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The Role of Male Annihilation Technique to Get Rid of Notorious Fruit Flies (Tephritidae: Diptera) in Fruit and Vegetable Farms

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Abstract

Fruit fly (Diptera: Tephritidae) is a major trade barrier for many fruit and vegetable crops, and any strategies which improve field control can provide economic benefits for growers with the potential to enhance market access opportunities. This paper is aimed at improving fruit fly's control in major commercial horticulture crops and implementing more serious consideration given to the eradication of injurious species. Early eradication of invasive fruit flies depends largely on the deployment of both effective and safe detection and control systems. Timely detection of these serious pests prompts the adoption and application of measures to contain fruit flies with a view to their eradication. Amongst the focal methods used for fruit fly's control, the Male Annihilation Technique (MAT) involves the use of a high density of bait stations consisting of a male lure combined with an insecticide, to reduce the male population of fruit flies to such a low level that mating with female flies does not occur. This technique 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). The commercial product mehtyl eugenol is used for trapping of Oriental fruit flies (*Bactrocera dorsalis*), whereas cue-lure is used to trap the male of melon fly (*Bactrocera cucurbitae*), and Trimedlure captures Mediterranean fruit fly (*Ceratitis capitata*). The technique can be achieved successfully by distributing cordelitos (cotton string) or caneite (compressed fibre board) blocks (50 mm x 50 mm x 12.7 mm), or coconut husk blocks impregnated with the lure and insecticide mixture. These are distributed from the ground or air in densities of at least 400 per km^2 and the treatment is repeated every eight weeks. This study has shown the several examples of the successful eradication of fruit flies by male annihilation technique on its own, or in combination with other methods. Outstanding successes using this method have been recorded for eradicating and to get rid of notorious fruit flies worldwide.

Keywords

Fruit Fly, Male Annihilation Technique, Insecticides, Pheromone and Lure Application

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1. Introduction

For several decades, a large number of fruit fly (Diptera, Tephritidae) pests of fleshy fruits and vegetables have been existed in several regions. Fruit flies are recognized as one of the most damaging pests in the world, especially due to their very wide host range, high reproductive potential, high mobility and adaptability to certain climates. Their presence and establishment in a specific locality or record from a region would be a serious threat to nearby countries. The occurrence of fruit flies in horticulture areas is an obstacle for the promotion of export of fruits and vegetables (Sarwar, 2014 a; 2014 b). Worldwide, tephritid fruit flies are the most important threat to the horticultural industry of plant hosts species developing either wild or cultivated or in both. Most fruit flies are polyphagous in host feeding, attacking important fruits and vegetables and causing both direct damage and indirect losses because of quarantine constraints

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in export markets. The severe extreme residue levels of pesticides in important fruits and vegetables further composite the problem and endanger exports. Peach fruit fly *Bactrocera zonata* (Saunders), oriental fruit fly *Bactrocera dorsalis* (Hendel) and melon fly *Bactrocera cucurbitae* (Coquillett), are considered as one of the most economically important pests for several kinds of fruits and vegetables (Sarwar et al., 2013; 2014 a; 2014 b; 2014 c; 2015).

Pesticides, additionally organophosphate insecticides, have received widespread scrutiny for their negative impacts on non-target animals and humans health, and thus the identification of reduced-risk alternatives for use in these area-wide control programs is of high priority (Mau et al., 2007). The main control methods employed in orchards and in the town areas are regular protein baiting of host trees and the distribution of male annihilation. The Bait Application Technique (BAT) is directed at killing both male and female flies, whereas MAT attracts and kills male flies through the use of parapheromones. Presently, BAT has also been used in the area wide eradication program, on its own, or in combination with other methods to control fruit flies. The BAT is frequently used to eradicate exotic species entering in an area, and bait applications are used with sterile releases for eradication of the fruit flies (Permalloo et al., 1997).

Current methods utilized for rapid detection of accidental introductions of species of Dacinae (comprised of the two major genera, Bactrocera Macquart and Dacus Fabricius) require the deployment of large numbers of traps baited with highly attractive male-specific lures. For example, methyl eugenol (4-allyl-1, 2 dimethoxy benzene-carboxylate) is used for detection of oriental fruit fly *Bactrocera dorsalis* (Hendel), and the Pacific fruit fly, *B. xanthodes* (Broun), and cue-lure [4-(p-acetoxyphenyl) 2-butanone] is used for *B. kirki* (Froggatt), melon fly, *B. cucurbitae* (Coquillett), and the Queensland fruit fly, *B. tryoni* (Froggatt). Trimedlure [t-Butyl-2-methyl-4-chlorocyclohexane carboxylate]- a powerful lure for the Mediterranean fruit fly (*Ceratitis capitata*) is used to detect incipient manifestations of the injurious insect combined with an insecticide (usually technical malathion or spinosad), to reduce the male population to such a low level that mating does not occur. All these species, have been introduced to certain states and have become severe pests of tropical fruits (Leblanc and Putoa, 2000; Vargas et al., 2007).

2. Recommended Male Annihilation Technology (MAT)

The MAT is aimed at reducing the number of male flies on an area wide, long term basis with the eventual effect of reducing female fertility due to the greatly reduced number of males available for mating. The MAT devices used in the program are used as lures in monitoring traps. Marketed as Fruit Fly Cups these consist of a cotton wool wick mounted in a well on the underside of plastic lid. After some problems with the original design which allows birds to remove the wicks, a plastic base with holes cut in it is fitted to the underside of the 'cup' so that flies could still have access to the wick but the wick could not be easily removed. Growers are advised to distribute MAT cups at the rate of 10 per hectare in fruit fly host crops and to replace them with new cups three times per year. Old cups could be left in orchards as these are still effective for several months after the recommended replacement period and are generally removed during pruning before the next season. In a test of the male annihilation technique, aerial distribution of Celotex wafers impregnated with methyl eugenol containing 3% and Dibrom at the rate of 70 or more per square mile along flight lines about 1/5 mile apart reduced the oriental fruit fly to only 28 males per 1000 trap days in 12 months. Indications are that use of the method on incipient infestations of the oriental fruit fly that may be found will prevent their further development and spread, with eradication being a definite possibility. Male attractants for other tropical fruit flies are strong enough to warrant consideration as possible male annihilation agents (Christenson, 2009).

Of many fruit flies, Bactrocera species are found to enhance their mating competitiveness after consumption of the kairomone lure, methyl eugenol that is a component of plant essential oil found in at least 200 species of plants from 32 families. Male annihilation technique (lure and kill) is applied as spot treatments by using dispensers as carriers of the main component of MAT, methyl eugenol (the male attractant) and toxicant. Male annihilation technique is one of the fruit fly control methods where it aims to remove male insects, thus reducing male population. This disturbs the male: female ratio and reduces the insect's chances of mating and these females produce few progeny. Accordingly, the insect population at the target area declines and the insects could be eradicated at the end (Zaheeruddin, 2007; Stonehouse et al., 2008).

The effectiveness of using Cue-lure for male annihilation of species attracted to it is not as great as that using methyl eugenol. Therefore, past attempts at using Cue-lure to eradicate melon fly populations have been unsuccessful, though melon fly is eradicated using caneite blocks treated with Cue-lure and fipronil. The prolonged drought and the resultant reduction in cucurbit host availability are favorable conditions that facilitated its eradication. The application of Cue-lure-treated blocks, in combination with protein bait

spraying, has reduced populations of mango fly (*Bactrocera frauenfeldi*) to very low numbers that is the only species remaining in treated area (Christenson, 2009).

Performance of solid male lure cuelure (C-L) and raspberry ketone (RK) against *Bactrocera tryoni* (Froggatt), and methyl eugenol (ME) against oriental fruit fly *B. dorsalis* both formulated with insecticide, have been as alternatives to current monitoring and control systems using liquid formulations of attractant and organophosphate insecticides. Captures of *B. dorsalis* with Mallet ME wafers outperformed any other ME formulation. For control applications, traps baited with ME and RK combined in a single Mallet MC wafer captured as many *B. tryoni* and *B. dorsalis* as traps baited with a single liquid lure. This suggested that solid Mallet dispensers with RK are longer lasting than those with CL. The Mallet MC wafer could be used in a single trap in place of two separate traps for detection of both ME and C-L responding fruit fly species, and thereby reducing trap and labor costs. In addition, the Mallet MC wafer in a single trap should be tested further in fruit fly programs (Leblanc et al., 2010).

3. Evaluation of the Fruit Flies Control

Two methods are used for evaluation of the fruit flies control measures, namely detection from traps, and rearing from samples of collected fruits. The traps used are a local version of the Steiner type and are baited with methyl eugenol. These are initially placed around detection points, and traps are checked daily for a period of five months since the first detection. These are now monitored twice a week except at detection points where checking is done daily for a month. Samples are taken daily from collected fruits in the eradication area and kept in the laboratory for determination of infestation by different species. The identification of the species is done at the adult stage.

A study has been carried out to evaluate different control methods and their efficacy. The IPM (Integrated Pest Management) is adopted for controlling oriental fruit fly that comprised cultural control, Bait Application Technique (BAT) and Male Annihilation Technique (MAT). Farmers are randomly interviewed through questionnaire. Statistical analysis of the data revealed that farmers favored MAT as it is found to be economically feasible and environment friendly. Maximum control is found in MAT which is followed by BAT; however the lowest control is noted in cultural control. This study suggests that farmers should be encouraged to adopt the IPM that involves MAT, which is found the most effective control method (Hussain et al., 2010).

Further, the effectiveness of technical products mixed with methyl eugenol in the ratio of 1:4, or in addition mixed with methyl eugenol in two ratios of 1:2 and 2:3 have been evaluated under field conditions as male annihilation technique (lure and kill) of *B. zonata*. Plant fiber blocks saturated with mentioned mixtures have been used for over 12 successive weeks. Efficiency (as lured and killed populations per block per day) of all tested mixtures degraded over time regardless of the area. The obtained results revealed that Naled mixture is significantly superior to all other mixtures regardless area or inspection. Naled mixture blocks are relatively effective for up to 8 weeks while others efficiency does not exceed 4 weeks. Commercial Malathion (1:2), technical Malation and Dimethoate are the worth. It is recommended that Naled mixture can be used successfully in *B. zonata* male annihilation technique and renewed every two months. Lambada, Lebaycid, Sumithion, commercial Malathion (2:3) mixtures could be used with monthly renewal (Ghanim et al., 2010).

In the fruit fly control program, caneite has been used as a carrier for the lure and pesticide in MAT blocks for many years. In that paper, MAT blocks containing cuelure as an attractant and malathion as a toxicant are manufactured using two methods, namely bag immersion and roller painting, as part of the control program. These blocks are sampled from storage and the field, along with historical blocks in the field deployed before the current study period. Chemical analyses of these three block types are conducted for malathion, cuelure and raspberry ketone (a breakdown product of cuelure). There is significantly more cuelure and malathion in blocks made by the bag method than the roller method and in historical blocks. The bag method resulted in chemical concentrations closer to the desired standards. There are no significant differences between the three methods in block weight or in level of raspberry ketone. Cuelure levels declined more quickly than malathion although both chemicals are found in all blocks. For the analysis within samples, there are few significant correlations between raspberry ketone and other parameters, but there are many significant correlations between cuelure, malathion and the block weight (Dominiak and Nicol, 2012).

Solid Mallet TMR (trimedlure [TML], methyl eugenol [ME], raspberry ketone [RK]) wafers and Mallet CMR (ceralure, ME, RK, benzyl acetate) wafers impregnated with DDVP (2, 2-dichlorovinyl dimethyl phosphate) insecticide have been measured in traps as potential detection and male annihilation technique devices. Comparisons are made with 1) liquid lure and insecticide formulations, 2) solid cones and plugs with an insecticidal strip, and 3) solid single and double lure wafers with DDVP for captures of Mediterranean fruit fly *Ceratitis capitata* (Wiedemann), oriental fruit fly *B. dorsalis* Hendel;

and melon fly *B. cucurbitae* Coquillett. Bucket and Jackson traps are tested in a coffee plantation and avocado orchards in survey trials. Captures of all three species with Mallet TMR are not different from Mallet CMR; therefore, subsequent experiments found that a solid Mallet TMR wafer is safer, more convenient to handle, and may be used in place of several individual lure and trap systems, potentially reducing costs of large survey and detection programs (Vargas et al., 2012).

In order to reduce the cost of male annihilation technique for controlling *B. zonata*, dilution of methyl eugenol with paraffin oil have been evaluated to reduce the quantity of methyl eugenol. Five concentrations of methyl eugenol (10, 25, 50, 75 and 100%) have been tested with three insecticides belonging to different groups of pesticides; fentrithion, spinosad and a mixture of thiamethoxam+ abamactin. Methyl eugenol-fentrithion mixture at 100% of methyl eugenol showed that the weekly mean numbers of captured males all over 10 successive weeks have been significantly higher (87.3 individuals/ block) than those obtained at 75% (45.9), 50% (32.4), 25% (34.2) and 10% (9.0). There are no significant differences between concentrations 50, 75 and 100% of methyl eugenol in spinosad mixture, while their effects on captured males are significantly higher than that obtained when 10% and 25% are used. Mean numbers of captured males subjected to methyl eugenol-thiamethoxam+ abamactin mixture averaged 8.8, 19.0, 24.9, 24.9 and 48.0 individuals/ block at 10, 25, 50, 75 and 100%, respectively. Statistically, the mean number of captured males over the tested period at 100% of methyl eugenol is significantly higher than those obtained at 10, 25, 50 and 75%. Males of *B. zonata* are more attracted to methyl eugenol-spinosad mixture compared with methyl eugenol- (fentrithion and thiamethoxam+ abamactin) mixtures. As a conclusion, dilution of methyl eugenol in paraffin oil till 50% in MAT by using spinosad (as an insecticide) do not significantly affect the captured males and has a high effect against *B. zonata* population (Ghanim, 2013).

4. Field Bioassay Using Professional Trap

Monitoring of fruit flies should be conducted in areas in which the risk of spread of these pests has been identified and where outbreaks have occurred in the past. Monitoring procedures including in particular trapping scenarios, relevant attractants and trap types are based on the delimitation of an area or areas within the country in which eradication measures are applied (European Plant Protection Organization, 2010**)**. For evaluating the efficiency of insecticides against fruit flies males, field bioassay can be carried out by using plant fibers blocks (measuring 5 x 5 x 1.1 cm). Blocks are impregnated with the solution of tested insecticide and methyl eugenol according to the ratios of mixture for about four hours in the laboratory. The any technical insecticide products of Naled 90% (Naled), Lambada 92% (Lambada), Fenthion 90% (Lebaycid), Fenitrothion 95% (Sumithion), Malathion 96% (T. Mal.), Dimethoate 90% (Dimethoate) and commercial Malathion (Malathion 57% EC) (C. Mal.) can be used. All of the mentioned insecticides are mixed with methyl eugenol in ratio of 1:4 (insecticide: methyl eugenol); except that of commercial malathion which can be mixed in two ratios of 1:2 and 2:3. The impregnated blocks are transferred to the field in plastic bags. The blocks are hanged on the trees by metallic wire on regular distance at a height of about two meters in shady and airy place. Blocks are distributed at 50 meters intervals along all of each study area. In each location, each treatment is replicated several times and distributed in a completely randomized design. The chemical is loaded in the wooden block lures and the flies enter the trap from the entry hole at the bottom of the trap. On their way to the block these travel inside the dome and fell down in the water filled in the yellow bowl. Application is @ 3-4 traps per acre and the lure remains viable for 50-60 days under field conditions. To collect the dead insects, plastic containers (measuring 20 cm in height and 10 cm in diameter) are fixed under the treated blocks by metallic wire for receiving the dead male flies. The lured and killed fruit fly males in the plastic containers are counted and recorded weekly without renewal of the treatments.

More recently, the method, using lengths of string or cord soaked in methyl eugenol and malathion or a similar method, using caneite blocks nailed instead of using string, is successful in eradicating of fruit fly from several territories in efforts to keep this species out of area. Impregnated coconut husk blocks treated with methyl eugenol and malathion are distributed by ground teams and from the air by helicopter in an attempt to eradicate fruit fly. The method, with caneite blocks (50 mm x 50 mm x 12.7 mm) treated with methyl eugenol and using fipronil instead of malathion, and distributing cordelitos (lengths of 6-ply cotton string about 30-45 cm) or caneite (compressed fibreboard) blocks (50 mm x 50 mm x 12.7 mm), or coconut husk blocks (50 mm x 50 mm x 10 mm) impregnated with the lure and insecticide mixture is also convenient.

5. Integrated Pest Management

Because several fruit fly species commonly co-exist in the fragmented fruit and vegetable production systems, thus, fruit

fly control program promotes an IPM approach which offers better prospects for the horticulture industry. For example, the combined application of food baits and lures can result in a huge reduction of fruit fly populations (Sarwar, 2012; 2013; Shah et al., 2014). A combination of male annihilation and protein bait application techniques has been used for eradication of four Bactrocera species. The technique involved distributing fibreboard (Canite) blocks impregnated with male fruit fly lure (methyl eugenol and or cue-lure) and the insecticide Fipronil in a loose grid, resulting in at least 300 blocks per km², and the blocking campaigns are repeated every eight weeks. The protein bait application technique involved spraying host fruit trees in hot spot areas with protein insect lure and Fipronil gel on a weekly schedule. Three of the four species, namely Oriental fruit fly (*B. dorsalis*), Pacific fruit fly (*B. xanthodes*), and melon fly (*B. cucurbitae*), are declared eradicated, while populations of mango flies (*B. frauenfeldi*) persisted (Allwood et al., 2010). All the enumerated management techniques are currently available worldwide and growers education might be crucial for their adoption (Sarwar, 2015 a; 2015 b; 2015 c; 2015 d; 2015 e; 2015 f; 2015 g; 2015 h).

6. Conclusion

In summary, the male annihilation technique (MAT) is a chemical control method designed to deplete the males available for mating in a population and thus breaks the reproductive cycle of fruit flies. The growers are advised to implement MAT in their orchards as a supplement to baiting. The Tech Mallet TMR and CMR wafers are promising substitutes to traditional trapping using liquid lures that are mixed with naled or malathion for detection of fruit flies. These products should be further tested for the development of environmentally-friendly area-wide IPM procedures for early detection of accidental introductions of fruit flies into a land. The major pests fruit fly can be well managed by a combination of other measures including the eradication program such as cover spray on and soil drenching under bearing fruit trees, and fruit clean-up which comprises collection of fallen fruits and their disposal in trenches and these are drenched with an insecticide and covered with soil. The help of the public can be enlisted for intensive fruit collection and disposal. Fruit stripping, especially in the case of mangoes, is also carried out in certain public places. These strategies have been very effective resulting in reduction in peak trap catches and infestation across the fruit areas. It is hoped that this additional level of fruit fly field control can enhance market access opportunities for all growers in the future. In the context of this program, a regional fruit fly program which includes research, extension and quarantine to back up, and an action plan should be prepared so as to be ready to meet the challenge of any future incursions, in terms of material, technical and scientific resources. It should be funded by the Governments of each participating country and quarantine procedures should also be harmonized so as to minimize risks of entry of exotic fly pests.

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