Control of Mediterranean Fruit Fly *Ceratitis capitata* (Diptera: Tephritidae) with the Parasitoid *Muscidifurax raptor* (Hymenoptera: Pteromalidae) in Vineyards

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Abstract. The control of *Ceratitis capitata* (Diptera: Tephritidae) has been mostly done with chemical insecticides and some selected natural enemies. However, these control methods are not popular because of the adverse effects of chemical controls and the unreliability of some natural enemies (*Spalangia* sp. and *Pachycrepoideus* sp.: Hymenoptera: Pteromalidae). The generalist parasitoid, *Muscidifurax raptor* (Hymenoptera: Pteromalidae), has been used successfully for biological control of the house fly [*Musca domestica* (Diptera: Muscidae)] pupae in poultry houses. Our study investigated the use of this parasitoid to control *C. capitata* in a vineyard. Parasitoids were released at rate of 5, 10, and 20 per m² in a vineyard and in laboratory cages to parasitize pupae of *C. capitata* and *M. domestica*, respectively, for 2 days. The number of killed pupae of both host pests increased with the number of released parasitoids in the field. The highest rate of 20 released *M. raptor* resulted in 23.52% (± 0.30 SE) killed pupae, respectively, for house fly and fruit fly. *M. raptor* parasitized indiscriminately host species of pupae and the daily oviposition rate was 4.9 (± 0.07 SE) eggs per female. The parasitoid laid the same number of eggs as when released in poultry houses for the control of *M. domestica*. We conclude that *M. raptor* constitutes a promising biocontrol agent for the control of *C. capitata* in vineyards.

The Mediterranean fruit fly (Medfly), *Ceratitis capitata* (Diptera: Tephritidae), that infests crops probably originated from the eastern sub-Saharan African region (Camargo et al., 1996; Hancock, 1989). The adult females make oviposition punctures into the fruit and various microorganisms use the same openings to attack fruits and cause decay while the maggots cause additional feeding damage inside the host fruit (Etienne, 1966; Hancock, 1989; Morin, 1967; White and Elson-Harris, 1992). The larvae, when ready to pupate, emerge from the fruits and drop to the ground (Black and Pemberton, 1918). Worldwide, most fruit flies (Diptera: Tephritidae) are considered pests of great commercial and quarantine importance (Montoya and Cancino, 2004) to fruit and vegetable growers, commercial and market-

ing exporters, government regulatory agencies, and the scientific community (Stibick, 2004). Plant protection agencies strictly regulate the movement of potentially infested products because consumers throughout the world demand high-quality, blemish-free produce. That becomes very costly to local state and national governments (Penä et al., 2002; Stibick, 2004). In the United States, the cost per year to maintain the trapping systems for fruit flies, laboratories, and identification has exceeded U.S. \$27 million and has increased every year (Schreibner, 1983). The cost of eradication of the oriental fruit fly (*Bactrocera dorsalis*) from southwestern Japan was close to U.S. \$32 million in the 1980s (White and Elson-Harris, 1992). In South Africa, *C. capitata* (Wiedemann) infests fruit trees and vegetables and is the only dipteran pest that occurs in vineyards (ARC, 2001; Kapongo and Giliomee's personal field survey 1999–2000, unpublished). It causes heavy economic losses, which are compounded by costs of control, and presents a major handicap for the export of fruit, trees, and vegetables to countries that allow only imports from countries declared fruit fly-free (NDA, 1998; Penä et al., 2002).

To try to minimize these losses and high costs, South African growers have unsuccessfully used various measures to control this pest at the larval and adult stages. Those measures were sanitation control to destroy larvae and adults in infected material (Penä et al., 2002), ground treatment with insecticides under host trees in affected areas, aerial bait made from the insecticides malathion and trichlorfon in high infestations (NDA, 1998), sterile insect techniques (Boller, 1987; Knipling, 1955), and control of larvae by releasing parasitic braconid wasps (Hymenoptera) as natural enemies [*Opius longicaudatus* var. *malaiaensis* (Fullaway), *O. vandenboschi* (Fullaway), *O. oophilus* (Fullaway), *O. humilis*, *Diachasma tryoni*, *Bio-steres oophilus*, *B. vandenboschi*, and *B. longicaudatus*] (Beardsley, 1961; Wharton and Marsh, 1978). An attempt was made in Hawaii to establish permanent biological control with the introduction of pteromalid parasitoids (*Spalangia* sp. and *Pachycrepoideus* sp.: Hymenoptera) to parasitize pupae of *C. capitata*, but the technique was concluded to have no promising impact (Penä et al., 2002).

In the early 1990s, laboratory trials by Wong et al. (1991) in Hawaii demonstrated the possibility of controlling *C. capitata* through its larval stage with some braconid parasitoids such as *Diachasmimorpha longicaudata* (Ashmead) and *Fopius arisanus* (Sonan). Later, Montoya and Cancino (2004) pursued Wong et al.'s work with the release of another larval parasitoid, *D. tryoni* (Hymenoptera: Braconidae), in peach orchards to control larvae of *C. capitata*.

The parasitoid, *Muscidifurax raptor* (Hymenoptera: Pteromalidae), was found to be a potential candidate and an efficient agent for the control of the pupal stage of *Musca domestica* (Diptera: Muscidae) (Crespo et al., 2002; Geden et al., 1992; Henn et al., 1999; Miller et al., 1993; Petersen and Cawthra, 1995), which occurs in the soil, in and outside dairy farms, poultry houses, as well as in suburban and urban localities (Achiano and Giolomee, 2005; Murphy, 1982).

As a generalist parasitoid, we thought it could be used to parasitize the pupae of *C. capitata* in a vineyard. However, to be considered a biological control agent in an environment in which it had never been tried, *M. raptor* must comply with rules of safety for nontarget organisms (Goettel and Jaronski, 1997; Jetter, 2005; Sheppard et al., 2003; Vestergaard et al., 2003).

The aim of our study was to determine the potential of using *M. raptor* to control *C. capitata* pupae and its potential impact on non-target organisms as estimated by its potential to disperse.

Materials and Methods

Insects

Larvae and pupae of *C. capitata* and *M. domestica* (both species reared on an artificial diet consisting of wheat bran, milk, and water) were provided by the Institute of Fruit

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and Technology (Infruitec), Agriculture Research Council in Stellenbosch, South Africa. The viability of the 1-day-old fly pupae (*M. domestica* and *C. capitata*) was checked by wind removing. This was achieved by releasing a batch of pupae into the wind of a fan. All light and empty pupae were blown from the immediate area of the fan and the heaviest ones gathered around the stand of the fan. We collected only pupae located in the vicinity of the fan. The remaining batches around the fan were considered healthy after being tested for emergence rate at 95%.

Two-day-old *M. raptor* (virgin) with a 4:6 sex ratio (male:female) were used in laboratory and field tests as the parasitoid of *M. domestica* and *C. capitata*. The parasitoids came from a colony maintained on pupae of *M. domestica* as host in the Department of Entomology and Nematology, University of Stellenbosch, South Africa. This insect occurs naturally in South African animal production and has a lifespan of ≈ 21 d and lays ≈ 100 to 115 eggs (Kapongo and Giliomee, 2000; Lysyk, 2000; Watson et al., 1994).

Plant

A vineyard of 24 ha, located 12 km southeast of the University of Stellenbosch (Western Cape, South Africa), was selected and trials were made on plots of 1.20 ha each on Grabbo grape variety (white grape: *Vitis vinifera*). Blocks were 200 m distant from each other.

Experimental design and procedures

Three separate experiments were conducted from May 1999 to Mar. 2001 at Stellenbosch, South Africa, using a complete randomized block design with four blocks of four replications over time. Three different densities of parasitoids were tested for their capacity to parasitize pupae of *M. domestica* and *C. capitata* in three different experiments. Those densities corresponded to three treatments in which five, 10, or 20 parasitoids were released, respectively, and a control (no parasitoids).

The first and second experiments were conducted concurrently from May 1999 to Dec. 1999 in the laboratory (12-h photoperiod) in a homemade Perspex cage. Each experiment comprised four Perspex cages $\times$ 4 replications/treatment $\times$ 4 treatments. The third experiment was carried out in the field to assess the capacity of *M. raptor* as an agent for the control of *C. capitata*. The field experiment was conducted in two seasons (Feb. to Mar. in 2000 and 2001) after the parasitoids demonstrated their ability to parasitize both species of host pupae. A set of four quadrats of 1 m² each straight aligned in the vineyard was selected as the experimental unit. Each season had 4 blocks $\times$ 4 replicates/treatment $\times$ 4 treatments.

Laboratory experiments.

Direct exposure of host species to the parasitoid. The first experiment was performed to assess the parasitism preference of female *M. raptor* for pupae of *C. capitata*

or *M. domestica* when both host species were directly either separately or together exposed to parasitoids in the laboratory. The experiment was subdivided in two subexperiments. In the first subexperiment, 250 1-day-old pupae of each fly species were placed in separate cages and exposed to parasitoids. In the second subexperiment, 250 1-day-old pupae from each host species were thoroughly mixed using a small brush and exposed simultaneously to parasitoids. In both subexperiments, pupae were placed in a plastic tray (12 $\times$ 6 $\times$ 2 cm), which was then laid in a Perspex cage (45 $\times$ 50 $\times$ 32 cm with a removable rectangular entrance of 8 $\times$ 15 cm in front and three holes of 8 cm in diameter covered with net cloth for aeration, one on the back and each side). Five, 10, and 20 adult parasitoids were released per cage as treatments and aspirated out after 48 h. Pupae were separated manually and kept in aerated jars placed in a growth chamber (24 $\pm$ 2 °C and 65 $\pm$ 5% relative humidity [RH]). The emergences of adult flies and parasitoids were completed in 1 and 2 weeks, respectively. Mortality (parasitism) percentages of exposed pupae to parasitoids were calculated as follows: number of pupae of the specific host species from which young parasitoids have emerged divided by the total number of that specific host species and multiplied by 100. This way of counting the effect of parasitoids on host pupae did not consider the number of pupae, which, although parasitized, could not produce young parasitoids.

Therefore, we applied the Abbott formula (Abbott, 1925) so that all pupae killed (pupae that produced young parasitoids + pupae from parasitoid-induced mortality [PIM]—natural death) by parasitoids were counted. PIM was the number of pupae that were killed by the parasitoid feeding mechanism and those from which young parasitoids did not emerge because of premature death.

Laboratory-simulated field conditions or semifield experiment. The second experiment studied the ability of *M. raptor* to kill pupae in the laboratory where field conditions were simulated. Five hundred third instar larvae of *M. domestica* and *C. capitata* (250 of each species) were left crawling freely on orchard soil (14-cm depth) placed on the bottom of the Perspex cage. One day later, adult *M. raptor* (5, 10, and 20 per m²) were released in the cages as different treatments and aspirated out after 48 h. Pupae were separated from the soil by sieving (sieve of 1-mm diameter) and those of each species were separated and kept in aerated jars stored in a growth chamber (24 $\pm$ 2 °C and RH 65 $\pm$ 5%) for emergence. That occurred in 1 to 2 weeks for *M. domestica* and *C. capitata*, respectively. The percentage of killed pupae of each fly species was calculated as described in Expt. 1.

Field or vineyard experiment. The third experiment was intended to determine the ability of *M. raptor* to kill pupae of *C. capitata* or *M. domestica* in a vineyard and to evaluate the risk of the parasitoids dispersing by measuring their dispersal index.

The ability of *M. raptor* to kill the pupae of *C. capitata* and *M. domestica* was determined by making four sets of four quadrats of 1 m² each that were aligned 5 m apart in a straight line in the vineyard. Each set of four quadrats was done in middle of each block of 1.20 ha. Five hundred third instar larvae (250 *M. domestica* and 250 *C. capitata*) were left crawling freely for 1 d on each of those four quadrats of the set. The next day, parasitoids were released only on the first quadrat of each set as follows: one set of quadrats had a single release of five parasitoids, the second set a release of 10 parasitoids, the third set a release of 20, and the fourth set was used as the control (no parasitoid). Forty-eight hours later, 0.14 m³ (1 m² $\times$ 0.14-m depth) of soil was excavated from each quadrat and sieved to collect all pupae of *M. domestica* and *C. capitata*. The pupae were processed as described in Expts. 1 and 2.

The daily oviposition rate of a female in a batch of 20 released parasitoids was calculated as follows: the overall number of killed pupae (*M. domestica* + *C. capitata*) divided by 12 females (considering the sex ratio of 4:6 [male:female] in 20 released parasitoids) and by 2 (duration of the experiment, which was 2 d).

The risk assessment of the parasitoid was estimated by calculating the dispersal index of the released parasitoids. This index was established for measuring the capacity of *M. raptor* to kill (parasitize) pupae of host species (*C. capitata* or *M. domestica*) located at certain distances (5, 10, and 15 m) from the initial point of the release of parasitoids. It was calculated as the percentage of killed pupae by *M. raptor* in each of three quadrats (at 5, 10, or 15 m) divided by the percentage of killed pupae by the same parasitoids in the first quadrat of the same set. Its values were between 0 and 1, in which zero corresponded to the absence of the parasitoid and value 1 indicated the maximal killing capacity of the released parasitoids.

Statistical analysis. Two- and three-way analyses of variance (SAS Institute, 2001) were used to compute the effects of parasitoid on host species (pupae of *M. domestica* and *C. capitata*) and the effects of location of different experiments on the killing capacity of released parasitoid densities. The percentage of killed pupae was used as the dependent factor with host species (*C. capitata*, *M. domestica*), parasitoid densities (5, 10, and 20), and location of each experiment used as independent factors. Killed pupae of both host species from the same experiment were pooled together to serve in the computation of interaction between different experimental locations.

Percentage of killed pupae was arcsine square root transformed before any analysis to ensure variance homogeneity and to normalize data. The control treatment was only used in the Abbott formula and omitted in all analyses. The least significant difference test was used to separate means. The significance level of the statistical hypothesis test was set at $P = 0.05$.

The regression equation was calculated on dispersal index of the parasitoids in the vineyard. A separate equation was calculated for each density of released parasitoids and we pooled together all three treatments to establish a general regression equation.

Results

Effects of parasitoids on host species

Laboratory experiments.

Direct exposure of host species to the parasitoid (250 pupae of each host in a separate experimental unit): First subexperiment. When exposed to each of host species separately, the parasitoid *M. raptor* equally killed pupae from each host species ($F_{1, 90} = 0.02$, $P = 0.89$) and no interaction occurred between host species and density of released parasitoids ($F_{2, 90} = 2.89$, $P = 0.06$). However, the number of killed host pupae increased significantly with the augmentation in number of released parasitoids ($F_{2, 90} = 71.07$, $P < 0.0001$). The highest number of killed pupae of each host species occurred when 10 and 20 parasitoids were released (Table 1).

Direct exposure of host species to the parasitoid (500 pupae: 250 from each host, mixed in a single experimental unit): Second subexperiment. No significant difference was found between two host species when they were simultaneously exposed to parasitoids ($F_{2, 90} = 0.76$, $P = 0.37$). The number of parasitoids released significantly influenced the number of killed host pupae in both species ($F_{2, 90} = 456.37$, $P < 0.0001$) with the highest number of killed pupae corresponding to the highest parasitoid density (Table 1). There was no interaction between treatments and host species ($F_{2, 90} = 0.37$, $P = 0.69$).

Laboratory-simulated field conditions or semifield experiment. When the release was done in the laboratory within a cage with

simulation of field conditions, the parasitoid *M. raptor* showed no preference for a particular host pupae species and each pupa species had the same chance to be located and killed by the parasitoid ($F_{1, 90} = 2.33$, $P = 0.13$). However, like in the previous experiments, the density of released parasitoids influenced the number of killed pupae ($F_{2, 90} = 284.79$, $P < 0.0001$) with a highest number when 20 parasitoids were released compared with the release of five and 10 (Table 1). Moreover, no significant interaction occurred between number of released parasitoids (density) and host species ($F_{2, 90} = 0.84$, $P = 0.44$) (Table 1).

Field or vineyard experiment. In field conditions, *M. raptor* did not show any preference for a particular host species and equally killed both types of host pupae ($F_{1, 90} = 1.71$, $P = 0.19$). A significant difference was found among three densities of released parasitoids to kill host pupae ($F_{2, 90} = 279.48$, $P < 0.0001$) with the highest number of killed pupae from the release of 20 parasitoids compared with treatments in which five and 10 parasitoids were, respectively, released (Table 1). The interaction between treatments and host species was not significantly different ($F_{2, 90} = 0.01$, $P = 0.99$) (Table 1).

Effects of different locations on the killing capacity of released parasitoids

Interaction between first and second subexperiments. There was an effect of location in the killing capacity of parasitoid between two subexperiments conducted in the laboratory ($F_{1, 186} = 9.20$, $P < 0.0028$). The average number of killed pupae per parasitoids was high in Subexpt. 1 (250 pupae of each host in a separate experimental unit) than in Subexpt. 2 (500 pupae: 250 from each host mixed in a single experimental unit) (25.67 versus 23.49% killed pupae).

Interaction between Subexpt. 2 and semifield. Location of the experiment had an impact in the killing capacity of parasitoid

($F_{1, 186} = 188.13$, $P < 0.0001$). The mean of killed pupae in Subexpt. 2 was higher than in semifield experiment (23.49 versus 17.00% killed pupae).

Interaction between semifield and field conditions. From semifield to field, the parasitoids lost the killing capacity ($F_{1, 186} = 53.37$, $P < 0.0001$). Few pupae were killed in the field than they were in the semifield condition (14.29 versus 17.00% killed pupae).

Dispersal index of the parasitoid in the vineyard

In general, the released parasitoid in the vineyard killed few pupae the more they moved away from their point of release ($F_{1, 46} = 87.98$, $P < 0.0001$; $R^2 = 0.657$) (Fig. 1A). The same results were also observed when each treatment was separately computed: T1 ($F_{1, 14} = 55.32$, $P < 0.0001$, $R^2 = 0.798$) (Fig. 1B), T2 ($F_{1, 14} = 43.09$, $P < 0.001$, $R^2 = 0.755$) (Fig. 1C), and T3 ($F_{1, 14} = 11.39$, $P = 0.0045$, $R^2 = 0.449$) (Fig. 1D). When comparing different values of the regression equation, it appeared that they decreased with the augmentation of the density of released parasitoids. This means the parasitoids dispersed more when their density was increased.

Discussion

Pteromalid wasp, *M. raptor*, effectively killed the pupae of *C. capitata* in the vineyard. The percentage of killed pupae increased with the number of released wasps, which indiscriminately parasitized the host species, *C. capitata* and *M. domestica*.

Current control measures of *C. capitata* are based on larval and adult stages; the larval stage is, to a certain level, manageable with some natural enemies (Beardsley, 1961; Montoya and Cancino, 2004; Wharton and Marsh, 1978; Wong et al., 1991, 1992), whereas good sanitary control and insecticidal baits can support existing techniques to

Table 1. Mean ($\pm$ SE) percentages of pupae of *Musca domestica* and *Ceratitis capitata* killed pupae by parasitoids (*Muscidifurax raptor*).^a

Experiments	Host pupae	Treatments			Overall mean ($\pm$ SE) of killed pupae
		5 released parasitoids (treatment 1)	10 released parasitoids (treatment 2)	20 released parasitoids (treatment 3)	
1	<i>M. domestica</i>	15.50 $\pm$ 0.86 a	31.20 $\pm$ 1.99 b	29.48 $\pm$ 1.63 c	25.67 $\pm$ 3.61
	<i>C. capitata</i>	13.65 $\pm$ 1.40 a	29.38 $\pm$ 1.85 b	34.82 $\pm$ 2.26 c	
	Mean ($\pm$ SE) killed pupae	14.58 $\pm$ 0.93 a	30.19 $\pm$ 0.91 b	32.15 $\pm$ 2.63 c	
2	<i>M. domestica</i>	11.51 $\pm$ 0.60 d	23.69 $\pm$ 0.93 e	36.07 $\pm$ 1.25 f	23.49 $\pm$ 4.59
	<i>C. capitata</i>	10.64 $\pm$ 0.35 d	22.74 $\pm$ 0.95 e	36.29 $\pm$ 0.90 f	
	Mean ($\pm$ SE) killed pupae	11.08 $\pm$ 0.44 d	23.22 $\pm$ 0.48 e	36.18 $\pm$ 0.11 f	
3	<i>M. domestica</i>	9.80 $\pm$ 0.54 g	15.63 $\pm$ 0.54 h	27.11 $\pm$ 0.72 i	17.08 $\pm$ 3.09
	<i>C. capitata</i>	9.09 $\pm$ 0.56 g	15.74 $\pm$ 0.77 h	25.10 $\pm$ 0.99 i	
	Mean ($\pm$ SE) killed pupae	9.45 $\pm$ 0.35 g	15.69 $\pm$ 0.06 h	26.11 $\pm$ 1.01 i	
4	<i>M. domestica</i>	7.19 $\pm$ 0.59 j	12.82 $\pm$ 0.45 k	24.00 $\pm$ 0.96 l	14.29 $\pm$ 3.10
	<i>C. capitata</i>	6.51 $\pm$ 0.43 j	12.20 $\pm$ 0.63 k	23.04 $\pm$ 1.16 l	
	Mean ($\pm$ SE) killed pupae	6.85 $\pm$ 0.34 j	12.51 $\pm$ 0.31 k	23.52 $\pm$ 0.30 l	
	Mean ($\pm$ SE) of eggs laid/ <i>M. raptor</i> /day		4.90 $\pm$ 0.07		

^aMeans were obtained after Abbott formula has been applied to mortality percentages of host species that were exposed to the different densities (5, 10, and 20) of parasitoids for a period of 2 d. Mean ($\pm$ SE) percentages of overall host pupae of *M. domestica* + *C. capitata* killed by parasitoids per experiment, and mean ($\pm$ SE) percentage of laid eggs per a parasitoid female in the Expt. 4.

Means followed by different letters in any given row are significantly different at $P < 0.05$ using the *F* test. Different experiments were: 1 = in laboratory with direct exposure of host species to the parasitoids (250 pupae of each host in a separate cage); 2 = in laboratory with direct exposure of host species to the parasitoids (500 pupae: 250 from each host, mixed in a single cage); 3 = in laboratory where field conditions "vineyard" were simulated (500 pupae: 250 from each host, mixed in a single cage); and 4: in vineyard where 500 third instar larvae (250 from each host species) were left crawling in each of four sets of four quadrats of 1 m² each that were aligned in a straight line and the release of parasitoid densities as treatment was only done on the first quadrat of the set.

Fig. 1. Dispersal of the parasitoid *Muscidifurax raptor* in the vineyard (A: When three treatments are pooled together; B: at a release density of five parasitoids; C: at a release density of 10 parasitoids; and D: at a release density of 20 parasitoids). Data lozenges are mean values of dispersal index of *M. raptor* each with a $^{\circ}$.

reduce the population of the adult and larval stages of the pest (Boller, 1987; Knippling, 1955; NDA, 1998; Penă et al., 2002).

Adding to these previous control methods, control of *C. capitata* at its pupal stage will have an additional effect on the overall control and reduce the pest status. In our investigations, we found that the generalist parasitoid (*M. raptor*) could fulfill the gap in the control of the fruit fly during its pupal stage. This will confirm the preliminary study of Podoler and Mendel (1979) who found the same generalist parasitizing the host pupae of *C. capitata* in the laboratory.

Muscidifurax raptor indiscriminately attacked pupae of both fly species with a high percentage of killed pupae when hosts were directly exposed to the parasitoids. The efficacy of the parasitoid was negatively affected by the position of the host pupae in the substrate. In the semifield and the vineyard, host pupae were buried in soil and parasitoids spent more time searching and localizing them; as a consequence, fewer pupae were found, leading to a lower percentage of killed pupae ($23.49 \pm 4.59\%$ SE killed pupae when directly exposed to the parasitoids compared with 17.08 ± 3.09 and $14.29 \pm 3.10\%$ SE, respectively, in the semifield and in the vineyard). Similar results were found with the same parasitoid when it killed only pupae of *M. domestica* located on top of the soil and 1 cm or 3 cm deep in a study in which pupae were buried at 1-, 3-, 5-, 10-, and 15-cm depth in poultry manure (Floate and Spooner, 2002; Rueda and Axtell, 1985).

The percentage of killed pupae increased with the increase in the number of released parasitoids when each of the experiments was

separately considered. Twenty released parasitoids caused more death among pupae than five and 10. This confirms the study of Mann et al. (1990) who found that the number of *M. domestica* pupae killed by *M. raptor* increased when a constant number of the host was exposed to an increasing density of parasitoids. However, the same number of parasitoid released in different locations performed differently. For example, at a density of 20 parasitoids, *M. raptor* killed more host pupae in the semifield than in the vineyard (26.11 ± 1.01 versus $23.52 \pm 0.30\%$ SE). The cause of this difference could be attributed to the fact that in the field, the parasitoids could easily be caught by wind and be dispersed away from the point of the release. This did not happen in the semifield condition where the movement of parasitoids was restricted in a confined cage.

The release of parasitoids is environmentally friendly in the vineyard, because the parasitoids can fly only a few meters away from the initial area of release in a period of 2 d. However, *M. raptor* may fly away and parasitize host pupae far from the point of release if they were left for a long period of time. This was observed by Floate et al. (2000) who found that the same parasitoid was able to fly for ≈ 100 m after having been mass-released in cattle confinements. We agree with their results because we found that when the number of released parasitoid increased up to 20 in our study (Fig. 4), they flew for more than 15 m from the point of release and killed pupae (the value regression equation of 20 released parasitoid was smaller than that of 10 and five: $Y_{20 \text{ parasitoids}} < Y_{10} < Y_5$). If we kept the pupae for more than 2 d in the field, probably more pupae

located far away from the point of release could be killed than what we got in this short period of 2-d exposure. However, the *M. raptor* remains an environmentally friendly species even when it disperses away from its point of release. Many factors will contribute to parasitoid death in the vineyard after the grape season. First, it will be difficult for escaping parasitoid *M. raptor* to survive for long in the vineyard after the season. Cold temperatures in the winter may kill them because of lack of warm places that could serve as refuges for adults and pupae. In contrast to the vineyard, barns in poultry houses or dairies will serve as warm refuges for *M. raptor* in winter (Geden et al., 1992), which improves their survival in these conditions. Additionally, a rim of 20-m wide made by growers around the vineyard will prevent the parasitoids to easily reach the wild vegetation (NDA, 1998). These factors will prevent the parasitoids from remaining in the area after release and they will not constitute a threat to the indigenous ecosystem, as observed in Hawaii by Henneman and Memmott (2001) where wasps that were released in the 1990s for the control of lepidopterous pests remained present in the area and caused more damage on the non-target organisms.

The release of the parasitoid, *M. raptor*, in the vineyard constitutes an additional potential tool for the control of *C. capitata*. This parasitoid is successfully controlling *M. domestica* in different animal-confined conditions (Crespo et al., 2002; Geden et al., 1992; Henn et al., 1999; Miller et al., 1993; Petersen and Cawthra, 1995) and a female will lay ≈ 100 to 115 eggs during her lifespan of 21 d (Kapongo and Giliomee, 2002;

Lysyk, 2000; Watson et al., 1994). In the vineyard, a female *M. raptor* from a released density of 20 individuals will lay on average of 4.9 eggs per day. If she could live for 21 d, probably 102.9 eggs will be laid in the host species. This density of parasitoids killed an average $23.52 \pm 0.30\%$ SE of pupae in the vineyard ($24.00 \pm 0.96\%$ and $23.04 \pm 1.16\%$ SE, respectively, for *M. domestica* and *C. capitata*). According to Navon and Ascher (2000), any control measure that kills more than 20% of the pest is a good control technique. Therefore, the parasitoid, *M. raptor*, might be capable of controlling the *C. capitata* in the vineyard as does control *M. domestica* in urban areas and confined animal conditions. To achieve good control of *C. capitata* with the release of *M. raptor* in vineyards, we will advise the same rate of *M. raptor* and their frequency of release as used in poultry houses for the control of *M. domestica*.

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