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Management Strategies for Western Flower Thrips in Vegetable Greenhouses in Iran: a Review

Zahra GHOLAMI and Amin SADEGHI

Department of Plant Protection, Faculty of Agriculture, University of Kurdistan, Sanandaj, Iran

Abstract

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Chemical, biological, cultural, and mechanical controls are the main strategies of the Integrated Pest Management program for *F. occidentalis*. The insecticides play an important role in the western flower thrips, *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), management. Spinosad, pyridalyl, and botanical insecticides such as oxymatrine and azadirachtin are new and effective insecticides for the control of *F. occidentalis*. The best control finally is possible when all of the strategies are used together. Awareness on integrated pest management strategies can improve the integrated pest management strategies.

Keywords: *Frankliniella occidentalis*; chemical control; biological control; pyridalyl; oxymatrine

Western flower thrips (WFT), *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae), is one of the most important economic pests in greenhouses. Thrips damage is caused directly by adults and nymphs feeding the contents of plant cells, reducing photosynthetic capacity, and indirectly via the transmission of tospoviruses such as *Tomato spotted wilt virus* (TSWV) and *Impatiens necrotic spot virus* (INSV) (Wetering *et al.* 1999). Currently, WFT is a common pest in many countries of America, Europe, Africa, and Asia (Kirk & Terry 2003). It was detected in cucumber greenhouses in Varamin, Iran, and has dispersed to many growing areas and crops including cucumber, tomato, strawberry, and eggplant. This review provides information on WFT biology, damage, and different strategies with the effectiveness of four insecticides for the Integrated Pest Management (IPM) program.

Biology and problems concerning *Frankliniella occidentalis*

The life cycle consists of an egg, two larval stages, two pupal stages, an adult stage, and it can be completed in 9–13 days (Reitz 2009). Females usually lay 150–300 eggs singly underneath the tissues of leaves, leaf buds, blossom stems, blossom petals, fruit buds and fruits and flowers (Reitz 2002a; Cloyd 2009; Terry & Alston 2011). Eggs hatch in 2–4 days, the first instar larvae immediately begin to feed (two days) and the then second instar larvae that are more active in feeding appear for 2–4 days (Robb *et al.* 1988). Toward the end of the second instar, larvae stop feeding and move down into the soil or leaf litter to pupate (Jensen 2000). The pupal stage is including prepupae and pupae and it takes 6 days. The pupal stage is very tolerant to most insecticides (Cloyd 2009). Then, adults with a pair of long wings emerge. WFT is very difficult to control biological characteristics such as small size, difficult identification, a broad range of host plants, thigmokinetic behaviour, and haplodiploid breeding system (Carriere 2003). Also, egg and pupae stages are placed into hidden locations (plant tissue and soil, respectively) protecting them from the exposure to pesticides (Jensen 2000).

Integrated pest management programs for thrips in greenhouses

Cultural control. Cultural and mechanical controls are practices that reduce pest establishment, repro-

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duction, dispersal, and survival features. A number of cultural control methods can only suppress the population density and are generally utilised in the IPM programs for *F. occidentalis*. These practices include: sanitation such as removing weeds (specifically, a number of species of the Solanaceae and Compositae families as reservoirs of viruses) and old plants, use of compost for pupae control, use of UV-reflective mulch to decrement thrips populations due to disruptions in host-finding behaviour, manipulating the greenhouse microclimate conditions, placing a weed fabric barrier underneath benches to prevent pupating in the soil (Kisha 1977; Helyer & Brobyn 1995; Shipp & Zhang 1999; Stavisky *et al*. 2002; Reitz *et al*. 2003; Cloyd 2009). Also, the application of fertilizers is an effective method with a major effect on the abundance and distribution of *F. occidentalis* growing on chrysanthemum and agricultural crops (Reitz 2002b; Chau *et al*. 2005). Optimising (lowering) the fertilisation level to reduce pest population growth may be a useful tactics for managing *F. occidentalis* (Chau *et al*. 2005). Acibenzolar-*S*-methyl is a resistance inducer and influences the salicylic acid pathway in the plant. It is an excellent replacement for foliar pesticides for bacterial and fungal disease control such as TSWV (Demirozer *et al*. 2012). Another method, trap plants, is a good method to aid the establishment and performance of biological agents. Trap plants are more attractive to pests than crops so this method can prevent colonization on the crop to reduce damage. *Chrysantemum* species, especially yellow flowering chrysanthemum, are trap plants for WFT (Brownbridge *et al*. 2013). Buitenhuis and Shipp (2006) studied behavioural factors of WFT that influence the use of trap plants. Eventually, it was concluded that flowering chrysanthemum plants are more attractive to dispersing adult *F. occidentalis* in potted chrysanthemum before flowering. Another research indicated that trap plants are more effective when placed in the chrysanthemum house immediately after planting (resident WFT). Also it was demonstrated that a combination of trap plants and chemical control is useful in the control of *F. occidentalis* (Choi *et al*. 2013). A novel method, push-pull strategy, involves the behavioural manipulation of insect pests and their natural enemies by the combination of stimuli that acts to make the crops unattractive or unsuitable to the pests (push) while luring them toward an attractive source (pull). Components of this strategy are generally non-toxic. Therefore, the strategy is usually combined with methods for population reduction such as biological control, preferably (Cook *et al*. 2006). For example, the plant volatile (*E*)-β-farnesene (EBF) in *Chrysanthemum* (*Dendranthema grandiflora)* is more attractive (trap plant) to WFT and its predator, *Orius laevigatus,* than the crop while rosemary leaves and volatiles are repellent to WFT (Buitenhuis & Shipp 2006).

Semiochemicals. Semichemicals are compounds that transmit chemical signals from one ganism and evoke behavioural response or physiological and biochemical changes in other organisms. These include Kairomone, Allomone, Synomone, and Pheromone (Sarmiento 2014). Pheromones are used to pull pests of their refuge and are divided into three groups: sex pheromones (on opposite sex), aggregation pheromones (attracting both males and females), and alarm pheromones (preventing pest establishment) (Teerling *et al.* 1993; Hamilton *et al.* 2005; Sarmiento 2014). The addition of the aggregation pheromone of *F. occidentalis* (neryl (*S*)-2-methylbutanoate) in blue sticky trap is useful to increment the number of trapping thrips (Sampson & Kirk 2013). Pheromones of thrips can be used to monitor thrips populations so that insecticides are only applied when is necessary. For example, maldison is less effective against adults and larvae but larval mortality significantly increases with the addition of dodecyl acetate (alarm pheromone) (Cook *et al.* 2002). Covaci *et al.* (2012) concluded that pheromone traps could be effective tools for *F. occidentalis* mass trapping and for the use in integrated pest management strategies.

Biological control. Biological control is the beneficial action of predators, parasites, pathogens, and competitors in controlling pests and their damage. Commercially available thrips predators are *O. insidiosus* (Say) and *O. laevigatus* (Fieber) (Hemiptera: Anthocoridae) the immature and adult bugs of which feed on the foliar stage (adult and immature stages) of WFT. However, in winter both *O. insidiosus* and *O. laevigatus* enter diapause due to the short day length and thrips population increases again (Sarmiento 2014). The "Black Pearl" (*Capsicum annum* L.) can be used as a banker plant for these bugs (Cloyd 2009). The predatory mites *Amblyseius cucumeris* (Oudemans) and *Amblyseius barkeri* (Hughes) (Phytoseiidae: Acari) are two biocontrol agents widely used for the control of thrips species and phytophagous mites on ornamental and field crops (Gillespie 1989; Zhang *et al.* 2000). During winter, *A. cucumeris* females enter the reproductive diapause so

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Table 1. Biological control agents of *Frankliniella occidentalis*

Classification	Type of agent	First use	Commercially available
Mites	*Amblyseius cucumeris*	1985	world wide
	Amblyseius barkeri	1981	world wide
	Hypoaspis aculeifer	1995	Europe
	Hypoaspis miles	1994	Europe
Minute bugs	*Orius insidious*	1990	North America
	Orius laevigatus	1990	world wide
Entomopathogenic nematodes	*Steinernema feltiae*	2005	world wide
Entomopathogenic fungus	*Beauveria bassiana*	2012	Europe and America

the presence of a non-diapausing thrips predator is needed to improve biological control (Houten *et al.* 1995). It is *Amblyseius barkeri* which feeds also on the first instar larvae of WFT. Brodsgaard and Hansen (1992) discussed that there is an interspecific competition between *A. cucumeris* and *A. barkeri* on cucumber greenhouses. Therefore, it is important to be aware of intra-guild predation. The soil-dwelling predatory mites, *Hypoaspis* (*Gaeolaelaps) aculeifer*) and *Hypoaspis miles* (*Stratiolaelaps scimitus*) (Acari: Laelapidae), feed on the pupal stage of WFT in either soil or growing medium (Cloyd 2009). These mites can be used in conjunction with a natural enemy that feeds on foliar stage. The effectiveness of the combined use of *Steinernema feltiae* Filipjev (Rhabditida: Steinernematidae) with *H. aculeifer* for the control of soil-dwelling stages of thrips is reported (Premachandra *et al.* 2003). The entomopathogenic nematode, *S. feltiae,* infects on soil-dwelling stage (mobile and non-mobile larvae) of *F. occidentalis* (Ebssa *et al.* 2001; Buitenhuis & Shipp 2005). The use of *Steinernema feltiae* has negative effects on the dynamics of *O. laevigatus* (Bonsignore & Vacante 2012) because unidirectional intra-guild predation has been observed between *O. laevigatus* and *S. eltiae.* The entomopathogenic fungus *B. bassiana* is a broad range pathogen and has the potential to be combined when *A. cucumeris* cannot control WFT on its own (Ansari *et al.* 2008; Sarmiento 2014). The adults of WFT are susceptible to *B. bassiana* more than larvae (Cloyd 2009). Infection is dependent on the concentration of spores. For example, *B. bassiana* as a biological insecticide at the dose of $10^{13} \times 2$ spore/ml well controls the population and remains effective even 60 days after application so this pathogen can be useful in program management of *F. occidentalis* (Bustillo Pardey 2009). The time releases of natural enemies must be initiated before thrips enter to buds or flowers (Cloyd 2009). Using more narrow-spectrum insecticides can reduce toxicity to the bugs and enhance the biological control potential. The biological control is more effective when the natural enemies suppress the pest synergistically. Table 1 presents the most commonly and commercially used biocontrol agents.

Scouting or monitoring. The kind of thrips species, the number of present thrips or what damage they have caused is checked by monitoring. Scouting also shows effectiveness of the used strategies (Cloyd 2009). They can be used in determining the seasonal patterns of thrips on different crops (Salguero-Navas *et al.* 1991). Four methods can be used for thrips scouting: direct observation, flower shake, berlese funnel, and sticky cards (Hollingsworth *et al.* 2002). In direct observation, each blossom must be checked by shaking or flicking vigorously into a white cup (Terry & Alston 2011). Flower shaking is a fast method of monitoring. The shaking should be of moderate power to prevent damage to the flowers (Hollingsworth *et al.* 2002). The third method, putting the flowers into a Berlese funnel under the light source, causes that the thrips gather on the bottom of the funnel. Then the number of thrips should be counted with the aid of a microscope (Tenbrink *et al.* 1998). Berlese funnel is the most useful for identification of thrips species after preparing microscopic slides. The placing either blue or yellow sticky cards above the crop canopy is the main method for scouting of thrips (Cloyd 2009). Weekly counting of the number of adult thrips can be effective to establish an action threshold for each greenhouse and to determine timing control and insecticides application. For example, 20 adults of WFT per blue sticky card per week in a cut carnation (*Dianthus caryophyllus* L.) in 10–40 sticky cards (Cloyd 2009). Based on a direct damage of *F. occidentalis*, Coll *et al.* (2007) have calculated the economic threshold of strawberry in winter and spring in Israel (about

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Table 2. Comparison between insecticides used for thrips control in Iran (Sheikhi *et al.* 2012) and insecticides recommended for western flower thrips at the Insecticide Resistance Action Committee (IRAC) (http://www.irac-online.org/pests/frankliniella-occidentalis)

Product	Active ingredient	Formulation (%)	Recommended for thrips		Mode of action
			Iran	IRAC	
Dichlorvos	DDVP	EC 5	*		acetylcholin esterase (AChE) inhibitors
Heptenophos	Hostaquick	EC 50	*		acetylcholin esterase (AChE) inhibitors
Malathion	Malathion	EC 57	*		acetylcholin esterase (AChE) inhibitors
Azadirachtin	NeemAzal	EC 1		*	ecdysone antagonist
Lufenuron	Match	EC 5		*	chitin synthesis inhibitors
Spinosad	Conserve Tracer	SC 24		*	nicotinic acetylcholine receptor agonist and GABA chloride channel activator
Abamectin	Vertimec	EC 1.8		*	GABA chloride channel activator
Thiamethoxam	Actara	WG 25		*	nicotinic acetylcholine receptor agonist

10 and 24 WFT/flower, respectively). It should be noted that in flowering stage, plants are more attractive to WFT than the traps so sticky cards may show a lower number of thrips than actual.

Chemical control. As damage tolerance in some ornamental crops for *Tomato spotted wilt virus* (TSWV) is relatively low, insecticides provide the main strategy to deal with WFT (Jensen 2000; Contreras *et al.* 2001; Herron & James 2005). In Table 2, a comparison between insecticides used for thrips in Iran and insecticides recommended for WFT by the Insecticide Resistance Action Committee (IRAC) is provided. The use of insecticides with a different mode of action provides a higher level of control in WFT and prolongs the efficacy of insecticides. To suitably reduce a massive occurrence of TSWV, 3–5 times insecticide application within a period of 7–10 days is required to prevent secondary spread (Seaton *et al.* 1997; Cloyd 2009). Otherwise, 3–5 weekly spaced insecticide applications are enough in tomato (Funderburk *et al.* 2000). Several studies have been done on the efficacy of insecticides to control WFT. Helyer and Brobyn (1992) examined the sensitivity of the WFT to 51 common and recommended insecticides for controlling this pest. Based on the results, 14 insecticides caused more than 75% mortality on nymphs. Among the recommended insecticides, malathion had the greatest potential for controlling thrips on a broad range of crops. In Australia, Kay and Herron (2010) demonstrated that fipronil, spinosad, and methamidophos had the greatest impact on adult and nymph stages. In another study to determine the most effective insecticides for the control of WFT, insecticides toxicity was tested in the LC99.99 and results showed that fipronil, with two formulations of WG and SC, came out as one of the most effective (Herron *et al.* 1996). Kontsedalov *et al.* (1998) evaluated the effect of abamectin, carbosulfan, methiocarb, monocrotophos, methamidophos, cypermethrin, and acrinathrin on fertility, mortality, and feeding behaviour of the adult *F. occidentalis* and the effect of abamectin, carbosulfan, methiocarb, and acrinathrin on immature stages in Israel. According to the results, cypermethrin at 2000 ppm had no direct effect on adult and carbosulfan had a greater impact on the feeding behaviour and fertility. It has been found out that spinosad highly affected *F. occidentalis* in the field pepper (Eger *et al.* 1998). Also fipronil had a higher impact on the control of thrips compared to formetanate and acrinathrin. After a 13-h exposure to fipronil more than 95% mortality was observed (Garzo *et al.* 2000). In another study in Japan, experiments on the nymphs of *F. occidentalis* indicated that fenthion and phenthoate with more than 90% mortality had the highest toxicity. Most of carbamates and pyrethroids are less toxic. Among the insect growth regulators, lufenuron, chlorfluazuron, and flufenoxuron have the most impact on WFT. Also chlorphenapyr and spinosad caused 100% mortality (Morishita 2001). The assessment of WFT susceptibility to formetanate, methamidophos, dimethoate, and spinosad indicated that WFT had the highest susceptibility to spinosad (Vargas & Ubillo 2005). In 2005, it was found that spinosad is an effective insecticide to control the immature and mature stages of WFT in cucumber greenhouses (Jones *et al.* 2005). Broughton and Herron (2007) showed that increasing the rate of abamectin and

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endosulfan improved the control of adults and larvae, whereas increasing the rate of endosulfan only caused more larvae mortality. Also, Bustillo Pardey (2009) examined the potential of ciromazin, abamectin, thiametoxam, lambda-cyhalothrin, lufenuron, imidacloprid, cartap, fipronil for the control of WFT on asparagus. The results showed that lufenuron, abamectin, and fipronil caused maximum mortality in two days after application. However, five days after application, there was no control on population maybe due to imigration of thrips from neighbouring fields or insecticide resistance. In another study, Kay and Herron (2010) suggested that fipronil and methamidophos were effective on nymph and adult stages, even 6 days after spraying process related to fipronil. Some farmers apply overdose of insecticides throughout the growing season, which may increase the development of insecticide resistance. So in line with the goals of integrated pest management, insecticide that is not able to reduce the population below the economic threshold or increases the population, must be removed from the chemical control program (Bielza 2008). The presentation of new and effective insecticides is very important. Spinosad, pyridalyl, azadirachtin, and oxymatrine are newly recommended insecticides for the control of *F. occidentalis* that have exhibited significantly effective control on WFT.

Spinosad. The available insecticide spinosad is commercially used in greenhouses to control WFT (Cloyd 2009). It is a mixture of two active metabolites (spinosyns A and D) derived from *Saccharopolyspora spinosa*. Spinosad shows a high impact on *F. occidentalis* in the field pepper and females are most sensitive (Vargas & Ubillo 2005). Spinosad acts either upon contact or ingestion (Cloyd 2009). No other insecticide class provides this level of control (Funderburk *et al.* 2000; Broughton & Herron 2009). The unique mode of action of spinosyn-based insecticides and their translaminar properties have made them highly effective against WFT (Demirozer *et al.* 2012). It has been proved that spinosad has no detrimental impact on natural enemies of *F. occidentalis*. Therefore, spinosad is a convenient and safe tool in combination with some natural enemies of WFT and it is one of the keys to conservation of *Orius* species (Eger *et al.* 1998; Jones *et al.* 2005). Unfortunately, a certain level of resistance to spinosad has been documented, therefore spinosad should be completely avoided in areas where the resistance has developed (Demirozer *et al.* 2012). A minimum application rate of spinosad was suggested for the use in strawberry greenhouses (Broughton & Herron 2007). Therefore, to prolong spinosad effectiveness, the use of alternatives to spinosad for thrips control during the season is recommended.

Pyridalyl. Pyridalyl was produced from two compounds with known insecticidal activity (3,3-dichloro-2-propenyloxy group, 2-(trifluoromethyl)-4-phenoxyphenyl 3,3-dichloro-2-propenyl) and it belongs to a new class of insecticides (unclassified insecticides) (Sakamoto *et al.* 2004; Isayama *et al.* 2005). Pyridalyl was firstly marketed in Japan (Isayama *et al.* 2005). It is toxic for insect cells via the inhibition of cell growth (Saito *et al.* 2004, 2006). The insecticidal activity and selectivity of this compound may be the result of selection inhibition of cellular protein synthesis (Moriya *et al.* 2008). The cytochrome P450 metabolises pyridalyl and leads to an active pyridalyl metabolite that produces reactive oxygen species. As a result, it enhances proteasome activity to protein degradation and necrotic cell death (Powell *et al.* 2011). Pyridalyl has a high selectivity in cytotoxicity between the insects and mammals (Sakamoto *et al.* 2004). It displays no acute toxicity to non-target insects such as beneficial insects (Sakamoto *et al.* 2004; Isayama *et al.* 2005). Therefore, it is an attractive insecticide for rotational use in integrated pest management programs. Pyridalyl in two formulations, Overture® WP 35% and Sumipleo EC 50%, is more toxic to larvae (especially second instar larvae) than to adults of the WFT. Pyridalyl has translaminar properties on plants. There should not be more than three applications in a cropping cycle and within six months. It kills a majority of WFT in at least seven days.

Botanical insecticides. Botanical insecticides are a new and alternative group of broad spectrum insecticides (Bakali *et al.* 2008). The biological activities of botanical insecticides on insects include: behaviour and feeding deterrence effects, fumigant toxicity, knockdown activity, and lethal toxicity. Therefore, botanical insecticides affect several targets at the same time, and decrease the target organisms resistance or adaptation (Isman 2006). Many of them provide a selective mode of action avoiding the emergence of resistant strains of pest species and in some cases they have no direct negative effects on beneficial insects. As a result, they can be safely used in integrated pest management (Charleston *et al.* 2005).

Oxymatrine. It is a new vegetable insecticide with contact and stomach action. It is a tetracycloquinolizindine alkaloid derived from *Sophora flavescens* Aiton (Leguminosae) roots, matrine and/or

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Table 3. Comparison between the insecticidal properties of spinosad, pyridalyl, oxymatrine, and azadirachtin

Insecticide	Source	Action	Mode of action	Stages	Reduction the number of thrips	Vertical integration
Spinosad	*Saccharopolyspora spinosa*	contact or ingestion	nicotinic acetylcholine receptor agonist and GABA chloride channel ctivator	adults and larvae	within 1–3 days	caterpilars, mites
Pyridalyl	3,3-dichloro-2-propenyloxy group, 2-(trifluoromethyl) and 4-phenoxyphenyl 3,3-dichloro-2-propenyl	contact or stomach	inhibition of the cell growth	more toxic to larvae than adults	at least 7 days	caterpilars
Oxymatrine	*Sophora flavescens*	contact or stomach	unknown	more toxic to larvae than adults	after 7 days	mites, leaf miners, caterpilars
Azadirachtin	*Azadirachtin indica*	contact or ingestion	insect growth regulator	larvae	–	aphids

oxymatrine, with trade name Kingbo (AS 0.2 + 0.4). Sophora is an ancient Chinese herb (Akdeniz & Ozmen 2011). It was found that oxymatrine is produced oxidation of matrine and it acts on nicotinic acetylcholine receptor in American cockroaches, *Periplaneta americana* (Liu *et al.* 2008). This insecticide has no cytotoxic and genotoxic effects on plants so it can be proposed as a safe biopesticide tool (Akdeniz & Ozmen 2011). Oxymatrine has a minor effect on acetylcholinesterase (AChE) activity of albino rats (El-Sayed *et al.* 2010). Apart from insecticidal effect, oxymatrine can inhibit the conidium germination of some fungi (Yang & Zhao 2006). It controls *Tetranuchus urticae*, *Spodoptera littoralis*, *Leucinodes orbonalis,* and *Liriomyza sativae* (Adiroubane & Raghuraman 2008; Asghari Tabari *et al.* 2009; El-Mageed & Shalaby 2011; Medo & Marcic 2013). It is low-toxic for honey bees (*Apis mellifera*) in comparison to spinosad and chlorfluazuron (Rabea *et al.* 2009). Oxymatrine is more toxic to WFT larvae (especially first instar larvae) than to adults (Gholami 2012). Application of oxymatrine on WFT reduces the number of population after 7 days (PCT 2008). It has a good potential to control WFT and it is more effective than fipronil (an insecticide recommended for thrips control), therefore it can be used in WFT management (Gholami 2012). It should be noted that more extensive testing is needed.

Azadirachtin. Azadirachtin is extracted from the neem tree and it is a commercially available pesticide that is effective against *F. occidentalis* (Thoeming *et al.* 2006; Cloyd 2009). Azadirachtin is an insect growth regulator and it acts as an ecdysone antagonist. It is toxic on larvae. It also has feeding deterrent properties for many insects. Azadirachtin is very low toxic for vertebrates (Morgan 2009). The systemic effects of azadirachtin are observed at all foliage-feeding stages of WFT, after soil applications also including the soil-inhabiting stages (Thoeming *et al.* 2003). Azadirachtin has no negative effects on *A. cucumeris* and *H. aculeifer* and the combination of azadirachtin with predatory mites enhances the efficacy of control up to 99% (Thoeming & Poehling 2006). In India the use of neem extracts in pest management is a part of the

Table 4. Rotation of insecticides based on insecticides with different mode of action

First	Spinosad[4]	Lufenuron[3]	Pyridalyl[7]	Abamectin[5]
Second	Thiamethoxam[6]	Dichlorvos[1]	Oxymatrine[7]	Spinosad[4]
Third	Abamectin[5]	Azadirachtin[2]	Pyridalyl[7]	Lufenuron[3]
Fourth	Oxymatrine[7]	Dichlorvos[1]	Spinosad[4]	Thiamethoxam[6]

List of insecticides adapted from Cloyd (2009) and modified by Sheikhi *et al.* (2012) for Iran; 1 – acetylcholin esterase (AChE) inhibitors; 2 – ecdysone antagonist; 3 – chitin synthesis inhibitors; 4 – nicotinic acetylcholine receptor agonist and GABA chloride channel activator; 5 – GABA chloride channel activator; 6 – nicotinic acetylcholine receptor agonist; 7 – unknown

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traditional practices (Schmutterer 1990). Thoeming *et al.* (2006) have suggested that seed treatment with the extract of neem before planting green beans effectively reduces populations of *F. occidentalis* in flowering time. In Kenya it was suggested that combining botanical and synthetic insecticides on crops is helpful to farmers and the environment because of the less damaging effects (Nderitu *et al.* 2010).

History of *F. occidentalis* in Iran

In 2000–2001 the performance of *Orius* species to control thrips on ornamental crops was investigated in Iran. During these experiments, thrips specimens were collected from a greenhouse in Varamin-Sharif Abad by Malekshi. In primary studies, the specimens were identified as *F. helianti* and *F. occidentalis*. Then Professor Zur Strassen proclaimed both names as synonyms and confirmed the designation *F. occidentalis*. Later on an abstract reporting the presence of *F. occidentalis* in Iran on flowers cut in Pakdasht was compiled and sent to the entomological society of Iran and congress for implementing the IPM program for WFT control. However, the publication of abstracts was refused because of some economic policies. Eventually, in 2003, *F. occidentalis* was declared as a new pest in Iran. The official report on WFT appeared in the Proceedings of the 16th Iranian Plant Protection Congress (Jalili Moghadam & Azmayesh Fard 2004). Nonetheless, despite repeated reports from various parts of the country by different people and severe economic losses to farmers and growers, the IPM program for WFT control has not been considered yet. Because until recently the onion thrips had been the most important thrips in farms and greenhouses, the damage on crops was attributed to them and to reduce damage, insecticides recommended for onion thrips were used. In fact, WFT is a new pest in Iran and hence, there is little information about the IPM program for this pest. However, some studies on *F. occidentalis* have been done in Iran. In the first research, the effect of four Iranian isolates of *Beauveria bassiana* on *F. occidentalis* was evaluated in laboratory conditions. DEBI001 and DEMI002 from *B. bassiana* and *M. anisopliae* showed the lowest LC_{50} (1.37×10^5 to 3.06×10^4, respectively). Finally, DEBI001 and DEMI002 were recognised as the main isolates for biological control of *F. occidentalis* (Kupi *et al.* 2010). Then the effects of extracts of three vegetables (garlic, onion, pepper) along with the extract of Neem on WFT were assessed by Kiani *et al.* (2010). The findings showed that all of the extracts were efficient on *F. occidentalis*. Also Gholami (2012) evaluated the susceptibility of WFT to some synthetic and botanical insecticides. Based on the results, fipronil and oxymatrine were two effective insecticides to chemically control *F. occidentalis*. Eshrati *et al.* (2014) provided life and reproduction tables of WFT on the greenhouse cucumber, Veola variety. Accordingly, rm, T, DT, GRR, and R_0 were calculated and the results were 0/008 ± 0/1908 p/d, 20/45 d, 3/64 d, 170/02, and 48/96, respectively. Currently, WFT on ornamental crops is being monitored and unfortunately no more research on WFT has been done.

Future outlook

The problem with *F. occidentalis* in Iran, especially in cucumber, tomato, pepper, and strawberry greenhouses, is the accurate identification of the species. The main morphologic characteristics of WFT are associated with head and pronotal setae, comb on abdominal tergites of female, and abdominal sternites of males (EPPO 2002). Keys for the identification of adults are available (Palmer *et al.* 1989). The European and Mediterranean Plant Protection Organization (EPPO) has collected comprehensive information on the identification of the thrips species, too. Lack of correct diagnosis of WFT causes that the growers use insecticides without knowledge which insecticide is really recommended and effective. It is a critical issue in fruiting vegetables. At the first step, scouting is a therapeutic approach that shows the percentage of the used strategies effectiveness. Also, economic thresholds and the timing of insecticide application can be estimated by scouting and monitoring. It is necessary to eliminate applications of insecticides against *F. occidentalis*. It was found that economic thresholds for pepper and eggplant greenhouses are mostly six WFT per flower or about two thrips larvae per fruit and for tomato greenhouses one WFT per flower or about two thrips larvae per fruit of any species (Demirozer *et al.* 2012). Tomato is more sensitive to WFT damage than pepper or eggplant. Biological agents have an important role in suppressing the population of thrips so monitoring and detection of the population and its number are essential in scouting for insecticides application.

Cultural control such as sanitation, plant resistance, and push-pull strategy can also delay the use

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of insecticides. Also the use of ultraviolet reflective mulches is useful. For example, it was found that the ultraviolet reflective mulches available for the raised-bed plastic mulch production system of Florida are effective in repelling migrating adults of WFT, and this repellency reduces the primary and secondary spread of tomato spotted wilt. Ultraviolet-reflective mulches are most effective early in the crop season before the plant canopy begins to cover the mulch (Demirozer *et al.* 2012). However, to prevent thrips from coming into the greenhouse it is important to keep doors closed and screens in place. The use of varieties with more pollen in the cucumber is good for natural enemies. In Iran, biological and chemical control is more effective because of the outbreak of this pest and detection problems. Combining insecticides with compatible natural enemies is excellent. In this case, studying about the population dynamics of *F. occidentalis* and natural enemies is necessary. For this purpose, the application of effective insecticides like spinosad, pyridalyl, and biorational insecticides such as oxymatrine or azadirachtin is useful. The exclusive confidence on insecticides for the control of WFT populations in greenhouses eventually led to the development of resistance (Cloyd 2009). After the first detection of resistance in the WFT, resistance management strategies for the rotational use of different groups of chemical insecticides were applied in Australia in 1993. In a field experiment with the use of α-cypermethrin with and without rotation, more than a 114-fold resistance to α-cypermethrin (LC_{50}) was found (Herron & Cook 2002). Nonetheless, cypermethrin resistance in pepper greenhouses in Israel evolved while no new individuals had entered the population for 7 years and the population had not been under any selection pressure (Kontsedalov *et al.* 1998). This may occur as a result of the host plant secondary metabolites. The resistance to spinosad in *F. occidentalis* was also reported more than 10 times (Bielza *et al.* 2007). In addition, spinosad has shown no cross resistance to acrinathrin, formetanate or methiocarb (Zhang *et al.* 2008). It has been presumed that maybe the resistance to spinosad is not due to metabolic detoxification and the rotation use of spinosad can be an effective strategy for spinosad resistance management (Bielza *et al.* 2007). Also, by the monitoring of the fipronil resistance, it was suggested that despite the use of fipronil in recent years, it has still been a good tool of *F. occidentalis* control (Herron & James 2005). A main point in insecticide resistance management (IRM) is to reduce selection pressure that can be achieved by rotation use of insecticides and minimizing the dosage and number of applications, use of insecticides only when it is necessary. For instance, it was suggested that the recommended application rate of spinosad in strawberries greenhouses can be minimized (Broughton & Herron 2007). The use of alternative insecticides that are effective on *F. occidentalis* and have no cross-resistance with conventional insecticides is one of the best strategies to reduce insecticide resistance. For example, alternating application of spinosad for thrips control during the season is recommended as an IRM strategy. So the alternation of insecticides with different mode of action is very useful in delaying the development of resistance. It is important to note that in the fruiting vegetable greenhouses, different pest species are present, e.g. *F. occidentalis*, *T. tabaci*, *T. urticae*, *L. sativae,* and *Trialeurodes vaporariorum*. Therefore a vertical integration is needed. The vertical integration is the use of multiple and compatible tactics to control one group of pests such as insect pests. For example, oxymatrine controls some insect pests in greenhouses such as: *T. urticae*, *L. sativae,* and *F. occidentalis*, thus the application of oxymatrine is useful when these pests are present. Also, *O. insidiosus* is the key natural enemy of many pests in eggplant and pepper. The vertical integration should be considered an effective part of the integrated pest management programs (Demirozer *et al.* 2012). Finally, the pest management programs are affected by the growers' decisions. To develop new methods, discover unforeseen problems and interactions of multiple strategies in this field are necessary.

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Corresponding author:

Amin Sadeghi, Ph.D professor, University of Kurdistan, Faculty of Agriculture, Department of Plant Protection, Box 66177-15175, Sanandaj, Iran; E-mail: a.sadeghi@uok.ac.ir