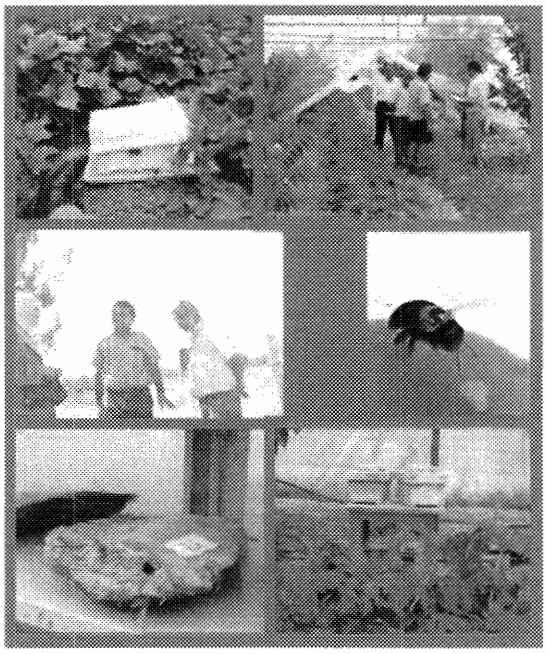
Final Report

Covering period from July 2002 to June 2005

Comparing the efficiency of native and domesticated bees in the pollination of field and orchard crops



Final Report C46

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Comparing the efficiency of native and domesticated bees in the pollination of field and orchard crops

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Executive Summary

Training and collaboration (knowledge, technical skills, and awareness acquired)
Several frequent field and classroom training sessions were conducted within the framework of the project, mainly during visits to Jordan. Those training sessions dealt with the following issues: understanding main parameters relevant to pollination efficiency in agriculture, studying and drilling in methods of assessing and quantifying those parameters, and comparative analysis of data collected. In addition, two training workshops were conducted, one full seminar in Jordan and one field-guided tour in Israel.
The trainees were extension specialists and field technicians from NCARTT staff and farmers who grow insect pollinated crops. Many women from NCARTT staff took an active part in training sessions and field studies. Participants of those training sessions acquired knowledge and skills which, we hope, will be utilized to guide and assist farmers and beekeepers in more efficient pollination applications through in growing seasons.

Comparing the efficiency of pollinators in the pollination of agricultural crops
Intensive and constant work was made in three NCARTT research stations, A-Rabba, Shoubak, and Ghor-A-Safi, as well as in several private farms. In all these sites and simultaneously in Israel, comparative pollination studies were conducted in experimental and commercial plots of zucchini, strawberry, melon, and watermelon. Commercial honeybee Langstroth hives, commercial bumblebee colonies, and "MiniHives" (see below) performed pollination at those sites (see table 1).
Special attention was given to the agrotechnical aspects of the grown crops. Several thousands of seedlings of melon and watermelon were brought from Israel to experimental plots for the pollination studies. Concurrently, several Israeli experts visited the experimental plots and commercial fields and gave guidance in growing and bees' pollination methods.
Under most circumstances the different pollinators performed efficiently with no significant differences in terms of crop yields.
A prominent pioneering and innovative result of those studies is the application of "MiniHive" to pollination in agriculture. This special honeybee hive configuration ("mating hive") proved to be effective for pollination of crops grown in small enclosures and has some specific advantages. To the best of our knowledge, this is the first time that Minihives have been applied for pollination and are currently under pilot commercial application.

Studying native bees' potential for pollination applications in agriculture
Carpenter bees (Xylocopa spp.), native and widely spread in both Jordan and Israel, were studied. Those solitary and semi-social bees are known to forage on several wild flowers, perform "buzz pollination" (which is needed to pollinate important crops like tomatoes, eggplants, and more), and are active under conditions of high temperatures.
Nesting behavior, preferred nesting materials, and diurnal activity were studied under natural conditions and in the lab and greenhouse.
We found that palm date petioles are the most efficient nesting material. Those artificial nests were used to transfer bees from the wild to the lab and greenhouse so that we could study their foraging characteristics and efficiency in pollinating melons. Primary results show that Carpenter bees forage and pollinate melon flowers under greenhouse conditions.

Research Objectives

Introduction

Efficient pollination is a limiting factor for the yield and quality of many agricultural crops. For insect-pollinated crops, the amount and type of activity of pollinating insects during the blooming period is crucial for commercial results (Delaplane, and Mayer 2000, RIRDC, 2003).

Since, due to human-enhanced processes, wild populations of pollinating insects are steadily deteriorating (Allen-Wardell et al., 1998, Kremen et al, 2002), the importance of applying domesticated pollinating insects has been increased significantly (Buchmann and Nabhan, 1996).

Recognizing the importance of this factor and including it in planning and performing agrotechnical tasks is not common among farmers, especially in developing countries (personal observation). When recognized, the availability of suitable domesticated pollinating insects (hives for purchase or rent) is not a matter of fact.

The ability to quantify and study those parameters is not obvious, even within advanced agrotechnical management systems (personal observations).

In Jordan there are 95,000 farmers and 4,000 beekeepers. Jordan is importing 20% of its demand and exporting 30% of its production in fruit and vegetables. Most beekeepers make their living solely out of honey production, because the renting of bees for agricultural pollination is rather undeveloped (Ministry of Agriculture Jordan. 1997).

The project addressed the above mentioned aspects of pollination of agricultural crops. Apart from the knowledge, skills and experience acquired through research work, we believe that the people involved in the process, who have been exposed to the ideas, terminology and practices of pollination and pollination research, increased their awareness of the role of pollination in modern agriculture

Methods and Results

Comparing The Efficiency of Honeybee Hives, Honeybee Minihives and Bumblebee colonies in Pollination of Crops

Methods

Table 1 summarizes all the comparative experiments conducted within the framework of the project, chronologically arranged. The table details crops, season, growing conditions (enclosures vs. open field), pollinators applied, etc. Important insect-pollinated crops were chosen for pollination studies, namely, melon, zucchini, watermelon and Strawberry. The sites chosen for the experiments represent distinct regions in terms of climate and soils. The Al-Shoubak and A-Rabba stations are located in the mountainous area of southern Jordan with altitudes of 700 m and above, while the Ghor-A-Safi station and Feife area is located near the Dead Sea at about – 400 m.

Data Collection

Collection of data was performed at each experiment using the task lists / protocols developed within the project (see appendix). Blooming phenology, reward presented by the flowers, pollinators' foraging activity, and hives condition were studied during blooming season.

Parameters related to pollination

Flower parameters related to pollination: Flower dimensions, flower density and sex ratio (where applicable), flower opening time, and flower longevity.

Flower reward: Nectar production and yield and Pollen Quantity.

Pollinators' foraging activity: Diurnal activity, bee visitation frequency.

Fruit set and yield.

Table 1: Experiments' summary

Country	Site	Year	Season	Crop	Cultivar	Planting Date	Plot \ Enclosure Design	Plots ID	Pollinators	Hives Type	Hives Density per 1000 Sqm.	Research Staff	Observations Date
Israel	Ein-Yahav Arava Valley	2003	Winter	Zucchini		Jan-03	Plastic tunnel	Neta Or	Bumblebees	Commercial colony	NA	Neta Or & Weil Dan (Kutzi)	February-2003 to March-2003
Israel	Ein-Yahav Arava Valley	2003	Winter	Zucchini		Jan-03	Plastic tunnel	Neta Or	Honeybees	MiniHive	NA	Neta Or & Weil Dan (Kutzi)	February-2003 to March-2003
Israel	SASA	2003	Spring	Apple	Grand Smith		Open orchard	Ahrnw.	Honeybees	Langstroth	0.25	Weil Dan (Kutzi)	Apr-03
Israel	Eilot Arava Valley	2003	Winter	Watermelon		Jan-03	Commercial open field		Honeybees	Langstroth	0.25	Weil Dan (Kutzi)	February-2003 to March-2003
Israel	Eilot Arava Valley	2003	Winter	Melon		Jan-03	Commercial open field		Honeybees	Langstroth	0.25	Weil Dan (Kutzi)	February-2003 to March-2003
Israel	Neot-Hakikar Arava Valley	2003	Autumn Winter	Zucchini		Sep-03	Net Houses	1st Cycle	Honeybees	MiniHive		Zipi Adiv	Oct-2003 to Nov-2003
Israel	Neot-Hakikar Arava Valley	2003	Autumn Winter	Zucchini		Sep-03	Net Houses	1st Cycle	Bumblebees	Commercial colony		Zipi Adiv	Oct-2003 to Nov-2003
Israel	Neot-Hakikar Arava Valley	2003	Autumn Winter	Zucchini		Nov-03	Net Houses	2nd Cycle	Honeybees	MiniHive		Zipi Adiv	Dec-2003 to Jan-2004

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Country	Site	Year	Season	Crop	Cultivar	Planting Date	Plot \ Enclosure Design	Plots ID	Pollinators	Hives Type	Hives Density per 1000 Sqm	Research Staff	Observations Date
Israel	Neot-Hakikar Arava Valley	2003	Autumn Winter	Zucchini		Nov-03	Net Houses	2nd. Cycle	Bumblebees	Commercial colony		Zipi Adiv	Dec-2003 to Jan-2004
Israel	Neot-Hakikar Arava Valley	2003	Autumn Winter	Zucchini		Dec-03	Net Houses	3rd. Cycle	Honeybees	MiniHive		Zipi Adiv	Jan-2004 to March-2004
Israel	Neot-Hakikar Arava Valley	2003	Autumn Winter	Zucchini		Dec-03	Net Houses	3rd. Cycle	Bumblebees	Commercial colony		Zipi Adiv	Jan-2004 to March-2004
Jordan	Al-Shoubak NCARTT station	2003	Spring	Apple	21 Cultivars		Open orchard	(Experimental Plot)	Honeybees	Langstroth	NA	Sayfuddin Shihadeh Ahmed Kheeisat Mrs. Hazza Mrs. Hoda Bdur	April 2003 to June 2003
Jordan	Al-Shoubak NCARTT station	2003	Summer	Watermelon	Crimson	June-03	Open field plot		Honeybees	Langstroth	NA	Sayfuddin Shihadeh Ahmed Kheeisat Mrs. Hazza Mrs. Hoda Bdur	Sep-03
Jordan	A-Rabba Al-Qasar Private Farm	2003	Summer	Zucchini & Watermelon		Jul-03	Open field plot		NA			Sayfuddin Shihadeh Ahmed Kheeisat Mrs. Hazza Mrs. Hoda Bdur	Jul-03
Jordan	A-Rabba Magdalena (Bashapsi Farm)	2003	Summer	Zucchini & Watermelon		Jul-03	Open field plot						
Jordan	A-Rabba NCARTT station	2003	Spring & Summer	Zucchini, Melon & Watermelon		April-2003 & June-2003	Open field plot	Experimental Plot	Honeybees	MiniHive	0.25	Ahmed Kheeisat Mrs. Hazza Mahamad Elabeden	
Jordan	Mu'tah University	2003	Summer	Watermelon	Seedless Crimson	Jul-03	Open field plot	Open Field Plot	Honeybees	Langstroth	0.25	Aymen Zayadeen	Aug-03

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Country	Site	Year	Season	Crop	Cultivar	Planting Date	Plot \ Enclosure Design	Plots ID	Pollinators	Hives Type	Hives Density per 1000 Sqm.	Research Staff	Observations Date
Jordan	Mu'tah University	2003	Summer	Zucchini		Jul-03	Plastic tunnel		Honeybees	MiniHive	0.17	Ayman Zeyadeen	Aug-03
Jordan	Mu'tah University	2003	Summer	Zucchini		Jul-03	Plastic tunnel		Control			Ayman Zeyadeen	Aug-03
Jordan	Mu'tah University	2003	Summer	Zucchini		Jul-03	Plastic tunnel		Bumblebees	Commercial colony	0.17	Ayman Zeyadeen	Aug-03
Israel	Revadim	2004	Spring	Melon	60402, Hazera	Mar-04	Net houses (unwoven cloth)	1,2	Honeybees	Langstroth	0.4	Weil Dan (Kutsi)	May-04
Jordan	A-Rabba NCARTT station	2004	Winter	Strawberry	Camarosa	Oct-04	Plastic tunnels		Honeybees	Langstroth	0.2	Mageda Zuraikat Saly Habashneh Laila Kraisha	Feb-05
Jordan	A-Rabba NCARTT station	2004	Winter	Strawberry	Camarosa	Oct-04	Plastic tunnels		Bumblebees	Commercial colony	0.2	Mageda Zuraikat Saly Habashneh Laila Kraisha	Feb-05
Jordan	Ghor Al-Safi NCARTT station	2004	Spring	Watermelon	Seedless Crimson	Mar-04	Plastic tunnels		Honeybees	Langstroth	NA	Mageda Zuraikat Saly Habashneh Laila Kraisha Yousef Al-Sha'ar	May-04
Jordan	Ghor Al-Safi NCARTT station	2004	Spring	Watermelon	Seedless Crimson	Mar-04	Open Field Plot		Honeybees	Langstroth	NA	Mageda Zuraikat Saly Habashneh Laila Kraisha Yousef Al-Sha'ar	May-04

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Country	Site	Year	Season	Crop	Cultivar	Planting Date	Plot \ Enclosure Design	Plots ID	Pollinators	Hives Type	Hives Density per 1000 Sqm.	Research Staff	Observations Date
Jordan	Ghor Al-Safi NCARTT station	2004	Spring	Melon	Galia & several cultivars	Mar-04	Plastic tunnels		Honeybees	Langstroth	NA	Mageda Zuraikat Saly Habashneh Laila Kraisha Yousef Al-Sha'er	May-04
Jordan	Ghor Al-Safi NCARTT station	2004	Spring	Melon	Galia & several cultivars	Mar-04	Open Field Plot		Honeybees	Langstroth	NA	Mageda Zuraikat Saly Habashneh Laila Kraisha Yousef Al-Sha'er	May-04
Jordan	Ghor Al-Safi H Magali ranch	2004		Watermelon	Seedless Crimson	Mar-04	Open Field Plot		Honeybees	Langstroth	NA	Isam Massade Jubran Rahayyem	
Jordan	Feifa Ragabi ranch	2004		Watermelon	Seedless Crimson	Mar-04	Open Field Plot		Honeybees	Langstroth	NA	Isam Massade Jubran Rahayyem	
Jordan	Feifa Ragabi ranch	2004		Melon	Galia & several cultivars	Mar-04	Open Field Plot		Honeybees	Langstroth	NA	Isam Massade Jubran Rahayyem	
Jordan	Ghor Al-Safi NCARTT station	2005	Spring	Melon	Sharaneti	Jan-05	Plastic tunnels	A-1	Honeybees	Langstroth	0.125	Mageda Zuraikat Saly Habashneh Laila Kraisha Yousef Al-Sha'er	Mar-05
Jordan	Ghor Al-Safi NCARTT station	2005	Spring	Melon	Sharaneti	Jan-05	Plastic tunnels	A-2	Honeybees	Langstroth	0.125	Mageda Zuraikat Saly Habashneh Laila Kraisha Yousef Al-Sha'er	Mar-05

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Country	Site	Year	Season	Crop	Cultivar	Planting Date	Plot \ Enclosure Design	Plots ID	Pollinators	Hives Type	Hives Density per 1000 Sqm.	Research Staff	Observations Date
Jordan	Ghor Al-Safi NCARTT station	2005	Spring	Melon	Sharameti	Jan-05	Plastic tunnels	A-3	Honeybees	Langstroth	0.125	Mageda Zuraiket Saly Habashneh Laila Kraisha Yousef Al-Sha'ar	Mar-05
Jordan	Ghor Al-Safi NCARTT station	2005	Spring	Melon	Sharameti	Jan-05	Plastic tunnels	B-1	Honeybees	MiniHive	0.125	Mageda Zuraiket Saly Habashneh Laila Kraisha Yousef Al-Sha'ar	Mar-05
Jordan	Ghor Al-Safi NCARTT station	2005	Spring	Melon	Sharameti	Jan-05	Plastic tunnels	B-2	Honeybees	MiniHive	0.125	Mageda Zuraiket Saly Habashneh Laila Kraisha Yousef Al-Sha'ar	Mar-05
Jordan	Ghor Al-Safi NCARTT station	2005	Spring	Melon	Sharameti	Jan-05	Plastic tunnels	B-3	Honeybees	MiniHive	0.125	Mageda Zuraiket Saly Habashneh Laila Kraisha Yousef Al-Sha'ar	Mar-05
Jordan	Ghor Al-Safi NCARTT station	2005	Spring	Melon	Sharameti	Jan-05	Plastic tunnels	B-4	Honeybees	MiniHive	0.125	Mageda Zuraiket Saly Habashneh Laila Kraisha Yousef Al-Sha'ar	Mar-05
Jordan	Ghor Al-Safi NCARTT station	2005	Spring	Watermelon	Gullivar	Jan-05	Plastic tunnels	A	Honeybees	Langstroth	0.125	Mageda Zuraiket Saly Habashneh Laila Kraisha Yousef Al-Sha'ar	Mar-05
Jordan	Ghor Al-Safi NCARTT station	2005	Spring	Watermelon	Gullivar	Jan-05	Plastic tunnels	B	Honeybees	Langstroth	0.125	Mageda Zuraiket Saly Habashneh Laila Kraisha Yousef Al-Sha'ar	Mar-05

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Results

As there is a large volume of collected data, the results are demonstrated by representative examples. Table 1 summarizes all the comparative experiments conducted.

Blooming phenology

The plants of the cucurbits crops studied for this project — melon, watermelon and zucchini — are monoecious, Only the female flowers produce fruit, but they depend on pollen availability from male flowers for fruitset. So, male and female flower density and sex ratio are important parameters in studying pollination efficiency.
Fig. 1 and Table 2 present examples of analyzing blooming phenology which relate to pollination efficiency, and male and female flower density at treatment plots in this case. There were no significant differences between treatments (one-way ANOVA).

Fig. 1: Male and female flower density

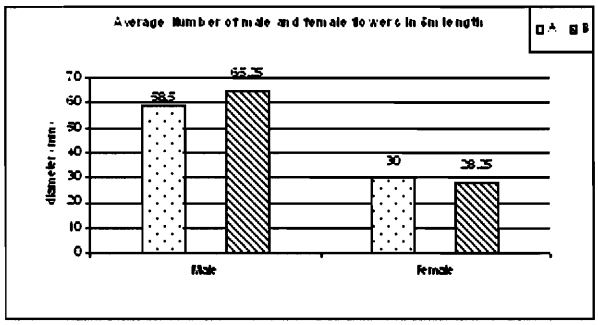

Table 2: Male and female flower density

Distance (m)	No. of Flowers per meter (Male + Female)									
	A1	A2	A3	A4		B1	B2	B3	B4	
1	18	18	14	15	16.25	15	21	21	20	19.25
2	13	18	17	20	17	16	18	21	13	17
3	17	16	17	16	16.5	15	18	16	21	17.5
4	18	23	21	14	19	20	15	20	17	18
5	16	20	23	20	19.75	16	14	22	25	19.25
Sum	**82**	**95**	**92**	**85**	**88.5**	**82**	**86**	**100**	**96**	**91**

Sex Ratio

The plants of the cucurbits crops studied for this project — melon, watermelon, and zucchini — are monoecious. Only the female flowers produce fruit, but they depend on pollen availability from male flowers for Fruitset. So, sex ratio is an important parameter.
Table 3 and Fig. 2 present examples of analyzing sex ratio in melon flowers at the Ghor-A-Safi NCARTT station

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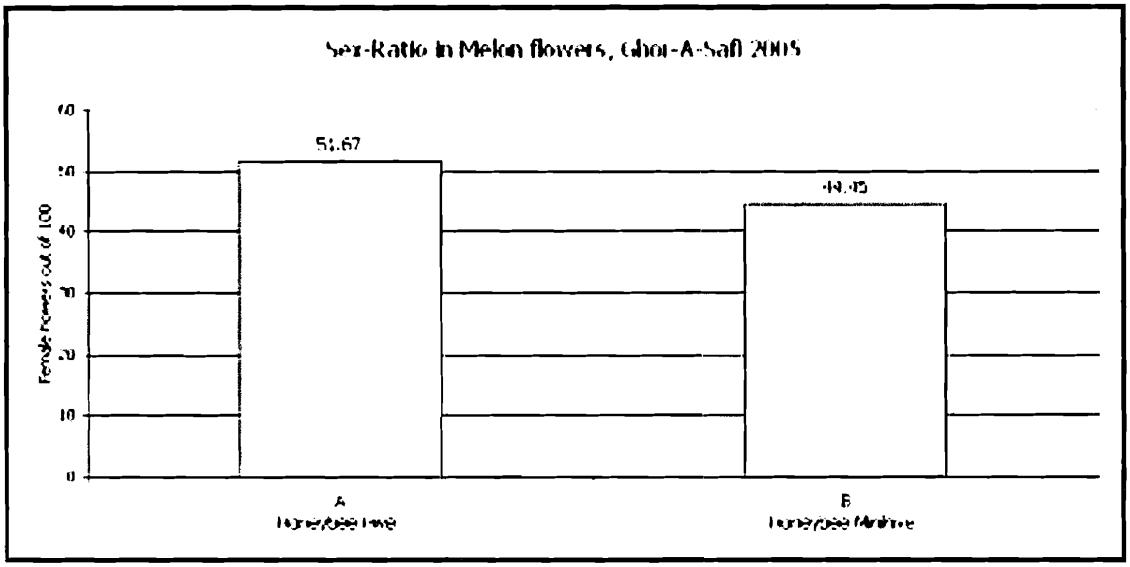
Fig. 2: Sex ration in melon flowers, Ghor-A-Safi, 2005



Plot	Sex Ratio (Female/Male)	
A1	58.7	51.67
A2	38	
A3	49	
A4	61	
B1	45	44.45
B2	47	
B3	38.8	
B4	47	

Table 3: Sex ratio in melon flowers, Ghor-A-Safi, 2005.

The sex ratio was greater (higher number of female flowers) for melon plants in the plastic house with honeybee hive (A) than for melon plants in the plastic house with honeybee Minihive (B) but statistically the difference was not significant (t-test, P = 0.244).

Flower reward

The nectar reward presented by the flowers determine the attractivity of the flowers for the pollinators. Nectar yield (standing crop) and nectar production were measured.

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Figs. 3 and 4 presents examples of nectar yield and concentration in melon flowers at the Ghor-A-Safi NCARTT station.

Fig. 3: Nectar yield in melon flowers, Ghor-A-Safi 2005.

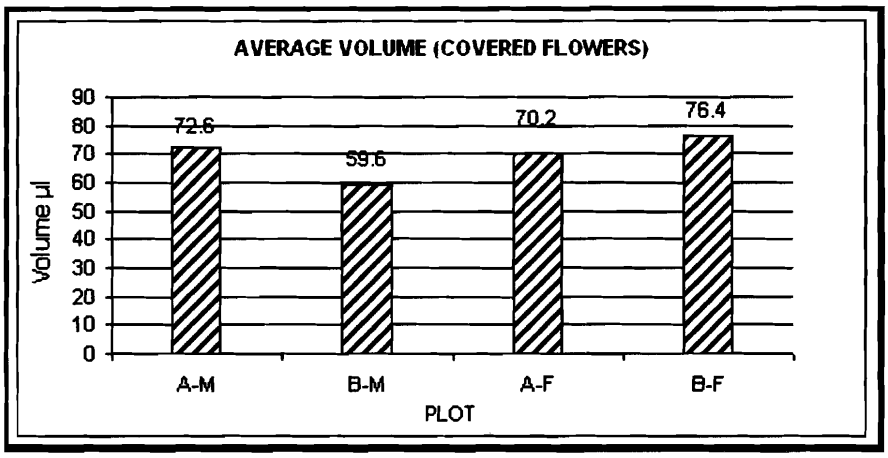
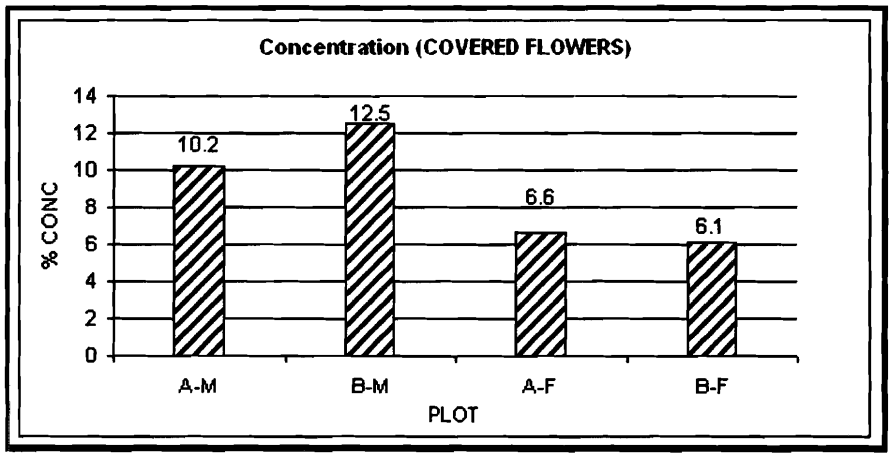


Fig. 4: : Nectar yield in melon flowers, Ghor-A-Safi 2005.



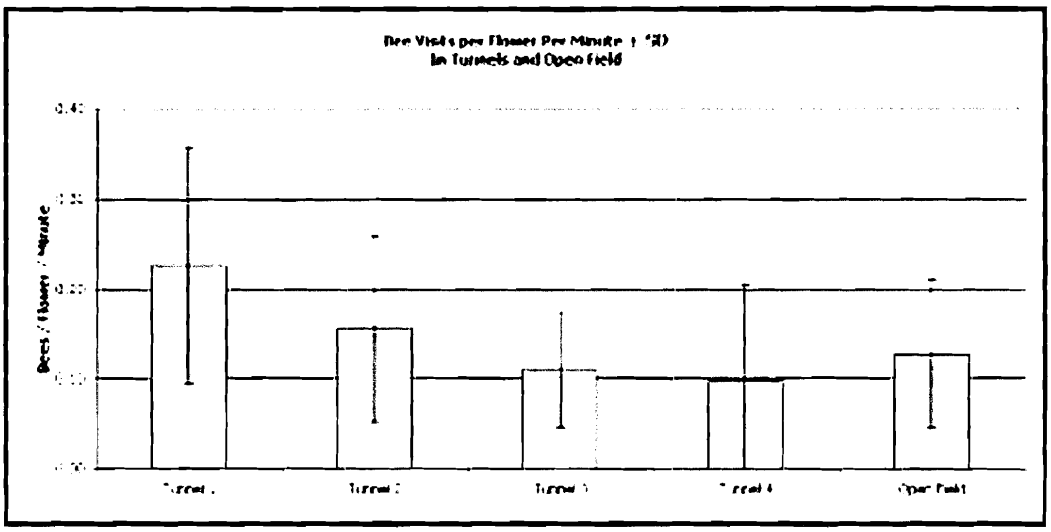
There was no significant difference in the nectar production between male and female uncovered flowers for melon plants in the plastic house with honeybee hive or Minihive (B).

Also, there was no significant difference in the average sugar concentration of uncovered male and female flowers of melon plants in the plastic house with honeybee mini-hive (B) and with honeybee hive (A).

Pollinator activity

Fig. 5 presents examples of pollinator activity data collected at the Revadim 2004 experiment, where melon pollination under conditions of low enclosures (0.7 m. high nethouses) by Honeybee hives (Tunnels No. 1 & 2) was compared to pollination by Minihives (Tunnels No. 3 & 4) and to pollination by Honeybee hives in the open field.

Fig. 5: Bee visits per flower per minute, melon flowers, Revadim 2004



The minimal values are six visits per flower per hour.

Fig. 6 presents Pollinator diurnal activity data collected at the Revadim 2004 experiment. Foraging activity starts at 07:30 AM and continues until late afternoon with the peak between 07:30 AM and 10:00 AM, so that each flower receive at least fifteen visits before noontime.

Fig. 6: Bee visits per flower per minute during the day, melon flowers, Revadim 2004

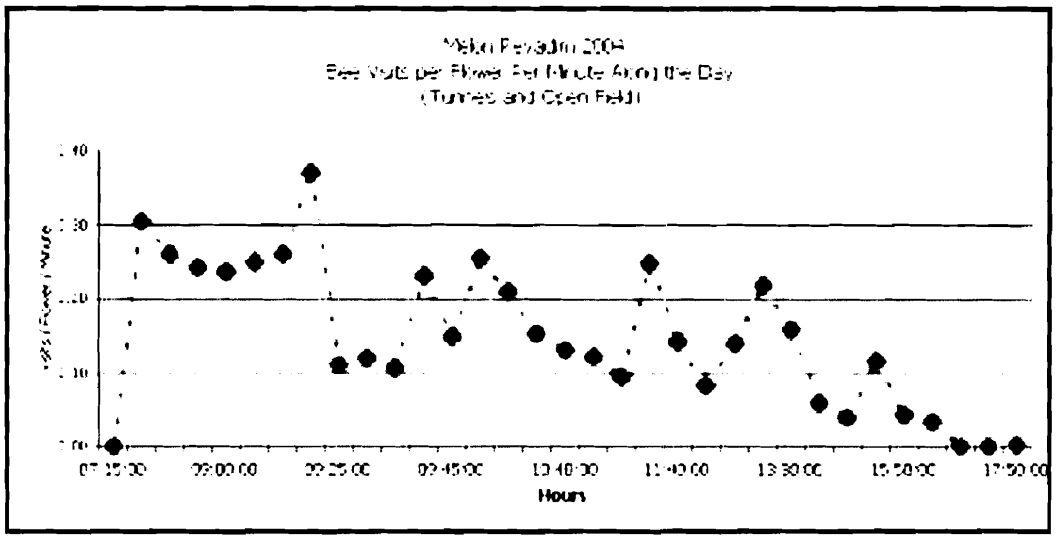


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Fig. 7 presents hives (Honeybees & Bumblebees) activity in strawberry at the A-Rabba NCARTT station. There were two-minute counts of bees entering the hives. It is to be remembered, while looking at the figures, that the two pollinators differ significantly in terms of population size.

Fig. 7: Hives activity in strawberry at the A-Rabba 2005

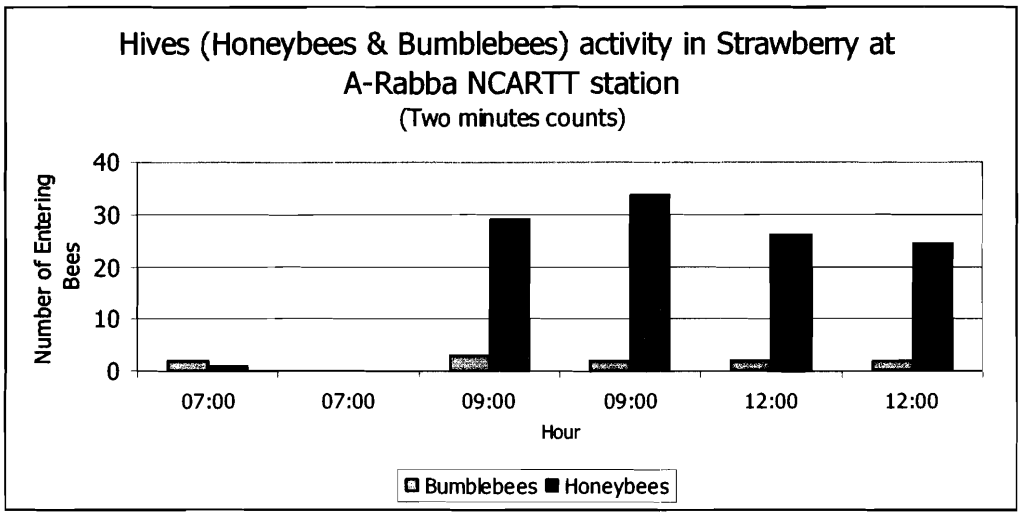

Table 4 presents Pollinator (Honeybees and Bumblebees) visitation rates on strawberry flowers. Although the activity of bumblebees at the hive entrance is much lower than that of honeybees (see Fig. 7), visitation rates of bumblebees on flowers is very similar to those of honeybees, which means that the bumblebees' foraging rate is higher.

Table 4: Bee visitation rates on strawberry flowers, A-Rabba 2005

Date	Time		Observed flowers Number	Bee Visits Per 10 Minutes	Bees visite per flower per minute
02-02-05	12:00PM	Honeybees	8	10	0.125
03-02-05	10:00AM	Honeybees	6	11	0.183
26-01-05	10:00PM	Bumblebees	8	19	0.238
26-01-05	1:00AM	Bumblebees	10	12	0.120

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Fruit set and yield of crops

Table 5 presents examples of fruit yield of melon at the Ghor-A-safi station, during the 2005 season, comparing the efficiency of Honeybee hives (Langstroth) and Honeybee Minihives.

Table 5: Fruit yield of melon Ghor-A-Safi 2005

Average Yield Kg. / 5m.	Plot ID	
Date	Honeybee Hive	Honeybee Minihive
05/04/2005	13.03	12.60
26/04/2005	12.68	11.28
Average	12.85	11.94

The yield in the Honeybee hive-pollinated plots was slightly higher than in the Minihive-pollinated ones, but not significantly so (t-test, P = 0.212).

Fig. 8 presents an example comparing the yield in zucchinis in net houses, pollinated by Honeybee Minihive vs. Bumblebee colony. Here, again, there was no significant advantage of any pollinator (t-test, P = 0.129).

Fig. 8: Yield of Zucchini in nethouse pollinated by Minihive vs. Bumblebee 2003

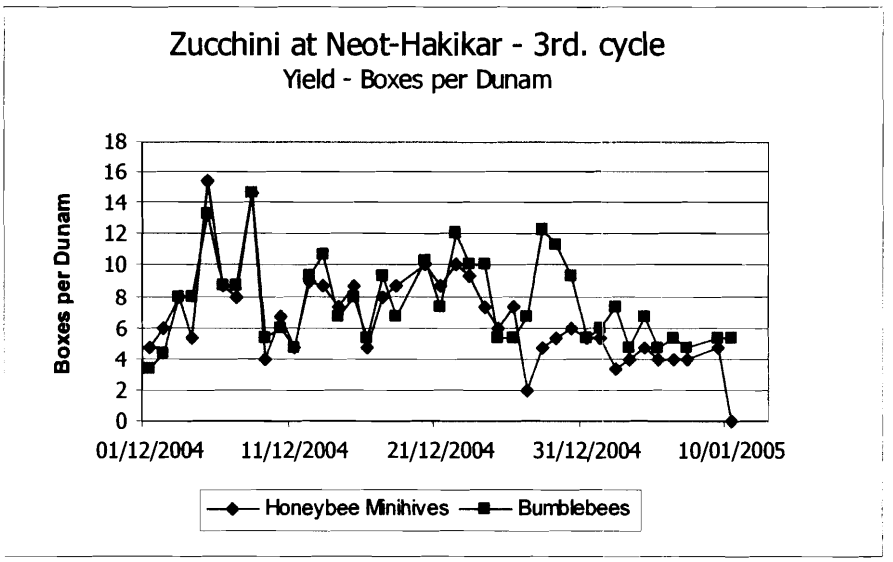

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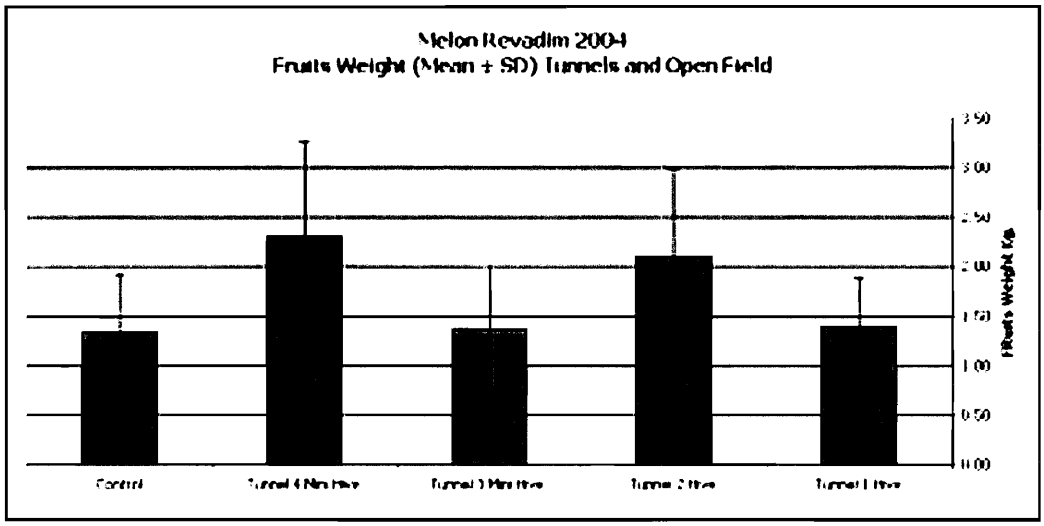
Fig. 9 presents a yield (fruit weight) at the Revadim 2004 experiment, where melon pollination under conditions of low enclosures (0.7 m. high nethouses) by Honeybee hives (Tunnels No. 1 & 2) was compared to pollination by Minihives (Tunnels No. 3 & 4) and to pollination by Honeybee hives in the open field. No significant differences of yield were found among the treatments.

Fig. 9: Melon yield in Revadim experiment 2004



Discussion: Comparing The Efficiency of Honeybee Hives, Honeybee Minihives ("Nucs") and Bumblebee colonies in Pollination of Crops

It was demonstrated that:

Under most circumstances, excluding plots where crop failed to grow, the different pollinators performed efficiently with no significant differences in terms of visitation rates and crop yields. Even under extreme conditions (like in low enclosures in the Revadim experiment), bees' foraging activity was found to be good to high.

Minihives functioned as efficiently as the regular hives. Minimal honeybee visit numbers on melon flowers in Revadim experiment was above 15 visits per flower between 9:00 AM and 12:00 AM. This figure is almost twice the required number of visits for good fruitset (Adlerz, 1966).

Since the various pollinators performed equally efficient in the pollination of the tested crops, we conclude that future decisions about which pollinators to apply, will have to consider more factors. Such factors will be: expenses, operational flexibility in terms of transportation to target crops, manipulation during pesticide treatment and maintenance.

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Honeybee Minihives Sustainability

Results of comparative experiments conducted within the frame of the project (see above) demonstrated that the pioneering application of Honeybee Minihives for pollination of agricultural crops is feasible and efficient. Applying Minhives for pollination in agriculture has specific advantages over regular (Langstroth) honeybee hives, like greater operational flexibility, lower bee aggression, and easier transporting. Minihives are manipulable by the farmer himself without the need of professional beekeeper attendance. This enables the farmer to feed the Minihive when needed and to close and transfer it out of the enclosure when there is a need to spray pesticides. Pollinators' poisoning by pesticides spray is a serious problem (e.g.: Pollination, BERRY, 2005-6, BC Canada) Another forecasted advantage is lower price potential, which depends, among other factors, upon the sustainability of Minihives under pollination activity conditions. Therefore, in a separate study, we examined, the long term sustainability of Minihives.

Methods And Data Collection

Data collected included observations of the activity at the Minihives' entrance and periodical monitoring of the hive population, queen presence and fertility, and brood and honey storage conditions. Most of the work was done in the "Beehave" lab in Jerusalem, where Minihives were transferred to after they had finished pollinating agricultural crops and were opened to free forage. A similar setup was used in Achva College Campus greenhouse. The Minihives were fed by sugar syrup at intervals defined by population condition.

Fig. 10 presents the activity of twelve Minihives' from March to August 2004. While examining the figures, bear in mind that Minihive population is two magnitudes of order below that of regular Honeybee hives. Note that certain Minihives, like those marked jerusalemגמ, jerusalem סל, and jerusalemשלחד, showed good activity for from four months to six months. The presence of an open brood in the Minihives, presented in Fig. 11, shows similar results with good potential for longer sustainability.

Fig. 10 : Minihives' activity March to August 2004

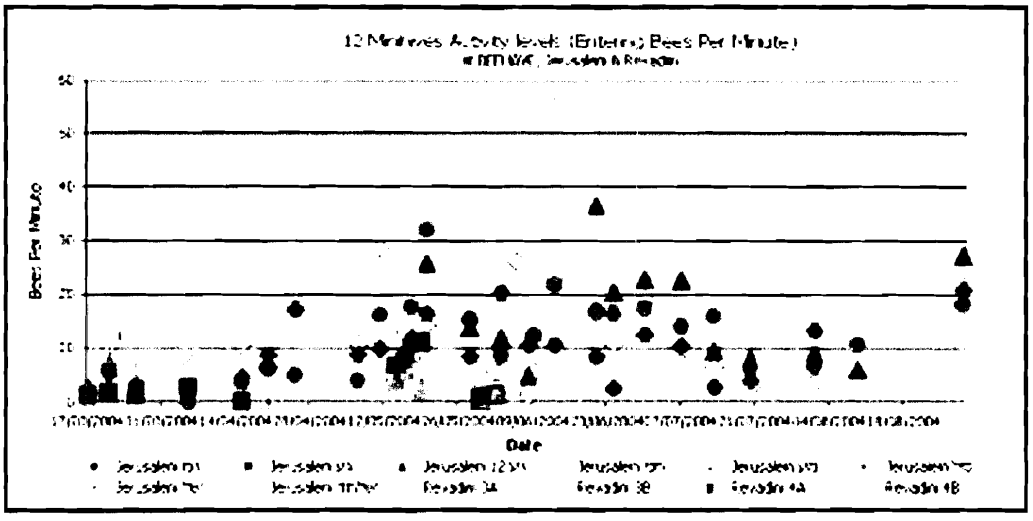

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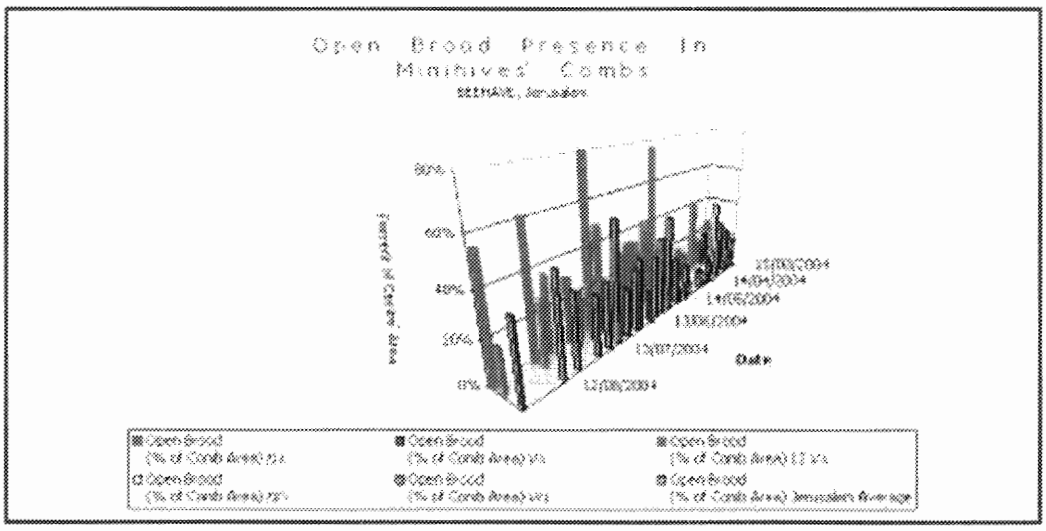
Fig. 11: Minihives - open brood presence March to August 2004



Discussion: Minihive Sustainability

We demonstrated that Minihives are sustainable for several months with potential, under good maintenance, for longer periods. Fig. 12 show Minihives in open Zucchini plot in A-Rabba NCARTT station (right) and within a net house in Revadim experiment (left).

Fig. 12: Minihives in open Zucchini plot in A-Rabba NCARTT station (right) and within a net house in Revadim experiment (left).

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Studying Native Carpenter Bees (Xylocopa) as Potential Pollinators for Agricultural Crops

Methods and Data Collection

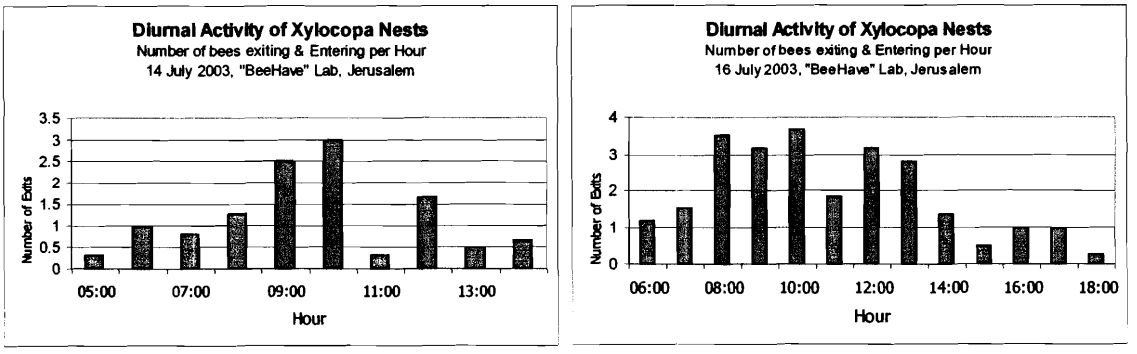
Nesting behavior, preferred nesting materials, and diurnal activity were studied under natural conditions in Ein-Gedi and under enclosures in the "BeeHave" Lab net house in Jerusalem and in the Achva College Campus greenhouse, where foraging behavior on melon flowers was studied too. Observations were conducted according to protocols developed for this purpose.

We observed Xylocopa nests in a greenhouse containing melons between October 2003 and September 2005. We recorded the bees' (a) daily activity patterns in relation to nectar yields in melon flowers, (b) seasonal activity patterns, (c) frequencies of visits to melon flowers, and (d) pollination efficiency.

Results:

Fig. 13 shows daily activity patterns at the Xylocopa nest openings in the "BeeHave" Lab net house in Jerusalem, in July 2003. The pattern is unimodal. Later observations in the Achva College Campus greenhouse showed different patterns (see below), but those should be related to lower temperatures typical in Jerusalem and to the fact that greenhouses warm up fast and create temperatures much higher than the air temperature, which is not the case for net houses.

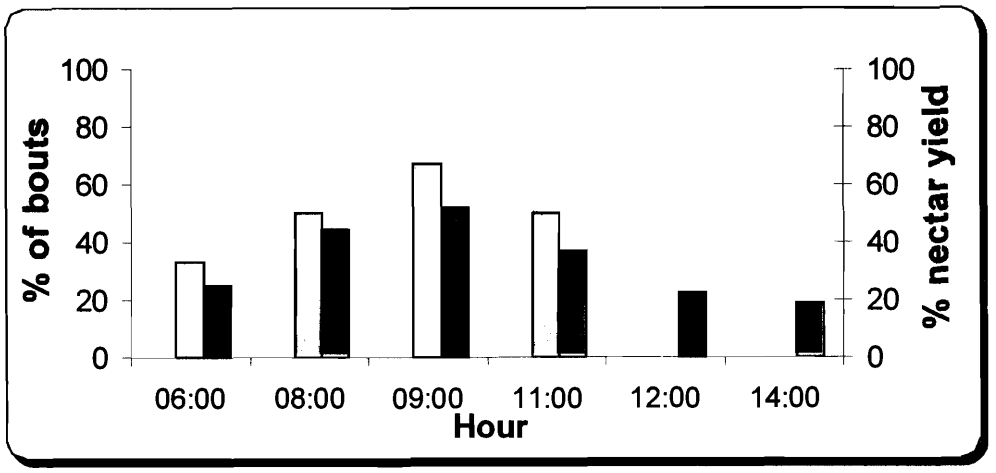
Fig. 13: Diurnal activity of Xylocopa at nest openings.



Recent observations show diurnal activity patterns which differ between seasons. Daily activity was bimodal (early morning and afternoon) in summer, and unimodal (morning only) during the rest of the year.

Fig. 14 shows bees' daily activity cycle in the Achva greenhouse. The daily activity cycle was found to be highly correlated with the daily pattern of nectar secretion in the melons (Spearman, df=5, r=0.971, P=0.001, Fig. ??).

Fig. 14: Xylocopa bees' daily activity cycle and nectar secretion



1st day (6 AM and every 3 hours thereafter)
- % of total daily foraging bouts
- % of total daily nectar yield

2nd day (8 AM and every 3 hours thereafter)
- % of total daily foraging bouts
- % of total daily nectar yield

Figs. No. 14 and 15 relate to the efficiency of Xylocopa bees as pollinators of melon plants in the Achva greenhouse. We observed bee visits on melon flowers and the fruits produced.

Fig. 14 shows Xylocopa visits to melon flowers per bee and per hour.

Fig. 14: Xylocopa visits to melon flowers per bee and per hour.

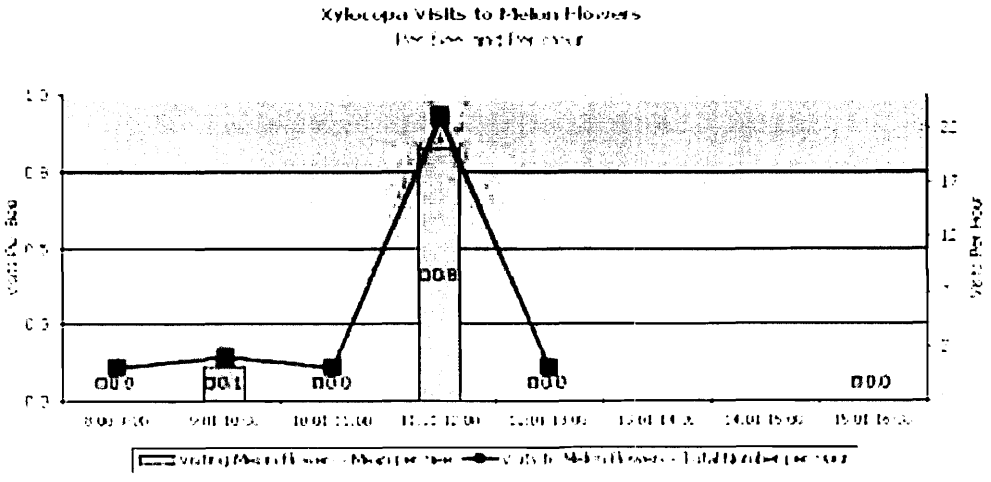


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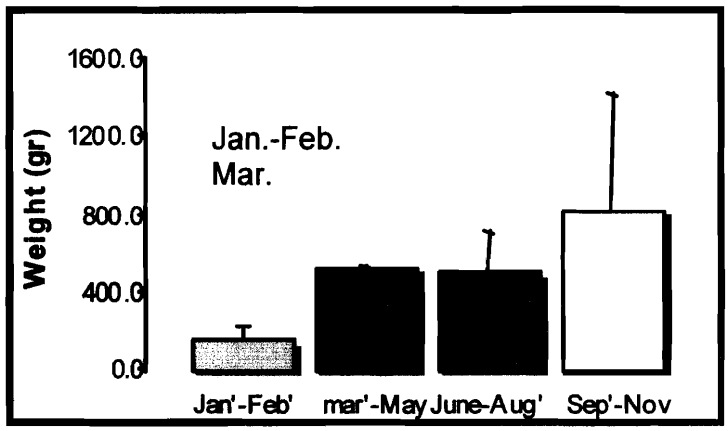
Fig. 15 presents the mean melon weight at different seasons as measured within the greenhouse in Achva.

Fig. 15: Xylocopa pollinated melon - fruit weight at different seasons.



Visits frequency found to be above required number of visits for good fruitset (Adlerz, 1966). Pollination by Xylocopa resulted in fruit development in all seasons. The highest weight was recorded in autumn (Fig. 15).

Discussion

We demonstrated (Kalish et al, 2005) that pollination of melons in greenhouse by Xylocopa result in fruit development in all seasons. The highest weight was recorded in autumn. Those results are far from being applicable to commercial crops and much work has yet to be done to test this applicability, but our work demonstrates the feasibility of using Xylocopa pubescens for greenhouse pollination.

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Activities and Productivity

Activities

Meetings

About thirty (~30) meetings were held during the projects' period, mostly in Jordan (see Appendix: Project Activities - List of Travels and Meetings). Several-tenths of Jordanian and Israeli participants took part in those meetings. Activity at the meetings included planning experiments, planting experimental plots, and training sessions dealing with the following issues: understanding main parameters relevant to pollination efficiency in agriculture, studying and drilling in methods of assessing and quantifying those parameters and comparative analysis of data collected.

Workshops

Two training workshops were conducted. One full Pollination Ecology Training Workshop was held in Al-Shoubak NCARTT Research Station in Jordan for four days in August 2004 with about twenty participants. The other workshop was a field-guided tour of experimental plots in Israel in December 2004.

Israeli experts who contributed to the project

Mrs. Noga Reuven – Apiculturist.
Mr. Beni Avni – Cucurbits agronomy.
Dr. Yossi Burger – Cucurbits genetics.
Mr. Shauli Ravid - Agrotechnical management
Mrs. Or Neta – Cucurbits agronomy and pollnation.
Mr. Zuf Or – Agrotechnical management

Productivity

It is important to notice that the budget for the Jordanian Institute was allocated only at the beginning of April 2003, after a delay of nine months. Political and security constraints created in Jordan during the project forced us to conduct the study in southern Jordan, since it was not plausible for the Israeli partners to work in the northern parts of Jordan.

As mentioned in the proposal, we planned to investigate the potential for using two native genera — blue orchard bees (*Osmia*) and carpenter bees (*Xylocopa*) — for crop pollination. Starting the studies on Xylocopa, we found that we underestimated the efforts needed to deal with field surveys, domesticating or semi-domesticating each species, and studying pollination activities. Such efforts for one more species were found to be practically beyond the scope of the project and we preferred to focus on the Xylocopa.

Another constraint was created by the failure of crop growth at several plots in Jordan. Causes included viral diseases and inadequate agrotechnical management. The implications included delay of the plan and the need for more detailed agrotechnical management training for the growers.

Future Work

Applying Xylocopa for Pollination of Agricultural Crops

Our work demonstrated the feasibility of using Xylocopa pubescens for greenhouse pollination. Results showed fruit development in all seasons, but those results are far from being applicable to commercial crops and much work has yet to be done to test this applicability. Ongoing work focuses on comparison of pollination parameters between Xylocopa and honeybees in the greenhouse.

Future work should examine pollination efficiency of Xylocopa on other crops, especially crops that benefit from "buzz pollination" and on pilot commercial scale. Contemporaneously, techniques for mass nests initiating under natural conditions should be developed (Donovan et al. 2001, 2003).

Using Minihives for Pollination of Agricultural Crops

The work done within the framework of the project demonstrated that the use of Minihives for the pollination of agricultural crops in enclosures (greenhouse or nethouse) is feasible and efficient.

There are several advantages of this application over regular honeybee hives:

Greater operational flexibility.

Lower bee aggression.

Transporting Minihives to the target crops is easier without the need of professional beekeeper services.

Minihives are manipulable by the farmer himself.

The farmer can feed the Minihive when needed.

The farmer himself can close and transfer the Minihive out of the enclosure before spraying pesticides.

Future work should study the lower price potential of rented Minihives for pollination. To realize this and other advantages mentioned above, a long-term (at least two years) study of sustainability of Minihives under pollination activity conditions should be performed. Contemporaneously, the applicability of Minihives to pollinate various crops should be studied. Also, guidelines for farmers and protocols for pollination practices and the maintenance of the Minihives should be developed.

Enhancing Awareness and Advancing Pollination Practices in Jordanian Agriculture

During the ninety to one hundred days we were in Jordan for the project, in talking with farmers as well as with NCARTT technicians and extension specialists, we found that majority of the farmers are not aware of the importance of pollination for getting high quality and bigger harvests.

We believe that apart from continuing the development of pollination practices and techniques as mentioned above, it is very important to educate farmers and teach them the role of pollination in the potential increase of their income.

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Appendices

Project Activities: List of Travels and Meetings p. 29

Protocols and Tasks Lists (examples) p. 33

Project Activities: List of Travels and Meetings

Date	Location	Activity & Collaborators
13-17 Sept 2002		Visit to Jordan: Prof. Shmida, Mr. Shihadeh
13-16 Oct 2002		Visit to Jordan
4-6 Nov 2002		Visit to Jordan
27-29 Jan 2003		Visit to Jordan
17 Feb 2003	Jordan	Al-Haq Farms Staff: Visit fields of Muskmelon and Watermelon to choose observation plots.
7-9 Apr 2003	NCARTT Res. Station at Al-Shoubak, Jordan	Prof. Shmida, Mr. Shihadeh, Mr. Dan Weil, Mrs. Hodda and Mr. Ahmad Khraisat. Apples: Developing protocol, training and performing study of: Flower phenology, Assessing bloom volume, Nectar reward, Pollinators' activity, Pollination Efficiency.
7-9 Apr 2003	NCARTT headquarters -Amman	Dr. Fardous (NCARTT DG), Prof. Shmida, Mr. Shihadeh and Mr. Dan Weil: Discussion of collaborative project(s) –current (C46) and future ones.
7-9 Apr 2003	NCARTT Res. Station at Al-Rabbah and Ghor A-Safi, Jordan	Dr. Majali (NCARTT A-Rabba Station GM), Prof. Shmida, Mr. Shihadeh, Mr. Dan Weil, Muskmelon and Watermelon: Planning a plot at Al-Rabbah Station for those crops to be blooming on May 2003 (seeds brought from Israel for this purpose). At Ghor A-Safi Station: Planning for work in watermelons, Sept – Dec 2003. Meeting farmers to evaluate the current situation of pollination activity in Ghor A-Safi area.
7-9 Apr 2003	NCARTT Res. Station at Ghor A-Safi, Jordan	Mr. Said (NCARTT Ghor-A-Safi Station deputy manager), Prof. Shmida, Mr. Shihadeh, Mr. Dan Weil. Planning for work in Watermelons, Sept – Dec 2003. Meeting farmers to evaluate the current situation of pollination activity in A-Safi area.

Date	Location	Activity & Collaborators
5-8 May 2003	NCARTT Res. Station at Al-Shoubak, Jordan	Dr. Ismail Tawissyi (Shoubak Station GM), Prof. Shmida, Mr. Shihadeh, Mrs. Hodda and Mr. Ahmad Khraisat.
5-8 May 2003	Al Quwayra region	Prof. Shmida, Mr. Shihadeh and Mr. Ahmad Khraisat. Al Quwayra area, where some thousand dunams of watermelons are cultivated by local Bedouin tribesmen. There we worked with our Jordanian colleagues, providing training in pollination study methods developed in the Israeli Arava Valley.
2-6, June 2003	NCARTT Res. Stations at Al-Shoubak and at Al-Rabba and Al-Qasser, private farm.	Prof. Shmida, Mr. Shaul Ravid and Mr. Shihadeh,. Planting seedless watermelons and zucchini in three plots, one an intercropping at an olive orchard.
17-25, June 2003	NCARTT Res. Stations at Al-Shoubak and at Al-Rabba and Amman. NCARTT Res. Stations at Al-Shoubak	Prof. Shmida and Mr. Shihadeh. Tour with AID representatives. Prof. Shmida and Mr. Dan Weil Checking watermelons' growth problem, reported by Stations' staff.
15 Jan 2004	NCARTT Res. Station at Al-Rabbah, faculty of Agriculture Muta'h University	Visit to Jordan: Prof. Shmida, Mrs. Noga Reuven, Mr. Shihadeh: Installing Minihives at both sites.
26 February 2004	NCARTT Res. Station at Ghor-A-Safi	Visit to Jordan: Prof. Shmida, Mr. Shihadeh
4 Mar 2004	NCARTT Res. Station at Ghor-A-Safi, & Feifa Jordan	Visit to Jordan: Prof. Shmida, Mr. Shihadeh, Mrs. Neta Or, Mr. Zuf Or and Mr. Dan Weil. Planting Melons and Watemelons
15 Mar 2004	NCARTT Res. Station at Ghor-A-Safi, & Feifa Jordan	Visit to Jordan: Prof. Shmida, Mr. Shihadeh,
28 Mar – 1 April 2004	NCARTT Res. Station at Al-	Visit to Jordan: Prof. Shmida, Meeting with Mr. Shahahat and Mrs. Hodda – working plans.

Date	Location	Activity & Collaborators
	Shoubak, Jordan	
24 - 25 April 2004	NCARTT Res. Station at Al-Rabbah	Visit to Jordan: Prof. Shmida. Working with Dr. Majali
24 - 25 May 2004	NCARTT Res. Station at Al-Rabbah and Ghor-A-Safi, Jordan	Visit to Jordan: Prof. Shmida. Working with Dr. Majali. Meeting with Dr. Nizar Haddad – discussing ongoing project plans.
24 June 2004	NCARTT headquarters -Amman	Meeting with Dr. Nizar Haddad. Planning work for next season.
8-7 July 2004	Beit Idis (Irbid) Rabba area	Visit to Jordan: Prof. Shmida with Mr. Osama Migdadi (technician) Mustafa Khwayleh (technician). Studying phenology and pollination ecology.
8-11 August 2004 17-19 August 2004	Beit Idis (Irbid) Al-Shoubak	Visit to Jordan: Prof. Shmida. Studying phenology and pollination ecology. Pollination Ecology Training Workshop at Al-Shoubak.
30 September 2004	Beit Idis (Irbid)	Visit to Jordan: Prof. Shmida. Studying phenology and pollination ecology.
11-14 October 2004	Rabba Station	Visit to Jordan: Prof. Shmida. Working with Dr. Majali on next season's plan.
10 November 2004	Beit Idis (Irbid)	Studying phenology and pollination ecology.
December 2004	Israel	Visit of a Delegation from Jordan, headed by: Dr. Nizar Haddad, Coordinator of the bee research unit. Dr. Nedal Al Majali, Head of Al-Raba Regional Research Center – NCARTT. Workshop on Bee Breeding and Pollination for Jordanian Professionals.
28-29 December 2004	A-Saffi & Mazraat A-Lissan and A-Rabba NCARTT station	Planning experiments and planting experimental plots in Ghor-A-Safi & Mazraat A-Lissan (melons) and A-Rabba NCARTT station (strawberry)
16-18 January 2005	A-Saffi & Mazraat A-Lissan and A-Rabba NCARTT station	Visit to Jordan: Prof. Shmida. Studying phenology and pollination ecology Melons and strawberry
26-31 March 2005	NCARTT stations at Rabba & Shoubak,	Follow-up of experimental plots in A-Saffi & Mazraat A-Lissan (Melons) and A-Rabba NCARTT station (strawbwerry).

Date	Location	Activity & Collaborators
	Mt. Nebo & Edomia plateau	Studying honey plants in Madaba & Shoubak regions
1-2 May 2005	Amman	Visit to Jordan: Prof. Shmida. Discussing summation.

Protocols

Monitoring Honeybee Hives and Mini-Hives

Introduction: This tasks' list aims to supply a tool to monitor and assess the condition of Honeybee Hives and Mini-Hives (Nuclus, "YAARIOT").

Schedule: Twice a week or, at least, once a week on the same day.

Equipment: Bee suit, Bee veil, Gloves, Hive Tool, Smoker.

Preparations: Mark individually each hive.

External Observations:

General Condition:
Observe the entrance to the hive and vicinity. Look for any abnormal phenomena like dying and\or convulsive bees, thrown out brood, malformed bees etc..

Hive Weight: Weigh the hive. If fed lastly, consider quantity of unconsumed sugar (after opening the hive).

Foraging Activity:
At peak of daily activity (commonly 09:00 AM to 12:00 AM), Stand near the hive so you have good view of the entrance. DO NOT stand in front of the hive, where you disturb the bees. Count entering foragers during two minute. Count bees coming in with and without pollen loads. Use counters. Repeat counts twice.

Internal Observations:

To be conducted AFTER completing external observations.

Preparations:
Apply small dose of smoke to the entrance only (not needed for Minihives).

Marking Combs – the first time you open the hive number the combs with a marker and mark direction of each comb, so you'll be able to discriminate between comb sides (a,b).

Monitor Population Condition
Open the Hive carefully, with minimal disturbance to the bees. Observe the combs from above. Estimate and write down number of populated combs (= between combs spaces filled with bees).

Monitoring Brood condition
Take out combs, one by one, assess sealed brood area on both sides as percentage of total comb area.
Asses and write down presence of open brood, including eggs and larvae.
Asses and write down presence of Honey and Pollen storage cells.
If no open brood present, try to find the queen.
Note and write down presence of "wild combs", means combs built outside the frames, in other spaces of the hives (in feeders, under the cover etc.).

Follow Up
Compare results to former inspections. Try to see trends of development or deterioration.

Table 1.: External Observations Before Opening the Hive

Date_____
MiniHive ID.:_____
Observer_____
Write Data or Mark Choices

Hive Weight gr.			
Within greenhouse Exceptional bees' behavior: Under ceiling or near walls crowding	near walls	Under ceiling	None
Near Hive Entrance Exceptional bees' behavior: Sick, Dead Bees, thrown out garbage, chalk brood (number) _____	_____ Dead	_____ Sick	None

Entering Bees' Count	Time _____	Time _____	Time _____	Time _____
Number of bees entering in 5 minutes				
Number of bees entering with pollen loads (part of overall count)				

Table 2.: Internal Observations: MiniHive Honeybees (4 combs)

Date_____
Hive ID.:_____ Observer_____
Write Data or Mark Choices

	BROOD		POLLEN	HONEY	
Comb No. & Side (a\b)	Sealed Brood % of Comb Area	Open Brood % of Comb Area	Pollen Storage % of Comb Area	Sealed Honey % of Comb Area	Open Honey % of Comb Area
1a					
1b					
2a					
2b					
3a					
3b					
4a					
4b					

Aug 2003

WaterMelon & Melon Observations Tasks List

1. Flower Parameters

1.A. *Flower Dimensions: Measure flower diameter and Petal length in millimeters (mm).*
Sample: 10 Male Flowers and 10 Female Flowers

1.B. *Number of Anthers – NOT APPLIED TO WaterMelon & Melon*

1.C. *Anthers' Length - NOT APPLIED TO WaterMelon & Melon*

2. Flowers' Density

2.A. *Count flowers on plants along 5 meters. While counting, write down the sex of each flower (see Task No. 3).*

3. Flowers' Sex Ratio

3.A. *Count and write down the sex of each of 100 flowers. You can use the data from Task No. 2, but pay attention that if in 10 meters you do not have 100 (one hundred) flowers, you must continue counting until you get a hundred.*

4. Flowers' Opening Time

4.A. *Early in the morning (05:00 AM) mark 20 Male Flowers and 20 Female Flowers by colored tape. MARK CLOSED FLOWERS THAT WILL BE OPENED TODAY (to achieve this, you will have to perform two to three markings to get experience).*
Each half an hour check the flowers and write down the number of opened flowers.

5. Flowers' Longevity

5.A. *After all marked flowers from Task No. 4 open, continue to check them daily, at 6:00, 12:00 and 18:00, until they wilt.*

6. Nectar Reward

6.A. *Nectar Yield:*
Early in the morning (05:00) Before Pollinators' start visiting the flowers, Measure Nectar Volume and Concentration in 10 Male Flowers and in 10 Female Flowers. Repeat the same measurement at 9:30 AM.

6.B. *Nectar Production:*
Early in the morning (05:00) Before Pollinators' start visiting the flowers, choose and mark about 0.5 m. along a row, so you'll have at least 10 Male Flowers and 10 Female Flowers, and cover this part of the row with a net to prevent pollinators' visits. At the same hour next day** - Measure Nectar Volume and Concentration in bagged Flowers.*

* We use this technique, because it is difficult to bag individual watermelon and melons' flowers.

** Consider flowers' longevity (Task No. 5). If it is less than 24 hours, do second measurement afternoon the same day.

7. Bee Visitations

7.A. *Bee Visits: Ten Minutes Sampling. Choose a patch of flowers that you can observe simultaneously. Count Pollinators' Visitations for 10 minutes. If many bees are coming you can narrow the patch you observe. Make at least 3 replicates.*

7.B. *Transect: Count bees visiting flowers along 50 m. Measure fifty meters (50 m.) along a row. It is recommended to stick two marked poles at the edge of the field, so you can see them clearly. Go slowly, about two minutes, along the row and count the foraging bees. Count only bees visiting flowers.*

7.C. *Honeybee Hives' Activity: Monitor the hive's activity by counting entering foragers for One (1) Minute. Stand near the hive, but not in front of the entrance, so you will not disturb the bees. Using stopwatch and counters, count the bees entering the hive for one minute (use one counter to count all entering bees and the other to count bees coming with pollen pellets on their legs). Count at 07:00, 09:00 and 12:00 AM. Each hour do two replicates (twice one minute).*

7.D. *Percent of Bee Coming With Pollen: Use the data from the activity counting to calculate percentage of bees coming with pollen from entering foragers.*

8. Pollen

8.A. *Stamen Opening: NOT APPLIED TO WaterMelon & Melon*

8.B. *Pollen Weight in Anther: Cut and weigh an Anther from flower opening (Use for this the Male Flowers you sample for nectar yield production), than brush off all pollen grains and weigh again.*

8.C. *Quantifying Pollen Grains in Flower: NOT APPLIED TO WaterMelon & Melon*

8.D. *Quantifying Pollen Grains on Bees: NOT APPLIED TO WaterMelon & Melon*

8.E. *Pollen Load on Stigma: NOT APPLIED TO WaterMelon & Melon*

9. Fruitset and Yield

9.A. *Fruitset: Fruitset and Yield will be measured along 10 m. section of the row. At least once a week cut fruits, count, measure weight.*

10. Seeds' Number per Fruit

10.A. *Seeds' Number per section: Cut length median section of the fruit and count number of seeds at the section. Sample 10 fruits. NOT APPLIED TO WaterMelon & Melon.*

10.B. *Seeds' Number per whole fruit. NOT APPLIED TO WaterMelon & Melon.*