controlling oriental fruit flies *B. dorsalis*. A number of experiments have been performed in an orchard of commercial guava *P. guajava*, to determine how fly captures are affected by combining visual and olfactory stimuli, and by the timing of trap deployment relative to host phenology. Baiting sticky Ladd traps with hydrolyzed liquid protein significantly increased the number of captured flies. Mostly male flies are caught in the absence of mature guava fruit, whereas mostly female flies are caught when ripe fruit is abundant. These results suggest that an effective oriental fruit fly trap should include both visual and olfactory lures, and that proper timing of trap deployment can be an important factor in monitoring female abundance in oriental fruit fly populations (Andrei et al., 2000).

7. Mating Behavior

Field researchers have observed 2 mating strategies in the Mediterranean fruit fly *Ceratitis capitala* (Wiedemann):- 1) males aggregating on leaves to perform courtship rituals, and 2) males approach already mated and ovipositing females on host fruits and attempt to copulate with no prior courtship (Hcndrichs et al., 1991). There is no evidence to support whether these 2 field mating behaviors represent different subpopulations of males or males that alternate behaviors at different times. These useful ideas can be of immense value to those of us working in insect control.

8. Oviposition Behavior from the Field

Traps for tropical pest tephritids have relied primarily on chemical cues while traps for temperate pest tephritids have trusted principally on visual cues. Here we review research on the interactions between chemical and visual cues that have been observed in the development of traps for the tropical Mediterranean fruit fly *C. capitata*, and the temperate apple maggot *R. pomonella*. By exploiting these interactions, it may be possible to produce efficacious trapping systems that could be used in a behavioral approach to fruit fly population control (Nancy and Robert, 1998). The special emphasis must be placed on oviposition stimuli such as type of oviposition receptacle and use of fruit extract attractants. These observations suggest that there is natural variation within the species for female oviposition behavior and that strong selection during adaptation to laboratory rearing may decrease genetic variation to the point where it is difficult to select for alternate behaviors. Recent evidence suggests that these observed differences in oviposition substrate behavior may also be associated with morphological changes in female aculeus width (Jones et al., 1993).

9. Timing of Oviposition

Adult fruit flies are attracted to substances that offer food or an environment in which to lay eggs and develop larvae. These investigations explore a pattern in fruit fly behavior helpful to look for the environmental choices that fruit flies make. Like other fruit fly species, the oriental fruit fly prefers to deposits its eggs in old egg deposition lesions and in ripened fruit. Fruit fly infestations may be avoided by picking fruits and vegetables early as it increases the odds of a successful eradication, before the pest becomes established. Early harvests can also be achieved by planting early fruiting varieties which crop before fruit fly populations build up. Fruit flies prefer to attack fruits and vegetables depending on the stage of maturity, and in some crops there is the possibility to harvest fruits early to avoid fruit fly infesting.

10. Predation or Parasitism of Adult and Larva

Because, the fly's eggs are embedded underneath the fruit's epidermis and the larvae feed deep inside the fruit, the immature stages are protected from most generalist predators. Before the larvae of fruit flies pupate, these create a thin window on the fruit's surface through which it may be exposed to predators. If the fruit is still firm, the larva may often pupate inside. However, upon fruit maturation most fly larvae leave the older fruit, especially in the late summer and fall, and drop to the ground to pupate in the soil beneath the tree (Tzanakakis, 2006). For this reason, pupae while drop to the ground and walk to reach pupating site can be exposed to and accessed by both flying and walking natural enemies for predation or parasitism or may be vulnerable to hit by insecticides. Likewise, after emerging from the pupa stage, the adult fruit flies are trapped on the ground for up to 24 hours because it takes a long time for their wings to harden. During this time the adult flies can also be vulnerable to natural enemies or may be treated to chemical control.

11. Emerging and Diurnal Activity of Adults

Emerging adults crawl up through the soil, usually at an angle. Although these have been reported crawling up from greater depths, the adult usually does not has to emerge from a depth greater than 1 to 2 inches. Most flies emerge between 7:00 and 10:00 A.M., this period may be extended with overcast of skies, rain or low temperatures but rarely goes into mid-afternoon. The preliminary results suggest that fruit flies are more active during the morning. Therefore, for management of both melon fly and oriental fruit fly, the control efforts should be made during the time interval between 6 and 10 A.M. However, further and more intensive studies should be made to validate these results. For that reason, for controlling of fruit flies, the control struggles should be made during that time. Further, adult flies primarily feed during the morning hours. These search for food in all types of vegetation, including low cover plants and shrubs, and may travel to areas where host plants do not occur. Without food, flies die within three days at an average temperature of 80 ^{o}F. As a result, for supervision of fruit fly, the control operation should be made in broaden areas (Victor, 2009).

12. Combined Management Tactics

As with the control of many pest species, a single control method by itself is often not sufficient to eradicate or even effectively control the fruit fly from an area. The best results are gained from a combination of the methods in an integrate way. Integrated Pest Management (IPM) is a combination of pest management techniques to reduce the need for pesticides. The IPM programs rely on monitoring pests and pest's damage, and techniques include maintaining healthy plants, which resist insects and diseases better, encouraging natural predators of pests to stay in farm, using non-chemical means to remove insects when possible such as handpicking and sanitation on plant and ground, and when using pesticides choosing the one that is least toxic, most effective, most pest-specific and has the least potential impact on the health and environment (Sarwar, 2004; 2012; 2013; Shah et al., 2014; Sarwar et al., 2015).

13. Conclusion

Fruit flies are the world's most damaging or major insect pests to fruits and vegetables in some small and mainland states. Each year several global states spend around millions of dollars annually to maintain their fruit fly free status. This provides significant benefit to horticultural growers and exporters who do not have the capacity to spend millions of dollars to treat fruits and vegetables destined for interstate or overseas. Nonetheless, precise behavior analysis of flies is clearly important to optimize control programs. At present, we must reluctantly conclude that a genetic basis has been widely assumed for many behavioral traits, but not so widely demonstrated. Behavioral control technology can take the lead scientifically in combating fruit flies and to help in protecting the nation's horticultural production. It is possible that the flies undergo a dispersal phase, and that dispersal patterns and habitat colonization behavior are different in males and females. Also, if males stake out fruit, awaiting the arrival of females seeking oviposition sites, reduction in male captures when ripe fruit is present can be caused by competition between such fruits and the traps. However, additional work is required before we can draw more definite conclusions. Further investigations of this issue are essential for successful incorporation of different control methods, such as male annihilation, sterile insect releases, behavioral, cultural, and biological control, into an integrated system for managing fruit fly pests.

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