Pirimiphos-Methyl Residues and Control of Greenhouse Whitefly (Homoptera: Aleyrodidae) on Seven Vegetables[1]

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ABSTRACT A gas chromatographic analysis of pirimiphos-methyl, Actellic®, residues on four leafy vegetables (celery, radicchio, cabbage and kohlrabi) and three fruity vegetables (green beans, pepper and cucumber) is reported. The method proved to be accurate and reliable for residue estimation with recoveries of 90-96% from fortified vegetable tissues, depending on the crop species and the part of the plant analyzed. Initial deposition of pirimiphos-methyl and its disappearance rate on the different types of plant surfaces varied widely. Residue disappearance rates varied from rapid on cucumber fruits ($t_{1/2}$ = 1.8 d) to slow on pepper fruits ($t_{1/2}$ = 4.3 d) over a 42-day period. On leaves, green beans had the highest dissipation rate ($t_{1/2}$ = 2.0 d) while pepper had the lowest ($t_{1/2}$ = 4.7 d). Waiting periods (preharvest safety intervals) on each crop were also determined. The potential of pirimiphos-methyl was tested as a candidate for greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Homoptera: Aleyrodidae) control. Cucumber and bean foliage were preferred by greenhouse whitefly. One day following application of Actellic® 5E emulsifiable concentrate at the rate of 4.5 g (AI)/L of liquid spray, whitefly populations were reduced significantly on both cucumber (88%) and beans (96%). Pirimiphos-methyl may be a useful candidate for control of greenhouse whitefly and other insects in home gardens based on its effectiveness and human safety.

KEY WORDS *Trialeurodes vaporariorum,* host preference, Actellic®, residues, homegarden, vegetables.

Recommended pesticides on homegarden vegetables are based on efficacy and residue data obtained from large farms. There are, however, no specific programs that cater to the development of pest control technology for home gardens. In fact, there is a realization that such technology may not be directly transferable to small and mixed cropping systems (Narain et al. 1981).

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In 1992, the Pesticide Data Program (PDP) was established as a joint program between United States Department of Agriculture (USDA), Agricultural Marketing Service (AMS) and the Environmental Protection Agency (EPA), to access pesticide residues in commodities most prevalently consumed by the American public. Data collected by PDP indicated that out of the 259 celery samples collected and analyzed, 205 (79.2%) of the samples had detectable pesticide residues. Five domestic celery samples close to the consumer level contained Dacthal and iprodione residues having no established tolerance level set by EPA (Anonymous 1992). Out of the 238 green bean samples collected, 157 (66%) contained pesticide residues. Two green bean samples contained methamidophos; no tolerances for methamidophos on green bean have been established by EPA.

Because there are considerable numbers of home gardens in the United States, the requirements for residue data on minor vegetable crops are becoming more demanding. Relatively few studies have examined pesticide use in or around the home. Davis et al. (1992) examined family use of pesticides in home, garden, orchard, and yard in Missouri. Their results indicated that nearly all families (97.8%) used pesticides at least one time per year and two-thirds used pesticides more than five times per year.

Home gardens are usually located in populated area where the chances of human contact with sprayed insecticides may be greater than in rural areas. Accordingly, controlling pests with effective yet less environmentally toxic and disruptive insecticides has become particularly important in home gardens. Insecticides for use in home gardens should be safe, guaranteeing short persistence with no toxic metabolites in vegetables.

Pirimiphos-methyl, Actellic® (0-2-diethylamino-6-methyl-pyrimidin-4-yl O, O-dimethylphosphorothioate), is a broad spectrum contact insecticide-nematicide used for the control of stored grain pests, cockroaches, mosquitoes, lice, fleas, bedbugs, houseflies, and ants (Thomson 1979). It also has activity against a wide spectrum of pests including aphids, beetles, caterpillars, flies, mites, and thrips that commonly attack vegetables (Anonymous 1985, 1986). Pirimiphos-methyl has been approved for controlling vectors of human disease and an interim specification has been issued by the vector biology and control division of World Health Organization (WHO 1982). In 1986, FAO/WHO established Maximum Residue Limits (MRLs) for pirimiphos-methyl on vegetables and fruits (FAO/WHO 1986).

During the course of my investigation to study the dissipation of pesticides on edible portions of vegetables (Antonious and Abdel-All 1988, Antonious and Snyder 1994), I selected pirimiphos-methyl for more dissipation studies and evaluation for future use in home gardens. Results of the present research may help to focus the attention of the EPA and vegetable growers on the safety properties of pirimiphos-methyl as an insecticide that could be used on some homegarden grown vegetables, and to select candidate crop(s) for field dissipation studies.

The greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood), has a host range of > 250 plant species (Sanderson and Roush 1992) and is known to attack vegetables grown in greenhouses and outdoors. Marketability of produce is severely reduced when it is contaminated with whitefly 'scales' (nymphal stage) and honeydew (Liu et al. 1993).

The objectives of this study were: (1) to study the persistence of pirimiphos-methyl residues on 7 different plant species in the homegarden environment; (2)

to compare host preference of greenhouse whitefly in a mixed cropping system of 7 common vegetables grown in home gardens, and; (3) to correlate pirimiphos-methyl efficacy against greenhouse whitefly with residues at harvest.

Materials and Methods

Cabbage, *Brassica oleracea* (var. Stone Head); cucumber, *Cucumis sativus* (var. Poinsett 76); radicchio, *Cichorium intybus* (var. Ronnette); kohlrabi, *Brassica oleracea* (var. Grand Duke); celery, *Apium graveolens* (var. Large Smooth Prague); garden bush bean, *Phaseolus vulgaris* (var. Contender), and; bell pepper, *Capsicum annuum* (var. Lady Bell) were grown during July-August, 1991 in an open area surrounded by greenhouses and large trees at the Horticulture Department, College of Agriculture, University of Kentucky, Lexington. This environment is representative of a homegarden environment. A row of each vegetable (6 plants long and spaced 30 cm apart) was randomly assigned to a position in each of four blocks. Each block contained 14 rows (treated and untreated vegetables; rows (treatments) were spaced 0.5 m apart.

Vegetables grown in sandy clay loam soil (pH 6) were sprayed once with pirimiphos-methyl (Actellic® 5E emulsifiable concentrate) at the rate of 699.75 g [AI]/155.6 liter of water/ha (0.45% w/v). Both the commercial and standard material (97% purity) were obtained from ICI Americas Inc. (Western Research Center, Richmond, CA). Treatments were applied with a small hand-carried compression sprayer, in such a manner that the plants were drenched to the point of runoff. The fruits were tagged before spraying to insure sampling from treated fruits only. Composite samples of each crop were made by randomly collecting three mid-canopy leaves and two fruits, where appropriate, from each plant.

Fruits (2 kg) and leaves (250 g) were collected at intervals of 1 h, 1, 3, 7, 10, 14, 21, 28, 35, 42 and 50 d following spraying from both pirimiphos-methyl treated and untreated plants. Samples were immediately frozen and held at -18°C. For each extraction, subsamples of 50 g of leaves, 100 g of bean pods or seeds, or 200 g of fruits taken from each of 4 replicates, were blended with methanol at the ratio of 1:3 (w/v) for 3 min at high speed. Mixtures were filtered with Whatman No. 1 through a Buchner funnel. Extracts were then dried with anhydrous Na_2So_4 and evaporated to 5 ml using rotary vacuum evaporator at 40°C. Concentrated extracts were cleaned using the procedure described by Antonious and Snyder (1993).

Aliquots of 1 µl of cleaned samples were injected into a Hewlett Packard (HP) gas chromatograph equipped with a flame ionization detector (FID). The following GC conditions were maintained throughout the analysis: column, 10 m × 0.53 mn bonded (1.2 µm) polydimethylsiloxane (obtained from Alltech Chemical Co.); column temp, 130°C; detector and injector temp, 300 and 320°C, respectively; carrier gas, (He) 2.3 ml/min; air, 110 ml/min and, hydrogen, 4.5 ml/min. Under these conditions retention time of pirimiphos-methyl was 10.26 min. Quantitation of pirimiphos-methyl residues on the studied vegetables was based on a standard curve constructed with analytical grade pirimiphos-methyl (97% purity) and detector response (peak area).

Recovery was determined for each plant tissue. Two 50 g samples of each untreated vegetable tissue was fortified with a known amount (1-10 µg/g) of analytical grade pirimiphos-methyl prepared in methanol. The fortified samples were then blended, extracted, and analyzed in the same manner as the samples treated with the formulated form of the insecticide. Recoveries varied somewhat among crop species and the part of the plant analysed (90 ± 4.3 to 96 ± 1.9%). Residue data obtained were corrected according to their corresponding recoveries. Minimum detectable levels were 0.02, 0.01, and 0.005 µg/g for leaves, bean seeds, and fruits, respectively. Insecticide residue data were used to obtain half-lives. Half-life was calculated by regression of $\log_{10}$ (conc) on time in days following spraying using the methods of Sundaram (1993). Half-lives were statistically analyzed by ANOVA (SAS Institute 1991). Following covariance analysis means were compared by Fisher's protected LSD.

Greenhouse whitefly populations (adults and nymphs combined) were counted before and after spraying. Insect counts on the untreated plants were used for determining host preferences of whiteflies. The efficacy of pirimiphos-methyl for controlling greenhouse whitefly on the different types of foliage was evaluated by counting whiteflies on 6 randomly selected leaves per replication at the intervals used for determining residues. Live and dead adults and nymphs were counted. Insect counts were log transformed and then analyzed by ANOVA. Means were separated by Turkey's Omega procedure (Steel and Torrie 1960).

Results and Discussion

Initial deposition and rate of disappearance of pirimiphos-methyl residues varied widely among vegetable species and tissue (Table 1). Initial deposits retained on both the hairy bean leaves (206 ppm), the waxy cabbage (87 ppm), and smooth radicchio leaves (93 ppm) provide examples of the role of the physical characteristics of the plant surface on pesticide retention. Plant hairs increase leaf surface area and pesticide initial deposits (Antonious and Snyder 1993). The amount of leaf wax, its chemical composition, and its physical configuration on the surface have a great impact on the contact angle between spray droplets and the leaf surface (Hull 1970).

Differential amounts of the initial deposits of pirimiphos-methyl on the fruits and edible parts is attributable, in part, to the surface area of the fruit per unit weight of sample (Antonious and Snyder 1994) and the position of the fruit within the dense foliage that protects it from penetration of spray. For these reasons, cucumber fruits were found to receive lower amounts of initial residues of pirimiphos-methyl (3.7 ppm) as compared to other fruits analyzed. For example, the edible stem of kohlrabi, pepper fruits, and bean pods retained 6.4, 14.8, and 35.1 ppm, respectively, 1 h after spraying (Table 1).

Levels of pirimiphos-methyl residues detected on the sprayed vegetables at different intervals were used to estimate half-life ($t_{1/2}$) as a measure of retention on each type of surface. Results in Table 1 present half-lives, the respective maximum permissible levels of pirimiphos methyl (FAO/WHO 1986), and waiting periods corresponding to each type of plant.

Residue values of pirimiphos-methyl on kohlrabi leaves could be fitted with two consecutive first-order decay lines. The first line (disappearance line) occurred from 0-10 d after application ($t_{1/2}$ = 3.4 d), then the rate of disappearance during 10-35 d ($t_{1/2}$ = 5.0 d) was slow (persistence line). This degradation behavior through two consecutive first-order decays is very common for many other pesticides

Table 1. Initial residues (ppm), half-lives ($t_{1/2}$), maximum residue limits (MRL), and waiting period of pirimiphos-methyl on seven home garden-grown vegetables.

Tissue Analysed	Residues (ppm ± SE) Recovered 1 hour After Application	$T_{1/2}$ ± SEM (days) Leaves	Fruits or Edible Part	MRL† (mg/kg)	Calculated Waiting Period‡ (days)
Cabbage	87.29 ± 2.7	3.28 ± 0.10 e	–	2.0	21
Celery	130.48 ± 4.57	4.21 ± 0.05 bc	–	NT	
Radicchio	93.68 ± 2.45	4.02 ± 0.06 cd	–	NT	
Green Beans					
Leaves	206.72 ± 7.49	2.00 ± 0.08 f	–		
Pods	35.10 ± 1.56	–	3.05 ± 0.12 b	0.5	21
Cucumber					
Leaves	142.99 ± 3.01	3.74 ± 0.18 d	–		
Fruits	3.67 ± 0.32	–	1.83 ± 0.14 d	1.0	3
Kohlrabi					
Leaves	174.97 ± 3.56	4.30 ± 0.13 b	–		
Stem	6.42 ± 0.52	–	2.28 ± 0.12 c	2.0	3
Pepper					
Leaves	117.63 ± 3.60	4.66 ± 0.10 a	–		
Fruits	14.8 ± 0.73	–	4.26 ± 0.20 a	1.0	14

* Means ± SE within a column having different letters are significantly different from each other ($P < 0.05$; Fisher's protected LSD test [SAS Institute, 1991]).
† Safe residue limit recommended by FAO/WHO, 1986.FAO/WHO, 1986. NT = No tolerance level had been established.
‡ Preharvest safety interval based on data obtained from the dissipation study carried out in the present research work to reach acceptable MRL.

(Iwata et al. 1983). One h following spraying, residue levels on pepper leaves were less than those detected on cucumber and kohlrabi leaves. However, half lives on both pepper fruits and leaves were similar (Table 1).

Pirimiphos-methyl disappearance on cabbage and cucumber leaves occurred at a much slower rate during the first 10 d after application, where $t_{1/2}$ (± SE) were 5.0 ± 0.13 and 5.1 ± 0.02 d, respectively. These estimates were significantly higher than the remainder (10-35 d), where $t_{1/2}$ were 3.0 ± 0.10 and 3.3 ± 0.97 d, respectively. Residue disappearance rates on edible portions varied significantly from rapid on cucumber fruits ($t_{1/2}$ = 1.8 d) resulting in a waiting period of 3 d to slow on pepper fruits ($t_{1/2}$ = 4.3 d) with a waiting period of 14 d.

On cabbage, a residue limit of 2 mg/kg was achieved following a waiting period of 21 d. Wrapper leaves in cabbage are the predominant exposed leaves to pesticide sprays compared with inner tissues. Removal of wrapper leaves may result in very low or nondetectable residues since pirimiphos-methyl does not have systemic properties. A study of this phenomenon with lettuce (Cabras et al. 1988, Sances et al. 1992) using a variety of recommended pesticides indicated that removal of wrapper-cap leaves resulted in heads free of insecticide residues. Further, their data indicated that removal of wrapper leaves from lettuce previously considered unusable, because of accidental tolerance violations, can result in overall residues below legal tolerances.

Initial residues on hairy green bean leaves, though higher in quantity (206 ppm), dissipated at a higher rate ($t_{1/2}$ = 2 d) than on other leaves. Residues declined below 0.5 mg/kg on green bean pods by day 21 which resulted in an excessive waiting period of 21 d (Table 1). However, no residues were detected in bean seeds because pirimiphos-methyl is a non-systemic insecticide.

The non-polar and non-systemic properties of pirimiphos-methyl (vapor pressure 1×10^{-4} mm Hg at 30°C), which are similar to those reported for pyrethroids (Guillebeau et al. 1989), increase its susceptibility to physical weathering. This may partially be responsible for its rapid losses on hairy green bean leaves. Residues detected on fruits were higher on pepper throughout the intervals tested than on cucumber and the edible stem of kohlrabi.

On green beans, MRLs of 0.5 mg/kg required a waiting period of 21 d following pirimiphos-methyl spraying using the rate of 4.5 g (AI)/L of water. Laboratory assessment of the efficiency of four organophosphorus insecticides against different developmental stages of greenhouse whitefly indicated that pirimiphos-methyl at 0.15% concentration was the most effective insecticide followed by malathion, dimethoate, and methyl parathion (Sharaf 1978). The rate of application used in the present study (0.45%) is three times that used by Sharaf (1978). Therefore, at lower rates of Acetellic® application, waiting periods on bush bean pods may be lowered.

Preference of the seven home garden grown vegetables by *T. vaporariorum* and efficacy of pirimiphos-methyl are presented in Figures 1-2. Cucumber and green beans were the most preferred among all vegetables tested (Fig. 1). Insect counts on pirimiphos-methyl treated vs. untreated plants revealed a significant reduction of nearly 89 and 96% on cucumber and green bean leaves, respectively, 1 d post application. Two wks post application counts of adults and nymphs on cucumber and green bean leaves were 4 and 5 insects/6 leaves, respectively, compared with 250 and 78 insects/6 leaves on untreated plants. Three wks following

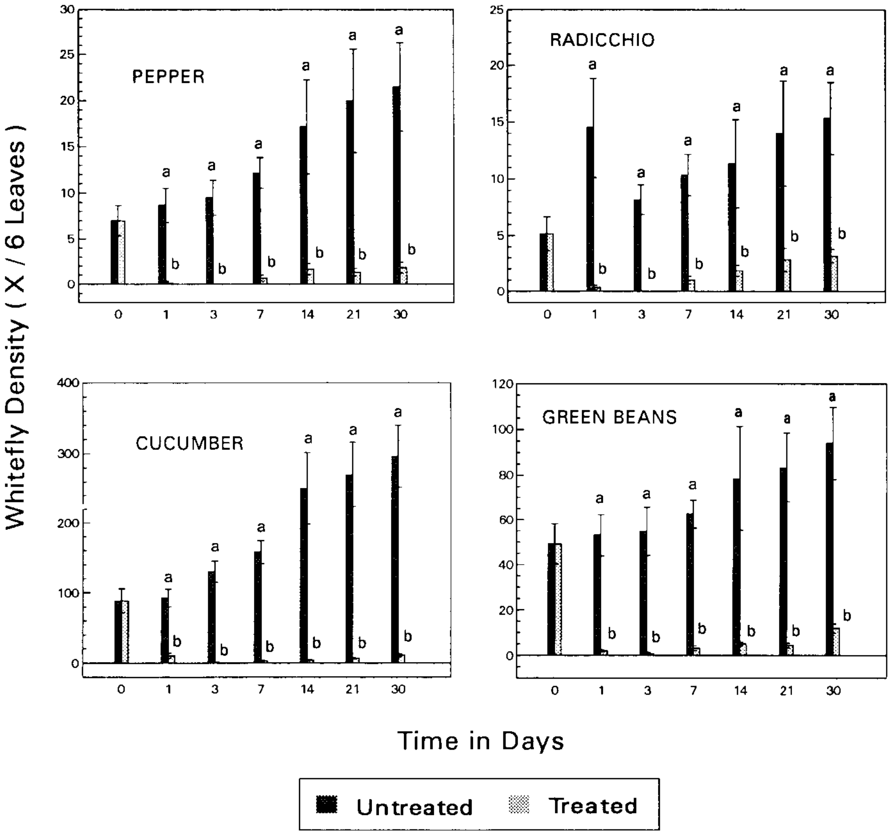

Fig.1. Efficacy of pirimiphos-methyl for *T. vaporariorum* control at different time intervals following spraying on pepper, radicchio, cucumber, and green beans. (Bars reflect $\overline{X} \pm$ SEM). Means having different letters per each sampling time are significantly different ($P < 0.05$).

spraying, counts were 7 and 4 insects on treated plants compared to 270 and 83 insects on untreated plants, indicating significant reductions of 97 and 95% on cucumber and green bean leaves, respectively. Pirimiphos-methyl was also effective for 30 d in reducing population density by 96 and 87% on cucumber and bean leaves, respectively.

For other vegetables tested, whitefly adults and nymphs were few and scattered which indicated that *T. vaporariorum* were probably present incidentally on these five vegetables because of their proximity to cucumber and green beans. Pirimiphos-methyl significantly reduced insect counts on pepper, radicchio (Fig. 1), celery, kohlrabi, and cabbage leaves (Fig. 2). The efficacy on the former five vegetables was similar.

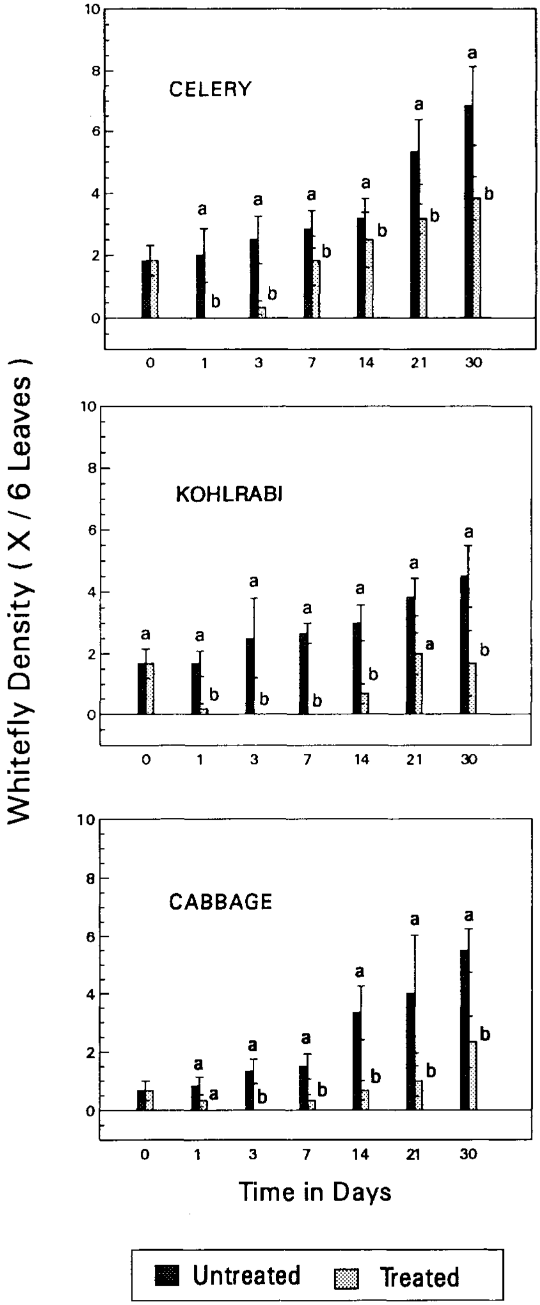

Fig. 2. Efficacy of pirimiphos-methyl for *T. vaporariorum* control at different time intervals following spraying on celery, kohlrabi, and cabbage (Bars reflect $\overline{X} \approx \pm$ SEM). Means having different letters per each sampling time are significantly different ($P < 0.05$).

Results indicated that young cucumber and green bean plants are the most seriously attacked by greenhouse whitefly among the seven vegetables tested (Fig. 1). The most commonly practiced form of chemical control for whitefly is routine insecticide application. In Kentucky commercial vegetable crop recommendations, no insecticide has been recommended to control whiteflies on cucumber while acephate (Orthene® 75S) is currently recommended to control whiteflies on beans when damage is first seen (Strang et al. 1994). However, acephate, a systemic insecticide, is toxic to mammals at 900 mg/kg (Ware 1989). In plants, 5-10% of the applied acephate is metabolized to methamidophos (Leary 1975, Magee 1974, Leidy et al. 1978, Hadjidemetriou et al. 1985, Levine and Felsot 1985, Antonious and Snyder 1994). Methamidophos, also systemic, is toxic to mammals at 13 mg/kg (Ware 1989).

Significant reductions in greenhouse whitefly populations on cucumber following pirimiphos-methyl spraying, its fast dissipation rate on cucumber ($t_{1/2}$ = 1.8 d), and its short waiting period (3 d) indicate that pirimiphos-methyl may be an effective alternative to acephate as a safe insecticide for control of this pest on cucumber. It has a much lower mammalian toxicity, oral LD_{50} > 2000 mg/kg (Leahey and Curl 1982) and dermal LD_{50} > 4592 mg/kg (Anonymous 1985) and, therefore, provides a greater degree of operator safety. Bassett and Wilkin (1981) indicated that pirimiphos-methyl may be used against cucumber pests in England. It gave good control of mites and was not phytotoxic to young cucumber plants at 0.5 g (AI)/L of water. The rate of application of pirimiphos-methyl used in the present study (4.5 g (AI)/L) was 9 times that used by Bassett and Wilkin (1981); therefore, efficacy at lower rates should be tested.

Studies were also undertaken in the present work to correlate pirimiphos-methyl residues on plant foliage and efficacy. Three wks following spraying, residues on green bean leaves were 0.09 mg/kg and these negligible residues reduced whitefly population significantly by 95%. On cucumber, residues dropped from 143 mg/kg (initial deposits) to 4.1 mg/kg 3 wks following spraying. That amount was extremely toxic to greenhouse whitefly and reduced populations by 97% (Fig. 1). These findings indicate that reducing pirimiphos-methyl rate of application below 699.75 g [AI]/155.6 liter of water/ha may reduce residues on produce, in particular, on green bean pods and, thereby, reduce waiting periods while still controlling whiteflies on green bean leaves.

Pirimiphos-methyl has no toxic metabolites (FAO/WHO 1983), has limited persistence with both contact and fumigant action (Yuen 1976), and is registered for use in different parts of the world to protect vegetables and fruits from many insects (FAO/WHO 1983, 1986). World-wide registrations and maximum residue limits of pirimiphos-methyl, that have been documented by the Food and Agricultural Organization of the United Nations, rapid loss of the insecticide from treated plant surfaces and low mammalian toxicity (Skimore and Tegala 1986), suggest a considerable degree of safety to consumers given the tolerance limits.

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