Entomologica, Bari, 33, (1999): 251-265

MENDEL, Z.[1]; GROSS, S.[2]; STEINBERG, S.[3]; COHEN, M.[3]; BLUMBERG, D.[1]
[1]*Dept. of Entomology, Agricultural Research Organization, The Volcani Center, Bet Dagan 50250, Israel* [2]*Dept. of Plant Protection, Agricultural Extension Service, Ministry of Agriculture, Tel Aviv 61070, Israel* [3]*Biological Control Industries, Sedé Eliyyahu 10810, Israel.*

TRIALS FOR THE CONTROL OF THE CITRUS MEALYBUG IN CITRUS ORCHARDS BY AUGMENTATIVE RELEASE OF TWO ENCYRTID PARASITOIDS.

ABSTRACT

TRIALS FOR THE CONTROL OF THE CITRUS MEALYBUG IN CITRUS ORCHARDS BY AUGMENTATIVE RELEASE OF TWO ENCYRTID PARASITOIDS.

Since the 1980s, the citrus mealybug *Planococcus citri* (Risso) has become a key pest in Israel, owing to intensive planting of highly susceptible varieties, the introduction of Insect Growth Regulators (which adversely affect coccinellids) and the development of resistance to chlorpyrifos. Management of the mealybug populations in citrus orchards by augmentative releases of parasitoids was investigated between 1993 and 1996 in a series of tests involving the release of 5,000-10,000 *Leptomastix dactylopii* (Howard) (Encyrtidae) per hectare. Results showed no significant effect on the density of the mealybug on the fruits. In general, the establishment of *L. dactylopii* was poor and population levels were inferior to those of the naturally occurring *Anagyrus pseudococci* (Girault) (Encyrtidae). In 1996-1997, augmentative early-spring releases of *A. pseudococci* at the rates of 10,000-50,000 individuals per hectare markedly increased the population density of *A. pseudococci* during April and June but had no significant effect on either the mealybug infestation or on fruit damage caused by the pest and its fruit moth associates.

Key words: grapefruit, persimmon, custard apple, coffee, cacao, *Citrus*, *Diospyros*, *Annona*, life cycle, damage, *Coccidoxenoides peregrinus*, *Cryptolaemus montrouzieri*, *Sympherobius sanctus*, mass rearing, cork ring, potato sprout, potato trap, low temperatures, fruit moths.

INTRODUCTION

The citrus mealybug, *Planococcus citri* (Risso) (Homoptera: Pseudococcidae) is a highly polyphagous pest. In open areas, it is mainly a serious pest of citrus but can also attack persimmon (*Diospyros kaki*) and custard apple (*Annona* spp.), coffee and cacao. The exact area of origin of the citrus mealybug, believed to be from the tropics, is uncertain.

In the Mediterranean, the mealybug is multivoltine and occurs on all parts of the citrus tree. It overwinters in crevices next to callus of old wounds on the stem and main branches. In the spring, the females migrate to the canopy and settle on young fruits or young flush. In all citrus varieties, they first occupy cryptic sites on the fruits or contact points between fruits. They can also be found under the sepals on navel orange, where they settle in the fruit navel and on the terminal twig segments next to the fruit (Bodenheimer, 1951). It can also be found on the roots of young trees (Bodenheimer, 1951).

In Israel, the citrus mealybug damages the fruit during the warm season. The course of injury is as follows: (i) between early May and early June, the mealybug causes flower and early fruit drop; (ii) from mid-May to late June, they damage the young fruits by feeding; (iii) from late June to mid-August, they feed on the immature fruit, producing much honeydew on which sooty mould fungi develop, causing premature fruit drop, and (iv) from late July to late September, the honeydew attracts the fruit boring moths *Ectomyelois ceratoniae* (Zeller) and *Cryptoblabes gnidiella* Miller, whose larvae damage the fruit (Bodenheimer, 1951; Gookes & Porath, 1974; Avidov & Harpaz, 1969).

In Israel, the citrus mealybug has for decades been considered a moderate pest of Marsh grapefruit (*Citrus paradisi*) but it has progressively become a major pest since the 1980s, due to the planting of susceptible varieties and to major changes in the chemical pest management in citrus groves and their surroundings. From the mid-1970s, highly susceptible varieties, mainly red grapefruit (Star Ruby) and Sweetie (*Citrus paradisi* X *C. grandis*) have been planted. Even at moderate densities, the mealybug could cause notable damage on these varieties. During the 1960s and the 1970s, the mealybug remained at low levels in Israeli citrus orchards, mainly due to the widespread application of organophosphate - carbamate “spray cocktails” against Florida wax scale (*Ceroplastes floridensis* Comstock) and California red scale (*Aonidiella aurantii* Maskell). Since the late 1980s, Insect Growth Regulators (IGRs) have been intensively used in Israeli agriculture (Peleg & Bar-Zakay, 1995). These chemicals are directed mainly against whiteflies and lepidopteran pests in cotton and tomatoes, and against armoured and soft scales in citrus and pome fruits. While mealybugs are not susceptible to IGRs, these insecticides have a destructive effect upon coccinellids (Mendel *et al.*, 1994), the major biocontrol agents of mealybugs in citrus in Israel. In South Africa (Hattingh & Tate, 1995) and Israel (Mendel, unpublished data), application of IGRs (mainly of pyriproxyfen) has resulted in frequent outbreaks of the citrus mealybug during the last decade. Consequently, treatments with the organophosphate chlorpyrifos have become routine in local groves against the citrus mealybug since the late 1980s. In spite of the fact that the mealybug has become highly resistant to chlorpyrifos in many orchards, the chemical is currently the sole tool for managing the mealybug on fruit-bearing trees.

In the Mediterranean, several local species of predators and parasitoids are associated with the citrus mealybug. However, their role as biocontrol agents in lowering the population to an economically acceptable level has never been thoroughly assessed. The major introduced natural enemies are not well adapted to the Mediterranean climate. In Israel, for example, the encyrtids *Leptomastix dactylopii* (Howard) and *Anagyrus pseudococci* are both susceptible to low temperatures; the former has failed to become established due to the low winter temperatures, while the latter manages to survive the winter although in reduced numbers. The activity of another encyrtid, *Coccidoxenoides peregrinus* (Timberlake), is low due to the high summer temperatures, whereas the coccinellid *Cryptolaemus montrouzieri* Mulsant occurs in very low densities and is unable to respond in time to the population changes of this mealybug. Since the origin of the citrus mealybug is not clear, there is little chance of improving its control by acclimatization of additional specific enemies.

Since classical biological control has failed to solve the problem of the citrus mealybug in many citrus-growing countries, augmentative releases have been suggested and practised. Augmentative releases against insect pests have been successfully practised in controlled environments (Van Lenteren & Woets, 1988). Effective augmentative biological control of the mealybugs has been achieved in interior landscapes and greenhouses (Hennekam *et al.*, 1987; Tingle, 1985; Carvalho, 1994). The inferiority of inundative releases in open areas as compared with greenhouses is evident and augmentation of natural enemies is often too expensive to compete with synthetic insecticides. However, there are some reports of successful use of *L. dactylopii* and/or *C. montrouzieri* in Queensland (Smith *et al.*, 1988), Spain (Llorens, 1994), Italy (Spicciarelli *et al.*, 1994), India (Krishnamoorthy & Singh, 1987; Krishnamoorthy, 1990) and Turkey (I. Karaca, pers. comm.).

This paper reports the results of a five-year project on the control of the citrus mealybug by augmentative releases of parasitoids. Two hymenopterous species were selected for this project. *Leptomastix dactylopii*, which displays a high specificity to *Planococcus* spp., was the first obvious choice. The parasitoid has been frequently used in greenhouses against the pest in Europe (Copland *et al.*, 1985). Although our findings indicate that *L. dactylopii* cannot survive the winter in Israel (e.g., Klein, 1994), this was not thought to be a significant obstacle in augmentative biological control, since it was expected to act during the warm season (e.g., Tingle & Copland, 1988). *Anagyrus pseudococci* (Girault) is another promising candidate, although it had been considered less specific than the former (Bodenheimer, 1951) and a significant portion of its progeny is lost due to egg encapsulation (Blumberg *et al.*, 1995). It is the dominant parasitoid of *P. citri* in the relatively warmer parts of the Mediterranean region and so is probably more suited to the climate of the Near East than *L. dactylopii.* However, when the project was initiated, *A. pseudococci* was not commercially available and, hence, this species has only been used in the last two years of the project. Augmentative releases of two predator species, *C. montrouzieri* and the sympherobiid *Sympherobius sanctus* Tjider, were also considered during the planning of this project but preliminary results showed that their establishment was very poor and the recovery of *S. sanctus* was practically nil (Gross, Steinberg & Mendel, unpublished data).

MATERIALS AND METHODS

The experiments were carried out between 1993 and 1997. All treatments were conducted in commercial groves of *P. citri*-susceptible varieties, i.e. “Sweetie”, red grapefruit, Marsh grapefruit or pomelo. Each experiment consisted of plots where the parasitoids were released (treated) as well as control (untreated) plots. Each plot was at least 2 hectares. The details for each experiment are given in Tables 1-4. In general, samples consisted of 20 fruits/tree in spring (until early June) and of 10 fruits/tree in summer, taken from 10 randomly selected trees, as suggested by Klein (1994). In 1994, we established 4 groups of 6 neighbouring trees in each plot (treated or control); we also eliminated the released parasitoids from two of the groups by caging them with 50 mesh nets. Fruit samples in 1994 consisted of 15 fruits per tree (24 trees per plot). The following parameters were recorded for each sample: number of (a) heavily infested fruits, (b) live mature larvae and live females of *P. citri* per fruit, (c) parasitized mealybugs per fruit, (d) fruits injured by fruit moths and (e) development of cork ring (a scar or necrotic ring that develops as a result of a wound periderm induced by feeding by the mealybug).

Mass rearing of the natural enemies was conducted by the Biological Control Industries, Sedé Eliyyahu, Israel, on citrus mealybug infesting potato sprouts. Releases were made mainly in the morning and, in most cases, a single introduction of the natural enemies was made but in a few cases, sequential releases over a period of 10 days were conducted. The initial number of released parasitoids, 5,000 per hectare, was established according to a compromise between our estimated optimal density (e.g., Smith *et al.*, 1988) and cost. The price of 5,000 individuals (more than 50% females) per hectare is equivalent to a single application of chlorpyrifos.

The relative density of natural enemies was determined in 1993-1995 by counting all emerging parasitoids from *P. citri* removed from the sampled fruits. In 1996-1997, use was made of small cages baited with a potato sprout infested with several hundred adult females of *P. citri*. These "potato-traps" were suspended inside the crowns of five trees per plot selected at random in treated and control plots for two weeks. The immature larvae of predators were removed and each potato sprout was placed in a rearing box from which the emerging parasitoids were collected daily and counted.

The mean number of emerging parasitoids per 'potato-trap' per plot was calculated. We combined the means obtained with either species or species combination (in 1996) and release rates (in 1997) into a single mean, and compared the results to those of the control plots. Differences in rates of fruit infestation and mealybug density per fruit between regions, groups of adjacent plots and between treated and non-treated plots were examined by two-way ANOVA (Sokal & Rohlf, 1981).

RESULTS

Except for a single occurrence of each of *L. abnormis* and *C. peregrinus,* only *L. dactylopii* and *A. pseudococci* emerged in significant numbers from the mealybug infested fruits or 'potato-traps'.

In 1993, *L. dactylopii* was present in all release plots as well as in most adjacent control plots situated a distance of 200-500m from the treated plots. In early July, *L. dactylopii* was the major parasitoid emerging from mealybugs removed from fruits taken from treated (79.3 ± 21.8%) and control (74.4 ± 29.5%) plots. The level of fruit infestation varied a great deal among plots ($P<0.0001$). Significant differences in live and parasitized mealybugs per fruit were found between sampling dates for treated and untreated plots. However, differences in the number of live and parasitized mealybugs between treated and control plots were not significant at any sampling date (Table 1).

In contrast to the results of 1993, recovery of *L. dactylopii* in 1994 was only from the treated plots and consisted of 4.7 ± 2.7% of the total parasitoids emerging from the infested fruits. All other recovered parasitoids were *A. pseudococci*. Differences in the number of live and parasitized mealybugs per fruit and the damage by fruit moths were not significant between treated and untreated plots, nor between netted and non-netted trees for the three sampling dates (Table 2).

Recovery of *L. dactylopii* in early July 1995 from mealybug-infested fruits was as low as 2.0 ± 2.3%; all other parasitoids were *A. pseudococci*. In 1996, the recovery of *L. dactylopii* and *A. pseudococci* from 'potato traps' varied with time, with practically nil parasitoids being recovered from traps in the control plots exposed during the first two weeks after the release, whereas, in the treated plots, the mean number of *L. dactylopii* and *A. pseudococci* per trap was 13.0 and 22.0 respectively (Fig. 1). On May 16, the number of *A. pseudococci* had increased to 40.0 per trap, while that of *L. dactylopii* had decreased to the same level as that of *A. pseudococci* in the non-treated plots, i.e. about 8.0 individuals per trap. Two months later, the number of *A. pseudococci* per 'potato-trap' was the same in the treated and control plots, and a further decrease was recorded in number of *L. dactylopii*. By mid-August, the number of *A. pseudococci* per trap had dropped to 2.0 per trap in both treated and untreated plots, whereas *L. dactylopii* failed to recover. The number of live and parasitized mealybugs per fruit, the rate of fruit heavily infested by the scale and the percentage fruits damaged by fruit moths did not differ significantly between treated and non-treated plots in either early August 1995 or in late July 1996 (see Table 3).

Table 1. Mean number of live and parasitised citrus mealybugs in 1993 (means from 4 locations (Bet She'an Valley, Sharon, western Galilee, Yezrae'el Valley); total number of plots for each treatment = 11). Inundative releases of 5000 *Leptomastix dactylopii* per hectare between the end of May and early July.

Variable	Sampling date	Treated plots	Untreated plots	df	*F*	*P*
Live mealybugs per fruit	early June	1.19	3.37	1,16	1.258	0.278
	mid-July	11.84	21.40	1,16	2.464	0.136
	mid-August	7.39	10.72	1,16	0.421	0.525
	early October	3.14	2.72	1.16	0.113	0.741
	between dates in treated plots			3,32	6.824	0.001
	between dates in untreated plots			3,32	3.659	0.022
Parasitised mealybugs per fruit	early June	0.01	0.02	1,16	0.368	0.553
	mid-July	0.09	0.25	1,16	3.347	0.086
	mid-August	0.44	0.47	1,16	0.018	0.895
	early October	0.44	0.50	1,16	0.156	0.697
	between dates in treated plots			3,32	7.999	0.0004
	between dates in untreated plots			3,32	6.885	0.001

Table 2. Mean number of live and parasitised citrus mealybugs in 1994 (means from 2 locations: eastern Galilee, Yezrae'el Valley); total number of plots for each treatment = 3). Inundative releases of 5000 *Leptomastix dactylopii* per hectare over a period of 10 days in mid-June. Additional netted trees served as a control in both the treated and untreated plots

Variable	sampling date	Treated plots		Untreated plots		*F* (3,20)	*P*
		netted trees	un-netted trees	netted trees	un-netted trees		
Live mealybugs per fruit	5 June	8.15	7.30	3.48	3.97	1.268	0.312
	19 July	1.15	0.94	3.20	0.68	1.436	0.262
	11 October	0	0	0.01	0.02	0.880	0.467
Parasitised mealybugs per fruit	5 June	0.13	0.09	0.07	0.05	0.778	0.520
	19 July	1.77	2.00	2.13	0.73	0.997	0.419
	11 October	0	0	0	0	1.667	0.413
% fruits damaged by fruit moths	5 June	0.33	0	0	0	0.166	0.413
	19 July	2.66	6.00	4.00	2.67	0.946	0.437
	11 October	5.66	15.67	28.33	20.33	0.903	0.457

Results on the recovery of *A. pseudococci* from 'potato-traps' during 1997 were fairly similar to 1996 (Fig. 2). On April 16, during the first two weeks after release, recovery of the parasitoids in the non-treated plots was 0.7 per trap whereas in the treated plots its average was 11.0. On May 15, the number of *A. pseudococci* increased to 58.0, while it only increased in the non-treated plots to 9.0 per trap. A month later, the numbers remained unchanged in the non-treated plots but had decreased in the treated plots. From August, a further decrease was observed in the numbers of *A. pseudococci*, which did not differ significantly between treated and non-treated plots. For all three sampling dates, live and parasitized mealybugs per fruits, as well as percentage fruits damaged by moths and/or cork rings did not differ significantly among treatments (Table 4).

DISCUSSION

Periodic releases of natural enemies are a second choice after classical biological control (DeBach & Rosen, 1991). Israeli citrus groves constitute an unfavourable, disturbed environment for the major natural enemies of the citrus mealybug. Tingle and Copland (1988) showed that temperature has a major impact on parasitism of both *A. pseudococci* and *L. dactylopii*. For example, immature stages of the former species are susceptible to temperatures below 15°C (Battaglia & Tranfaglia, 1994; Krishnamoorthy, 1989) and, therefore, the low spring temperatures in Israel delay the population increase in the early season, thus affecting the establishment of naturally occurring *A. pseudococci*. Later in the season, the natural enemies are decimated by climatic extremes, the large fluctuations in the mealybug populations and the late summer aerial applications of malathion against the Mediterranean fruit fly. Under these conditions, which are common in Israeli groves, augmentative releases may be a feasible alternative (e.g., DeBach & Rosen, 1991).

Table 3. Mean number of live and parasitised citrus mealybugs in 1995 and 1996 (means from 2 locations: 1995: central coastal plain, Yezrae'el Valley; 1996: southern coastal plain, Yezrae'el Valley; for number of plots see below). Inundative releases of 5000 *Leptomastix dactylopii* per hectare in mid-May (1995) and of 10,000 *L. dactylopii* or 10,000 *A. pseudococci* or 7000 *L. dactylopii* + 3000 *A. pseudococci* released over a period of 10 days between mid- to late April, 1996. In 1995, there were 12 treated plots and 12 untreated plots of susceptible varieties (Sweetie, red grapefruit and Marsh grapefruit) and 12 untreated plots of non-susceptible varieties (Shamuti and Valencia orange); in 1996, there were 2 plots with *L. dactylopii*, 3 plots with *A. pseudococci* and 7 plots with mixed parasitoids. Five "potato-traps" per plot were put out from mid-April to mid-August 1996.

Year & treatment	Variable	Treated plots	Untreated plots	*df*	*F*	*P*
1995 *L. dactylopii* (5000/hectare)	% heavily infested fruits	34.08	37.55	1,26	0.000	0.991
	live mealybugs per fruit	1.33	2.06	1,26	1.038	0.318
	parasitised mealybugs/fruit	1.94	1.68	1,26	1.007	0.608
	% fruit moth damage	6.25	2.61	1,26	1.444	0.240
1996 *L. dactylopii, A. pseudococci* or both (10000/hectare)	% heavily infested fruits	45.30	44.83	1,22	0.003	0.874
	live mealybugs per fruit	5.47	5.71	1,22	0.002	0.958
	parasitised mealybugs/fruit	4.48	4.94	1,22	0.000	0.996
	% fruit moth damage	5.92	5.00	1,22	0.132	0.720

In the present study, therefore, augmentative releases were considered as an option due to the poor performance of the local natural enemies, the ineffectiveness of chemical control and the fact that all known potential candidates for classical biological control (e.g., Bartlett, 1978; Moore, 1988) have already been tested in Israel. Laboratory parameters characterizing parasitoid efficacy, are often unrealistic (Godfrey & Waage, 1991) and so our selection of *L. dactylopii* and *A. pseudococci* was based mainly on host suitability and environmental adaptation, and on positive results reported in previous studies on the release of *L. dactylopii* (Krishnamoorthy & Singh, 1987; Smith *et al.*, 1988; Spicciarelli *et al.*, 1994; Llorens, 1994).

Table 4. Mean number of live and parasitised citrus mealybugs in 1997 (Yezrae'el Valley); 3 plots for each of three dosages plus 9 control plots. Inundative releases of 10,000, 20,000 or 50,000 *A. pseudococci* per hectare released over a period of 10 days between mid- to late March. Five "potato-traps" per plot were put out from mid-April to early October (a total of 90 traps).

Variable	Sampling date	Treatment				Control vs all *A. pseudococci* treatments	
		Untreated plots	*A. pseudococci* per ha[1]			*F* (1,16)	*P*
			10,000	20,000	50,000		
Live mealybugs per fruit	early June	0.27	0.55	0.32	0.65	0.210	0.653
	mid-July	1.56	0.80	0.41	0.26	1.490	0.240
	late August	0.17	0.16	0.23	0.12	0.710	0.412
Parasitised mealybugs per fruit	early June	0.03	0.03	0.13	0.09	1.226	0.285
	mid-July	0.34	0.53	0.48	0.68	0.347	0.544
	late August	0.41	0.59	0.60	0.80	0.002	0.789
% fruits with cork ring/fruit moth damage	late August	2.60	6.33	9.67	17.00	2.783	0.115

Assessing the efficacy of inundative releases of a biological control agent can be done by a quantitative evaluation of the reduction of the targeted pest population and/or by the economic impact, based on comparison with plots to which additional natural enemies have not been applied (e.g., Bellows *et al.*, 1992). Based on such comparisons, our results under local conditions show that augmentation by *L. dactylopii* (with dosages of 5,000 and 10,000 individuals per hectare) or by *A. pseudococci* (with dosages of 10,000, 20,000 and 50,000 per hectare) did not improve citrus mealybug control on the tested citrus varieties.

Only in 1993 did *L. dactylopii* form the majority of the recovered parasitoids. During that particular season, it also established itself in most of the non-treated plots. This was probably due to the unusually cold winter (which resulted in very low populations of the local natural enemies) and the

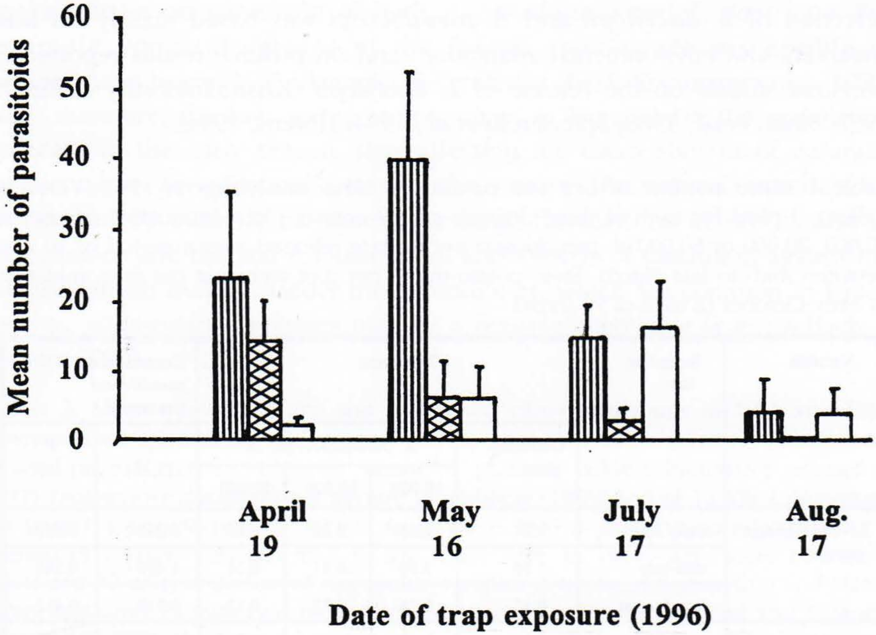

Figure 1. Mean number (+SE) of *Anagyrus pseudococci* (striped bars) and *Leptomastix dactylopii* (cross-hatched bars) that emerged from 'potato-traps_ per plot after being exposed for two weeks inside a crown of a citrus tree in treated and control plots (white bars). A total of 120 traps were activated in each sampling period, half of them in the control plots. In the treated plots release of the parasitoids was conducted in April 18, 1996, (10,000 *A. pseudococci*, 10,000 *L. dactylopii* or 3,000 *A. pseudococci* + 7,000 *L. dactylopii* per hectare).

release in June of *L. dactylopii* which contributed to the good establishment of the parasitoid in the groves. These results encouraged us to locate the non-treated plots further away from the treated ones in 1994 and to establish additional controls consisting of netted trees. However, the recovery of *L. dactylopii* in 1994 was poor and the releases had no significant effect on the mealybug populations. Similar results were obtained in 1995.

Due to the poor recovery of *L. dactylopii* in 1994 and 1995, *A. pseudococci* was added to the experiment in 1996 as another treatment and the release dosage was increased to 10,000 individuals per ha. The releases were conducted a month earlier than in the previous years. Due to technical problems, releases consisted of only a single parasitoid species in five plots,

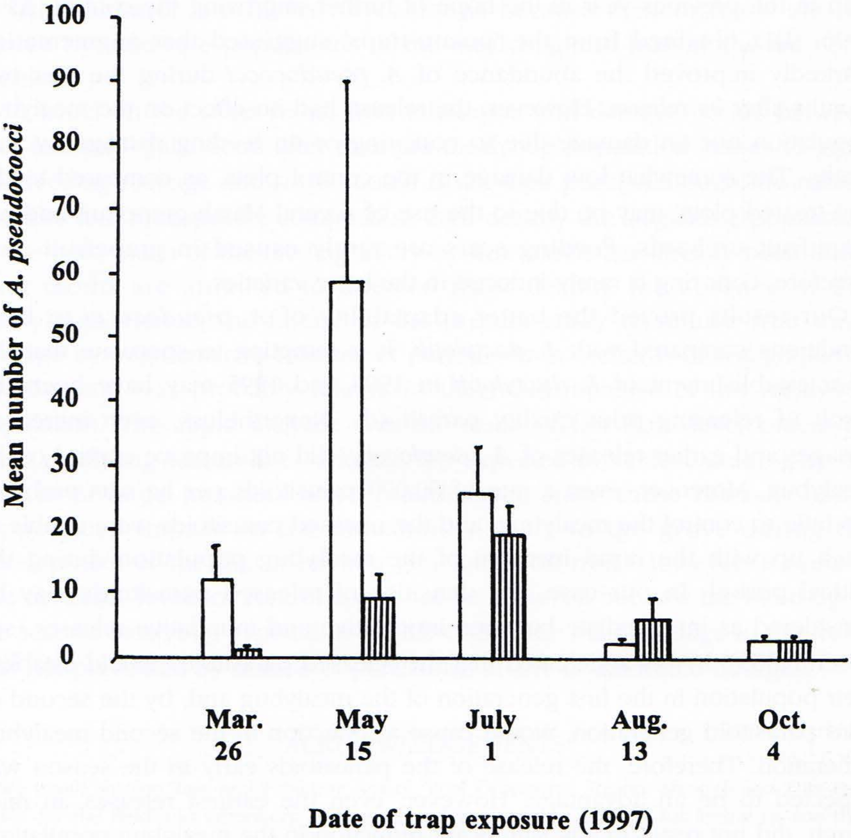

Figure 2. Mean number (+SE) of *Anagyrus pseudococci* that emerged per plot from 'potato-traps' after being exposed for two weeks inside a crown of a citrus tree in treated (white bars) and control (striped bars) plots. A total of 90 traps were activated in each sampling period, half of them in the control plots. In the treated plots release of the parasitoids was conducted in March 25, 1997 (10,000, 20,000 or 50,000 parasitoids per hectare).

whereas the other seven plots were treated with 7,000 *L. dactylopii* + 3,000 *A. pseudococci* per ha. Even so, the inferiority of *L. dactylopii* to *A. pseudococci* could be observed soon after the release by its poor rate of recovery. Data obtained from the 'potato-traps' suggested that augmentation markedly improved parasitoid abundance during the first two months after the release but did not improve control of the mealybug.

In 1997, only *A. pseudococci* was tested, using additional high dosages of 20,000 and 50,000 per ha. The releases were conducted three weeks earlier

1996, data obtained from the 'potato-traps' suggested that augmentation markedly improved the abundance of *A. pseudococci* during the first two months after its release. However, the release had no effect on the mealybug population nor on damage due to cork ring or on feeding damage by fruit moths. The somewhat low damage in the control plots, as compared to the non-treated plots, may be due to the use of several Marsh grapefruit and red grapefruit orchards. Feeding scars are rarely caused in grapefruit and, therefore, cork ring is rarely induced in the latter varieties.

Our results proved the better adaptability of *A. pseudococci* to local conditions compared with *L. dactylopii*. It is tempting to speculate that the poor establishment of *L. dactylopii* in 1994 and 1995 may have been the result of releasing poor quality parasitoids. Nevertheless, even increased dosages and earlier releases of *A. pseudococci* did not improve control of the mealybug. Moreover, even a rate of 50,000 parasitoids per ha was probably too little to control the mealybug, and the released parasitoids were unable to catch up with the rapid increase of the mealybug population during the critical period. In our case, the densities of released parasitoids may be considered as intermediate between inoculative and inundative releases (see Rosen, 1985). It was anticipated that the released parasitoids would establish their population in the first generation of the mealybug and, by the second or third parasitoid generation, would cause a reduction in the second mealybug generation. Therefore, the release of the parasitoids early in the season was expected to be an advantage. However, even the earliest releases, in mid-March, did not result in any significant reduction in the mealybug population. No information is available on the rate of migration of the released parasitoid from the relatively small treated plots to surrounding untreated groves, although such migration should be expected, especially early in the season when mealybug density is still low. Early releases face other problems - rain and cold periods. Hence, the low mealybug population and the extreme weather conditions probably hampered the establishment of the parasitoids at the release site.

Augmentative releases of parasitoids or predators may be effective against the citrus mealybug in areas where citrus varieties are not highly susceptible, where other mealybug species are not key problems, and where the growing period of the tree and the development of the mealybug population last well into the summer. This situation occurs in California, where inoculative releases of *C. montrouzieri* in the summer are able to reduce the mealybug population towards the end of the season (e.g., DeBach & Hagen, 1964). Sufficient control is achieved in California because their orchards are not injured by moderate populations of the mealybug and fruit moths are not a problem.

In Israel on the other hand, fruit infestation and damage occurs between May and mid- July. Soon after that, the mealybug population ceases to grow and feeding damage and sooty mould reach their peak. Although the natural enemies and intraspecific competition then destroy the stagnating population of the pest, much of the feeding injury by fruit moths has already been done. Fruit moths are attracted to infested fruits despite the absence of live mealybugs. Hence, the failure in the present study to reduce fruit moth damage by augmentative releases of parasitoids in orchards of red grapefruit and Sweetie was probably related to the rapid increase of the mealybug population. This rapid increase was the result of fast fruit development on these mealybug-susceptible varieties. We expected to achieve control by the release of large numbers of *A. pseudococci*, since these releases had a pronounced impact on the parasitoid density in the grove during the development of the first mealybug generation on fruit. However, it seemed that desirable levels of control could not be achieved because the build-up of the second mealybug generation, which causes the main damage to the fruits, was not prevented by release of parasitoids at any of the tested dosages.

ACKNOWLEDGEMENTS

We thank Shlomo Tam and Fabienne Assael, Yoel Drishpone, Shalom Shmueli and Zlila Ben-David for the field and laboratory assistance, and many citrus growers for letting us use their orchards for the experiments. The study was partly supported by the Israeli Citrus Marketing Board, as project no. 0131-777.

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