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# Comparative Effectiveness of Different Organic Insecticides to Blueberry Maggot Flies (Diptera: Tephritidae)

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## Abstract

Laboratory and field assays using organic insecticides were conducted on the blueberry maggot, *Rhagoletis mendax* Curran. Direct contact of flies to Entrust® (spinosad), PyGanic® (pyrethrum), and Aza-Direct® (neem extract) resulted in significantly higher mortality compared to the control (water) after 2 and 24 h. After 24 h Entrust and Pyganic were not significantly different from the positive control (phosmet); whereas Aza-Direct was significantly lower. A second laboratory assay evaluated fly mortality to leaves 3 h after insecticide application. In this assay, after 48 h PyGanic and Aza-Direct were not different from water, whereas Entrust formulations were similar to the positive control (phosmet). The conclusion from these assays was that Aza-Direct and PyGanic provided contact kill, but only Entrust had residual activity. A repellency assay found no measurable effects for Aza-Direct. Large scale field trials found no treatment affect for number of adult maggot flies captured in sticky traps; however, there were significantly lower levels of fruit-infesting larvae in treated plots compared to the untreated control. GF-120 NF Naturalyte Fruit Fly Bait® (spinosad bait), Entrust, and PyGanic were not different from the positive control (imidacloprid). There was a significantly higher infestation in the plot treated with Agroneem® (neem extract) compared to the positive control. The implications for an organic integrated pest management program for blueberry maggot are discussed.

KEYWORDS: *Rhagoletis mendax*, azadirachtin, pyrethrin, pyrethrum, spinosad

## Introduction

The blueberry maggot fly, *Rhagoletis mendax* Curran, is a serious pest of lowbush and highbush blueberries, *Vaccinium angustifolium* Aiton and *V. corymbosum* L. respectively, in the northeastern United States and Atlantic Provinces of Canada (Geddes and Le Blanc 1987). It is often the most important insect pest of blueberries, because of the zero-tolerance for maggot presence in harvested fruit (Canadian Food Inspection Agency 1999).

Although applying different types of insecticidal compounds, both organic and conventional farmers use either a calendar-based or an integrated pest management (IPM)-based spray program to control *R. mendax*. A calendar-based approach requires growers to start spraying insecticides within 10 d of the first detection of an adult fly in the area, and continue spraying at 7- to 10-d intervals until the end of harvest (Canadian Food Inspection Agency 1999). An IPM-based program requires growers to monitor the presence of adults using ammonium acetate baited sticky traps (Wood et al. 1983, Geddes et al. 1989). A recommended insecticide should be applied within 5 d of the date of capture of a single fly in any one of the monitoring traps, followed by a second spray 7-10 d later. This spray interval should be repeated for each subsequent fly detection until the end of harvest.

Broad-spectrum insecticides, such as organophosphates and carbamates, have been the cornerstone for conventional control of *Rhagoletis* flies. In addition to these compounds being unavailable to organic growers, there was no universal definition on what was an acceptable organic pesticide. The creation of the USDA National Organic Program (NOP) in October 2002 and the Organic Materials Review Institute (OMRI) provided a framework to evaluate and certify compounds as organic that met a set of established standards.

Several different types of OMRI-registered insecticides have potential for providing effective control of blueberry maggot. One group of organic insecticides is based on extracts from the neem tree (*Azadirachta* indica A. Juss.), some of which have repellant, feeding inhibition, and anti-hormonal activity in insects (Nat et al. 1991). Azadirachtin is the primary compound responsible for this activity in insects and Stark et al. (1990) found azadirachtin to affect metamorphosis, longevity, and reproduction in several tropical tephritids. However, Prokopy and Powers (1995) found no affect on oviposition or mortality of *R. pomonella* (Walsh). There are currently 14 different organic formulations of this insecticide available.

A second type of insecticides contain spinosad, which was developed from the bacterium *Saccharopolyspora spinosa* Mertx and Yao. There are organic formulations of this toxicant as a bait spray and a spray. Bait sprays, which contain ammonia-based attractants, a feeding stimulant such as sucrose, and an insecticide, have been used to control outbreaks of *Anastrepha ludens*, *Bactrocera dorsalis* (Hendel), and *Ceratitis capitata* since the 1950's in the United States (Steiner 1952, Moreno and Mangan 2003). The bait that is now commercially used with spinosad, GF-120 NF Naturalyte Fruit Fly Bait, was based on SolBait, which was developed by Moreno and Mangan (2003). Barry and Polavarapu (2004) found SolBait to be the best of several baits tested in evaluations on *R. mendax*. Non-organic formulations of bait sprays containing spinosad were developed for controlling tropical and sub-tropical tephritid pests, with feeding studies confirming high mortality for *Anastrepha ludens* (Prokopy et al. 2000), *A. suspensa* (King and Hennessey 1996), *Bactrocera cucurbitae* (Prokopy et al. 2003), and *Ceratitis capitata* (Peck and McQuate 2000, Vargas et al. 2001, Barry et al. 2003).

The last group contain pyrethrum, an insecticide produced primarily in the flowers of *Tanacetum cinerariaefolium* L. Pyrethrum has good knockdown ability, but very short residual activity, as it degrades rapidly after exposure to sunlight (Katsuda 1999). Many synthetic insecticides based on pyrethrum chemistry, called pyrethroids, have been developed to increase the residual activity.

In addition to insecticide sprays, previous work by Prokopy (1975) found painted spheres, baited with ammonia compounds, to be highly attractive to tephritids. Spheres were first coated with a sticky material to trap flies (Prokopy 1975), but the need for decreased deployment and handling time necessitated finding an insecticide replacement (Duan and Prokopy 1995). Several studies have found spheres to be effective in controlling *R. mendax* and *R. pomonella* (Duan and Prokopy 1995, Liburd et al. 1999, Ayyappath et al. 2000, Stelinski et al. 2001). However at present the use of spheres is not commercially economical for either conventional or organic blueberry growers, because of the necessary deployment density and the associated costs of products (i.e., spheres and residue extending agents) and labor (i.e., monitoring and applying insecticides to spheres) (Barry and Polavarapu in press).

Our goal was to identify the most effective organic insecticide for controlling *R. mendax* populations in highbush blueberry.

## Materials and Methods

**Insects.** Infested blueberries were collected near Chatsworth, NJ, in the summer and fall of 2003. The rearing procedures of Ayyappath et al. (2000) were used to obtain adult *R. mendax* for studies during 2004. Briefly, infested berries were placed over moist sand for larvae to drop and pupate. Puparia were sifted from sand three-five weeks later and kept in a screenhouse. Puparia were transferred to an incubator in November, at 6°C with a photoperiod of 12:12 (L:D) to complete diapause. The following March puparia were placed at 8°C. Periodically, groups of puparia were transferred from 8 to 15°C for approximately 8 d and then transferred to an incubator at 25°C with a photoperiod of 16:8 (L:D) until adult emergence, which occurred 25 to 45 d later. Adult flies were kept at 21-23°C and were provided a diet of sucrose and water. Flies used in assays were 7-13 d-old and allowed to acclimatize to experimental conditions for several hours before trials commenced.

**Direct Contact with Fresh Insecticide.** Fly survivorship was evaluated after direct exposure to insecticides in 1 liter plastic containers with a screened top. Prior to exposure, ten flies were placed in each container with a moist cotton ball. In addition to water and the organophosphate phosmet (20.8 oz/ac; Imidan, Gowan Co., Yuma, AZ), there were two rates of the following organic insecticides: Aza-Direct (16 and 32 fl oz/ac; Gowan Co), Entrust (1 and 2 oz/ac; Dow AgroSciences, Indiananopolis, IN), and PyGanic (16 and 32 fl oz/ac; McLaughlin Gormley King Company, Minneapolis, MN). All treatments were prepared at a rate of 25 gallons of water per acre. A total of 8 replicates were completed for each treatment. Insecticides were applied using a spray bottle (8-oz; Goody Products, Atlanta, GA) to mist approximately 0.7 ml per container through the screened top. Fly mortality was determined 2 and 24 h after exposure. This experiment occurred in a screen house with temperatures ranging from 20 – 30 °C.

**Exposure to 3hr –old Insecticide.** Fly survivorship was evaluated after exposure to insecticides in 1 liter plastic containers with a screened top. Eight treatments (the same as in Direct Contact with Fresh Insecticide section) were applied to each of eight blueberry bushes. Three hours after application (when vegetation was dry) 3 leaves from each treated plant were collected and placed in a 1 liter plastic container with a screened lid, which contained a moist cotton ball. Ten flies were then placed in each container. Fly mortality was determined 24 and

48 h after the start of exposure. This experiment occurred in the laboratory with temperatures ranging from 21 – 23 °C.

**Repellency.** The repellency of Aza-Direct was assessed in a laboratory assay. Aza-Direct was prepared (32 oz/ac in 25 gallons of water/acre) and applied to foliage of a blueberry plant until leaves were dripping. The control was a blueberry plant that was misted with (tap or distilled ?) water until dripping. Three hours after application (when vegetation was dry) 40 leaves from each treated plant were collected. Five flies were placed in a plastic container (12.5 cm in height and 13 cm in diameter) to which two leaves of one treatment were added. A total of 20 replicates were completed. Containers were observed for 70 min and any fly remaining on a leaf for at least 3 s was removed. Observations were made in the laboratory at 21-23 °C.

**Field Spray Trial.** Four organic insecticides were evaluated, GF-120 NF Naturalyte Fruit Fly Bait (20 fl oz/ac), PyGanic (32 fl oz/ac), AgroNeem (64 oz/ac; Agro Logistic Systems, Diamond Bar, CA) and Entrust (2 oz/ac), in a field spray trial to assess blueberry maggot control. This study was conducted in a recently abandoned blueberry field, located in Tinton Falls, NJ. Blueberry bushes were approximately 2 m in height and spaced 1.2 m within and 2.7 m between rows. Treatment plots were 30.5 m by 91.4 m, approximately 0.28 ha. Treatments were replicated three times.

Each insecticide, except GF-120, was mixed with 25 gal of water/acre and sprayed using a commercial (air blast) mist blower to both sides of bushes. GF-120 was mixed at a ratio of 1:5 with water for 120 oz of mix/acre, and applied to one side of every row using an ATV Olive Fruit Fly Sprayer (PBM Supply & Mfg, Chico, CA). This ATV sprayer had a 25 gal tank, a non-adjustable 100 psi pump, and two nozzles from airblast sprayers consisting of discs (D-3 orifice) without the core. Insecticides were applied on 7, 15, 22, and 29 Jul 2003. Adult blueberry maggot fly presence was assessed twice a week for 6 weeks using four Pherocon AM traps baited with ammonium acetate (Great Lakes IPM, Vestaburg, MI) per plot. Larval presence was determined on three dates (24 and 31 Jul, and 12 Aug) by randomly selecting 1,000 berries in center rows from each plot and boiling fruit (Pickett and Spicer 1931) or Polk (microwave). Maggots extracted from these samples were counted.

**Statistics.** Fly mortality in direct and 3-hr old exposure assays, and flies landing on leaves in the repellency assay were arcsine square-root transformed and analyzed using analyses of variance (ANOVA) (SAS Institute 1999). Means were separated using Fisher's least significant different (LSD) tests. Adult and larval numbers in field spray trial were square-root transformed ($\sqrt{x} + 0.5$) and arcsine square-root transformed, respectively prior to ANOVA and means were separated using Fisher's LSD test.

## Results

**Direct Exposure to Insecticide.** Exposure of flies to insecticides resulted in significant differences in fly mortality after 2 and 24 h ($F = 74.58$; df = 7, 56; $P < 0.0001$; and $F = 49.2$; df = 7, 56; $P < 0.0001$; respectively; Table 1). After 2 h fly mortality was significantly higher in all insecticide treatments compared to the control, with greater than 90% control in Imidan, and high and low rates of PyGanic. High and low rates of Entrust and Aza-Direct resulted in approximately 50% mortality. After 24 h fly mortality approached 100% for all treatments except rates of Aza-Direct , which were approximately 65%, and the control which was ?.

**Exposure to 3hr –old Insecticide.** Treatments resulted in significant differences in fly mortality after 24 and 48 hours of exposure ($F = 33.99$; df = 7, 56; $P < 0.0001$; and $F = 37.77$; df = 7, 56; $P < 0.0001$; respectively; Table 2). Fly mortality approached 40% for both rates of

Entrust after 24 h and was close to 90% after 48 h, both significantly higher than the control. After 24 h fly mortality was near 100% in the Imidan treatment and after 48 h, Imidan was not significantly different from the high rate of Entrust. After 24 and 48 h neither rate of Aza-Direct nor the high rate of PyGanic was significantly different from the control, which was approximately 4 and 21%, respectively. The low rate of PyGanic was significantly different from the control after 24, but not 48 h.

**Repellency.** Application of Aza-Direct to leaves did not result in a significant difference in the number of flies landing on leaves ($F = 1.75$; df = 1, 38; $P = 0.194$). Numerically more flies were removed from leaves in the control than Aza-Direct (31 vs. 21 percent, respectively).

**Field Spray Trial.** Treatments had no statistically significant affect on the number of adults captured in traps (table 3) due to high variability within the check. Nonetheless, there was a general trend towards reducing fly numbers from any of the treatments. The positive check, Provado, had the least number of adults numerically (~15 flies per plot), followed by GF-120 and Entrust (~100), AgroNeem and PyGanic (~150), and the control (225) (Fig. 1). Treatments had a significant affect on the percent of berries with maggots on each of the three sampling dates (Table 4). Larval infestation in the untreated check plot was approximately 12% and was significantly higher than any of the insecticide treatments (Table 4). The numbers of larvae in the GF-120, Entrust, and PyGanic plots were not significantly different from Provado, whereas the Agroneem plot was always significantly higher than Provado (Table 4).

## Discussion

All organic insecticides had some ability to control blueberry maggot, resulting in the potential for an insecticide rotation schedule that minimizes resistance development. In both laboratory assays fly mortality was initially highest in the organophosphate treatment, but after a period of 1-2 d fly mortality was comparable between the organophosphate and several organic treatments. In this study, residual activity was tested at a maximum of 3 h after application. At a larger interval, differences in residual activity between organic and organophosphate insecticides are expected to manifest.

Aza-Direct and PyGanic resulted in fly mortality only near application time, whereas spinosad-based compounds had a longer period of residual activity. The residual activity of these organic insecticides is related to the PHI (pre-harvest interval). The pre-harvest interval is 3 d for Entrust and 0 d for Aza-Direct, PyGanic, and GF-120 NF Naturalyte Fruit Fly Bait. Although Entrust applications resulted in the highest mortality of any organic insecticide in laboratory assays, the PHI restriction could present a challenge to U-pick operations that are open everyday. In our Field Spray Trial insecticides were all applied on either Monday or Tuesday because the grower was open only on the weekend. Compounds with a 0 PHI allow growers the option to spray the night before harvesting fruit.

Although bait spray use requires obtaining specialized application equipment, promising results were obtained in the field spray trial. It was not expected that spinosad spray and spinosad bait spray would be comparable, because 400x less active ingredient was used in the latter (Entrust: ai/ac = 80% of 2 oz = 1.6 oz; compared to GF-120: ai/ac = 0.02% of 20 oz = 0.004 oz). In a study with *R. pomonella* on apples (*Malus* sp.), GF-120 blank (without spinosad) was found to increase maggot infestation in comparison to both a control and GF-120 (with spinosad), suggesting that sufficient numbers of flies are capable of locating bait (K. Pelz, R. Isaacs, J. Wise, L. Gut, Michigan State University, East Lansing, MI, unpubl. data). Further study is necessary to determine the use of bait sprays as potential border sprays (Prokopy et al. 2003).

There was at least one maggot found in each treatment on each of the three occasions that berries were randomly collected and boiled., even in the non-organic control of imidacloprid. Had our trials occurred in a commercial setting, instead of a previously abandoned field, the maggot infestation rate would have been lower due to selective harvest. The pest pressure in our trials was also increased because of the close proximity of a large area of unsprayed blueberries (~10 acres), which provided a continual source of blueberry maggot migration into the experimental plots.

An organic integrated pest management program for blueberry maggot is likely to involve multiple sprays to achieve sufficient control. To avoid resistance we recommend switching to a product with a different active ingredient after each spray. In the simplest rotation, sprays would alternate between two compounds (i.e., spinosad, neem extract, spinosad…). Three different active ingredients were evaluated in this study (neem extract, pyrethrum, and spinosad). (The active ingredient in Entrust and GF-120 is the same, so use of both would not be considered a rotation.) Specific decisions on what insecticide to spray could be impacted by the following factors: resident or local maggot population, maggot pressure, presence of other pests, days to harvest, and previous insecticide use.

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Table 1. Mortality from Direct Exposure to Organic Insecticides

| Treatment | AI (oz/ac) | Mortality (%) 2 h | Mortality (%) 24 h |
|---|---|---|---|
| Aza-Direct | 16 | 52.5 ± 3.6c | 62.5 ± 4.9b |
| | 32 | 43.7 ± 7.3c | 68.7 ± 8.9b |
| Entrust | 1 | 60.0 ± 4.6c | 100.0 ± 0.0a |
| | 2 | 46.2 ± 8.2c | 100.0 ± 0.0a |
| PyGanic | 16 | 100.0 ± 0.0b | 100.0 ± 0.0a |
| | 32 | 93.7 ± 2.6a | 96.2 ± 2.6a |
| Imidan[1] | 20.8 | 95.0 ± 3.2ab | 100.0 ± 0.0a |
| Water (control) | --- | 0.0 ± 0.0d | 21.8 ± 6.6c |

Means in the same column having the same letter are not significantly different (Fisher's LSD, *P* = 0.05)

[1] organophosphate insecticide was included as a positive check

Table 2. Mortality to 3 h-old Organic Insecticides

| Treatment | AI (oz/ac) | Mortality (%) | |
|---|---|---|---|
| | | 24 h | 48 h |
| Aza-Direct | 16 | 7.5 ± 3.1cd | 32.5 ± 5.9c |
| | 32 | 8.7 ± 3.9cd | 23.7 ± 4.6c |
| Entrust | 1 | 38.7 ± 7.6b | 93.7 ± 3.2ab |
| | 2 | 36.2 ± 8.0b | 85.0 ± 5.9b |
| PyGanic | 16 | 10.0 ± 2.6c | 25.0 ± 5.6c |
| | 32 | 13.7 ± 3.7cd | 37.5 ± 7.0c |
| Imidan[1] | 20.8 | 96.2 ± 1.8a | 98.7 ± 1.2a |
| Water (control) | --- | 3.7 ± 2.6d | 21.2 ± 5.8c |

Means in the same column having the same letter are not significantly different (Fisher's LSD, $P = 0.05$)

[1] organophosphate insecticide was included as a positive check

Table 3. Adult captures in traps

| | Number of flies captured in 4 Pherocon traps (mean ± SE)[1] | | | | | |
|---|---|---|---|---|---|---|
| Treatment | 27 Jun – 6 Jul | 7-15 Jul | 16-21 Jul | 22-28 Jul | 29 Jul – 4 Aug | 5-11 Aug |
| Entrust | 47.0 ± 7.4 | 35.7 ± 6.7 | 15.0 ± 4.9 | 16.7 ± 2.7 | 7.7 ± 2.3 | 21.3 ± 7.1 |
| GF-120 | 68.7 ± 26.6 | 25.0 ± 10.6 | 8.0 ± 2.3 | 16 ± 2.7 | 11.7 ± 5.2 | 30.0 ± 15.5 |
| Agroneem | 84.0 ± 15.7 | 44.0 ± 11.0 | 20.0 ± 11.2 | 15.7 ± 9.7 | 36.3 ± 17.5 | 23.7 ± 5.2 |
| PyGanic | 90.7 ± 45.4 | 40.0 ± 22.8 | 48.0 ± 40.7 | 28.0 ± 20.5 | 14.3 ± 8.8 | 14.7 ± 7.3 |
| Provado[2] | 48.7 ± 16.1 | 5.7 ± 3.5 | 1.3 ± 0.3 | 1.7 ± 1.2 | 1.0 ± 0.6 | 4.7 ± 0.3 |
| Untreated | 40.0 ± 17.0 | 76 ± 41.8 | 50.7 ± 21.7 | 54.0 ± 30.0 | 23.7 ± 10.8 | 20.7 ± 10.1 |
| *F* | 0.58 | 0.49 | 1.22 | 2.06 | 2.29 | 2.54 |
| *P* | 0.717 | 0.781 | 0.36 | 0.142 | 0.111 | 0.086 |

df = 4, 10

[1] insecticides applied on 7, 15, 22, and 29 Jul

[2] organophosphate insecticide was included as a positive check

Table 4. Larval presence in blueberry fruit

| | | Percent of boiled blueberries with maggots[1] | | |
|---|---|---|---|---|
| Treatment | Rate (oz/ac) | 24-Jul | 31-Jul | 12-Aug |
| Entrust | 2 | 0.57 ± 0.20bc | 1.00 ± 0.46bc | 0.67 ± 0.34bc |
| GF-120 | 20 | 0.47 ± 0.17bc | 0.53 ± 0.03c | 0.53 ± 0.22bc |
| Agroneem | 64 | 2.27 ± 1.48b | 2.30 ± 1.08b | 1.90 ± 1.25b |
| PyGanic | 32 | 1.03 ± 0.34bc | 0.70 ± 0.23c | 0.50 ± 0.06bc |
| Provado[2] | 6 | 0.3 ± 0.06c | 0.23 ± 0.08c | 0.03 ± 0.03c |
| Untreated | --- | 13.70 ± 3.04a | 14.10 ± 4.50a | 9.7 ± 2.25a |
| *F* | | 19.49 | 25.29 | 13.55 |
| *P* | | < 0.0001 | < 0.0001 | < 0.0001 |

Means in the same column having the same letter are not significantly different (Fisher's LSD, *P* = 0.05)

[1] df = 5, 66

[2] organophosphate insecticide was included as a positive check

Figure Legends

Fig. 1. Number of adult blueberry maggot flies (mean ± SE) captured for the season after the first insecticide spray. (NS, $P > 0.05$, ANOVA)

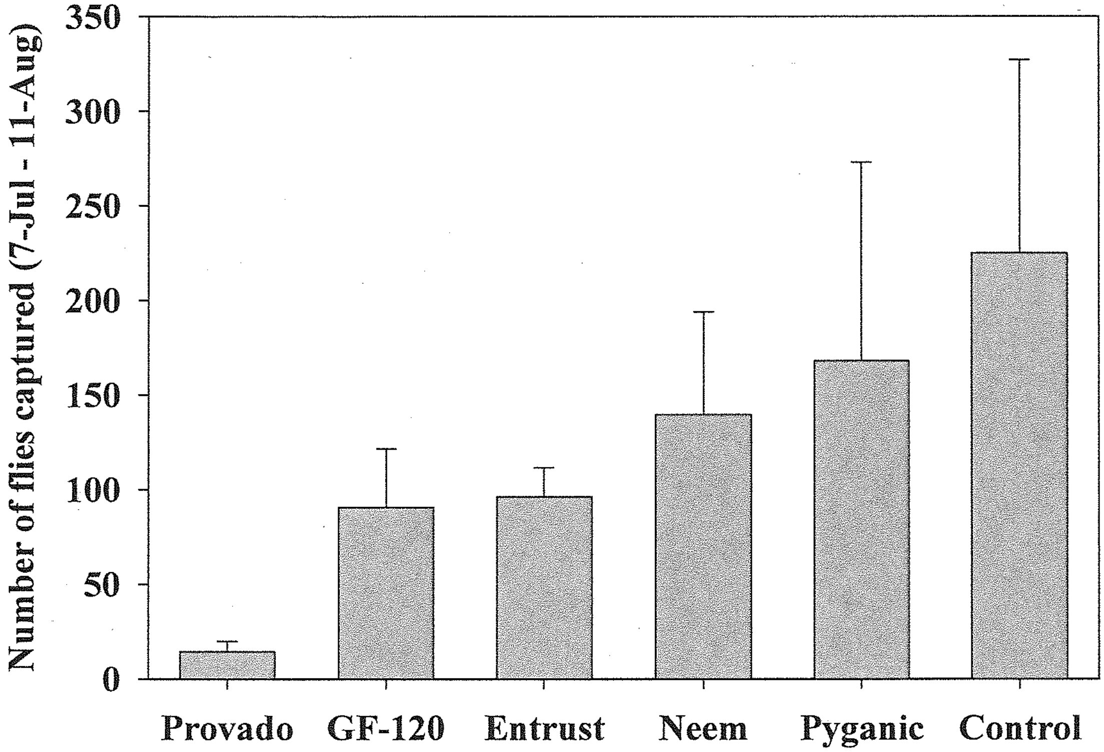
Number of flies captured (7-Jul - 11-Aug)
0
50
100
150
200
250
300
350
Provado
GF-120
Entrust
Neem
Pyganic
Control

Fig. 1.