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United States - Israel Binational Agricultural Research and Development Fund

13.11

FINAL REPORT

PROJECT No. US-151-79

Biological Control of Sap Beetles Attacking Fruit Crops

R.N. Williams, M. Kehat, D. Blumberg

1984

630.72

BAR

2nd copy

- 1) Beetles - Biological control
- 2) Fruit - Diseases and pests

630.72 : 632.76 : 632.96

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2011 3

Standard BARD Cover Page for Technical Reports

Date January 1, 1984

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P.O. BOX 6
Bet Dagan, ISRAEL

BARD Project No. U.S. -151-79

Title of Research Project:

Biological Control of Sap Beetles Attacking Fruit Crops

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Agricultural Research Organization, The Volcani Center, Bet Dagan, Israel

Project's starting date: 1 April 1980

Type of Report: Initial Comprehensive Final X

Signatures:

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RECEIVED
JAN 10 1984
U.S.

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1 ABSTRACT

2 Over the past three years a cooperative investigation of the natural
3 enemies of sap beetles has been conducted in Israel and the U.S. under BARD
4 sponsorship. Actually the first studies established benchmarks for the pop-
5 ulations of the sap beetles. In Israel the most important species are Haptoncus
6 luteolus (Er.), Carpophilus humeralis (F.) followed by C. hemipterus (L.) and
7 C. mutilatus (Er.). In Ohio Stelidota geminata (Say) was found to reproduce
8 in strawberry fields and migrate to other crops as food diminishes.

9 One hymenopterous parasite, Zeteticontus utilis (Noyes) was studied both
10 in the U.S. and Israel. It was found to have two strains and attacks major
11 date sap beetle pests as well as a major sweet corn sap beetle pest. Three
12 hymenopterous parasites indigenous to the U.S., Zeteticontus insularis (Howard),
13 Microctonus nitidulidis Loan and Brachyserphus abruptus (Say), have all been
14 studied. Z. insularis only attacks Lobiopa insularis (Castelnau) and was thus
15 not useful to our goals. Microctonus nitidulidis attacks adults of most of the
16 important pest while Brachyserphus abruptus attacks the larvae of all of the
17 important pests.

18 An egg predator, Atheta coriaria (Kraatz) was found to have a preference
19 for the eggs of C. hemipterus and also attack/consume eggs of other pest species.
20 A disease, Mattesia sp. attacks larvae, and adults. It is transmitted from
21 adult to progeny on the exterior of the egg.

22 All of the organisms studied have utility in laboratory investigations of
23 biological control of pest sap beetles. Attempts have been made to introduce
24 Microctonus nitidulidis and Brachyserphus abruptus into the date growing regions
25 of Israel. Both parasites could be most beneficial if they become established.

INTRODUCTION

1
2 This project was initiated to study the feasibility of biological control
3 of sap beetles through manipulation of their natural enemies. Exploration was
4 an intergal part of the investigation as some of the natural enemies were unknown
5 at the onset of the project. Our aim was to learn how we could use natural
6 enemies in order to reduce reliance on chemical control and/or protective netting
7 while increasing fruit quality.

8 One of the first steps necessary in this sort of pest population management
9 is to understand the seasonal fluctuations of the pests. Studies were conducted
10 in Israel and Ohio to better understand seasonal abundance of the injurious sap
11 beetles. This has aided in identifying the most significant pests as well as
12 documented population density throughout the year.

13 Biological studies of four parasites, a predator and a disease have given
14 us a much better understanding of the natural enemy complex of the pest species
15 of sap beetles. Also the laboratory studies have aided in the assessment of
16 parasites and the feasibility of their introduction and release.

THE PESTS

Israel

17
18
19 In Israel there are four sap beetles which attack dates causing damage.
20 They are Carpophilus hemipterus (L.), C. mutilatus (Er.), C. humeralis (F.)
21 and Haptoncus luteolus (Er.). These were all present on dates and considered
22 important pests. The nitidulids infest ripe fruit causing it to rot and damage
23 is reflected in both reduced yield and lower fruit quality. In order to document
24 seasonal abundance, a study was conducted in the date growing area in the Jordan
25 and the Bet She'an Valleys. Adult sap beetles were captured in traps consisting
26 of circular plastic containers baited with dates or oranges.

1 In these studies (Kehat et al. 1983) the phenology and importance of
2 each of the nitidulids infesting dates was assessed for the first time.
3 Green fruit was not damaged by nitidulids while on bunches, however, they
4 did infest fruit which had fallen to the ground. Adults of the four species
5 were detected all year round. Seasonal abundance of the species differed
6 greatly. Carpophilus hemipterus and C. mutilatus were found throughout autumn,
7 winter, spring and early summer. C. mutilatus was prevalent in both the Bet
8 She'an and Jordan Valleys while C. hemipterus was found mainly in the Bet She'an
9 Valley. C. humeralis was most abundant during the summer when C. hemipterus
10 and C. mutilatus populations were in decline. C. humeralis population some-
11 times remained high during autumn. Haptoncus luteolus was abundant mainly
12 during late summer and autumn. Thus, in date plantations in the north of Israel,
13 C. hemipterus and C. mutilatus dominate in the spring, C. humeralis in the
14 summer and H. luteolus in late summer and autumn.

15 Since date fruits ripen during autumn (Sept. - Nov.), damage to fruit by
16 sap beetles is apparently infected for the most part by H. luteolus and C.
17 humeralis and to a much lesser extent by C. hemipterus and C. mutilatus. This
18 is new information as previously C. hemipterus and C. mutilatus were thought
19 to be the major fruit pests of Israel date plantations (Kehat et al. 1983).

20 USA

21 In Ohio and neighboring states, the strawberry sap beetle, Stelidota
22 geminata (Say) has become a primary pest of ripe strawberries over the past
23 15 to 20 years. As much as 10% of the strawberry crop is damaged by adult
24 beetles.

1 In a BARD study (Miller and Williams 1982) the seasonal abundance of
2 the strawberry sap beetle was investigated in four habitats. They reproduce
3 in strawberry fields and migrate to other crops when the food supply diminishes.
4 Raspberries may serve as an additional breeding site. Corn and raspberries
5 may also be utilized by this sap beetle for overwintering. Populations of
6 the strawberry sap beetle remain relatively constant in wooded areas through-
7 out the season. Activity of the beetle was greatly influenced by temperature;
8 little activity was recorded when average maximum temperatures fell below 24°C.

9 PARASITES INDIGENOUS TO ISRAEL

10 In a three-year survey to determine parasites of nitidulids infesting
11 date plantations in Israel, only Zeteticontus utilis Noyes was found. It
12 was found in various date plantations during the spring and summer. This
13 same parasite has been found in Kenya. From Kenya it was introduced into
14 Hawaii in an attempt to control Carpophilus hemipterus (L.) infesting pine-
15 apples. It has become established in Hawaii, however, the impact of the intro-
16 duction has not yet been determined (Nagamine 1983 Pers. Comm.).

17 Little was known about the biology of the parasite and since such infor-
18 mation is of great importance for evaluating its potential as a biological
19 control agent, studies were undertaken.

20 Studies in Israel (Blumberg et al. 1984) concentrated on the Israeli
21 strain or biotype which was found to successfully parasitize C. hemipterus
22 and C. mutilatus. The values for the developmental threshold and the thermal
23 constant were, 10.4°C and 345 day-degrees for the male and 10.2°C and 370 day-
24 degrees for the female. The mean number of progeny per female was 78.6. The
25 life span was 12.6 days, while oviposition lasted for an average of 9.5 days.

1 Adult survival was maximal (9.2 days) when fed 10% honey solution and minimal
2 when only water, date extract, or no food was supplied (3.2 - 3.8 days). Adult
3 survival was greatly reduced by low relative humidities. The female parasite
4 showed no ovipositional preference for C. hemipterus or C. mutilatus, and
5 parasite development in both species was the same (19 days). Although develop-
6 ment was somewhat faster in large (6-7 mm) than in small (2-3 mm) larvae,
7 both sizes were suitable for parasite development. Percent parasitism was
8 similar in sizes of larvae. The female parasite was capable of locating its
9 host even when completely hidden inside the food.

10 In studies conducted in Ohio with Z. utilis (Werner 1983) the following
11 conclusions were reached. Z. utilis has four larval instars ranging from
12 0.097 mm to 0.477 mm. Developmental thresholds of the parasite and its host,
13 Carpophilus hemipterus (L.) were determined to be 4°C and 10°C, respectively.
14 Honey-fed parasites survived approximately four times longer than non-fed
15 individuals. The host range of Z. utilis included C. hemipterus, Carpophilus
16 humeralis (Fab.), Carpophilus mutilatus Erichson, and Carpophilus lugubris
17 Murray. In host preference tests C. hemipterus was most strongly preferred,
18 followed by C. mutilatus and C. lugubris. Z. utilis was found to strongly
19 prefer second and third instar C. hemipterus larvae over first instar larvae.
20 The parasite appeared to host-mark, as females rejected previously stung larvae
21 significantly more often than non-parasitized larvae. Electrophoretic evalu-
22 ation of Z. utilis native to different continents did not indicate genetic
23 differences between the populations. Females laid approximately 80 eggs during
24 their lifetime, which lasted approximately 8.5 days when fed honey. The sex
25 ratio of progeny approached 50:50. Z. utilis was found to have a type II
26 functional response. It appears to be "r" selected in its population ecology
27 strategy.

1 These studies are the subject of three manuscripts in preparation under
2 the authorship of Werner and Williams.

3 PARASITES INDIGENOUS TO USA

4 Over the three years of the grant, we made nitidulid collections from
5 many areas in order to obtain any parasites which might be utilized. We
6 studied three parasites, Zeteticontus insularis (Howard) and Microctonus
7 nitidulidis Loan and the newly discovered, Brachyserphus abruptus (Say). These
8 will be treated individually.

9 Zeteticontus insularis, a gregarious endoparasite, was found to produce
10 an average of 8 parasites from a single mummy. It is associated with sap
11 beetles found on ripe and overripe fruit in the Neotropics and surrounding
12 subtropical areas. Unmated females produce only male progeny. Oviposition
13 (a single sting) took an average of 5.5 seconds. In 30 observations the time
14 required for a sting ranged from 3 to 13 seconds. Parasitism was more success-
15 ful when hosts were stung twice or left with parasites for several hours than
16 when stung only once. In the field and in the laboratory only one species of
17 sap beetle was parasitized, i.e. Lobiopa insularis. The information given here
18 is Williams and Yassen (unpublished data); however, a manuscript is in
19 preparation.

20 Microctonus nitidulidis is a solitary endoparasite of several sap beetles
21 which are pests in both Israel and Ohio. It is the only known hymenopterous
22 parasite which attacks adult sap beetles. A method for mass rearing of M.
23 nitidulidis in the laboratory was developed through this grant. The rearing
24 method was simplified and streamlined to a degree thought impossible in the
25 past. We were able to obtain as high as 38.7% parasitism during the study

1 period as compared to less than 5% previously. The three key factors in
2 increasing production were (1) to expose fewer host/parasite, i.e. 15/
3 parasite rather than 50/parasite, (2) expose hosts to parasites for longer
4 periods of time (48 hours was ideal), and (3) to allow at least 24 hours
5 before new cocoons are disturbed. Newly formed pupae are extremely delicate
6 and should not be moved. During the grant more than 2500 M. nitidulidis
7 pupae were reared at OARDC and sent to Bet Dagan. Of these, approximately
8 50% emerged as adults in Israel. A few were used for rearing in the labora-
9 tory, however, the majority were liberated in the field. Establishment of
10 the parasite has not been determined.

11 Initially rearing utilized Stelidota geminata, as host exclusively.
12 Later it was found that Carpophilus hemipterus are equally suitable as hosts
13 and have an advantage as they are easier to rear. Results reported here are
14 unpublished data, although a manuscript is in preparation. For earlier work
15 see Weiss and Williams 1979 in the section entitled Related Publications.

16 Brachyserphus abruptus is a new larval parasite of various economically
17 important nitidulids. It was found during the second year of the grant and
18 has been the topic of considerable interest since its discovery. It was found
19 to have a wide geographic range in the eastern U.S.

20 We have studied its host range from field collected material where it was
21 found attacking Carpophilus, Haptoncus, Stelidota and Lobiopa. In the laboratory
22 it has been reared successfully from the same genera. In Ohio, field collected
23 nitidulid larvae are first found parasitized in late July. Parasitism by B.
24 abruptus increases until frost. More than 10% of all host larvae collected in
25 Ohio in August and September were parasitized. Of 652 S. geminata larvae
26 collected on fallen peaches in northern Ohio during August and September, 13%
27 were parasitized.

1 In laboratory rearing of the parasite using C. hemipterus as host, we
2 obtained 83% parasitism. This was accomplished by confining 30 C. hemipterus
3 larvae with three mated females for 24 hours. We also were able to rear the
4 parasite by placing mated females in cultures of C. hemipterus.

5 We have gained much biological information about B. abruptus since its
6 discovery in 1981, i.e.: (1) when rearing in the laboratory females should
7 be left with males 24 hours to insure mating, (2) it does well under 14 hours
8 photoperiod, (3) an undetermined disease organism attacks mature larvae shortly after
9 they push out of host, (4) parasitized host larvae become inactive, curl up
10 into a figure "C", after a few days the parasite emerges through the body wall
11 transforming into a pupa shortly thereafter, (5) the parasite remains attached
12 at the host until fully mature, (6) developmental time from egg to free living
13 adult ranges from 17 to 25 days.

14 Shipments of this parasite have been made from Ohio to Bet Dagan over the
15 past year. It took awhile to get the parasites to Israel alive. It is a
16 difficult species to ship. However, if host larvae are shipped within 48 hours
17 of the time they are parasitized the chances of successful shipment are greatly
18 enhanced.

19 Laboratory rearing of B. abruptus on C. hemipterus and C. humeralis has
20 not been successful to date. Field releases were conducted in the Bet She'aan
21 Valley with unknown results. We plan to make several additional releases in
22 this valley in the spring of 1984 to broaden the genetic variability of the
23 population. Establishment will need to be determined in a year or so.

24 The information about B. abruptus, its biology and hosts, was unknown until
25 these studies. Thus, this is all unpublished data. However, it was the subject

1 of a presentation before the 1982 annual meeting of the Entomological Society
2 of America in Toronto, Canada (Williams 1982 Papers Presented at Scientific
3 Meetings). It is also being covered in a BARD publication in preparation.

4 PREDATORS

5 Both the adults and larvae of Atheta coriaria are predatory on the eggs
6 and early instars of several nitidulid species and Musca domestica. Carpophilus
7 hemipterus and M. domestica were the preferred hosts, while C. lugubris, C.
8 humeralis, Stelidota geminata, Glischrochilus quadrisignatus, Lobiopa insularis,
9 Haptoncus luteolus, and C. freemanni were also preyed on (Miller and Williams,
10 1983a).

11 Generation time of A. coriaria at 26.7°C and 90% R.H. ranged from 11.5 to
12 13 days, when offered 20 C. hemipterus eggs daily. Time from oviposition until
13 larval eclosion was 2+ days. Larvae developed in 4.5 to 5 days, and the pupal
14 stage lasted 5 to 6 days. The number of eggs consumed during larval develop-
15 ment averaged 32.4 (range 29-38). A. coriaria pupated in loosely bound chambers
16 of silk. Small soil particles were incorporated into this chamber, when avail-
17 able.

18 Food supply and temperature influenced the rate of development of A. coriaria.
19 The most efficient temperature and food supply for development were 26.7°C and
20 20 C. hemipterus eggs/day.

21 The functional responses of the larval instars and adult A. coriaria in
22 relation to predator-induced decreases in the density of Stelidota geminata
23 eggs was illustrated by a linear rise to a plateau as initial density increased.
24 The model presented closely estimated the number consumed at all densities.
25 Increases in temperature resulted in an increase in the number of prey consumed
26 by adults at all densities (Millier and Williams 1982b).

1 This study has delineated some of the aspects of the biology and illus-
2 trated the effects of decreasing densities on the functional response of A.
3 coriaria. Additional studies are required to define other factors of the
4 biology of this predator and its potential as a biological control agent.
5 Further studies are also recommended to produce a more accurate model of the
6 functional responses of predator to predator-induced decreases in the density
7 of its hosts.

DISEASES

9 Spores of a neogregarine in the genus Mattesia have been recovered from
10 Carpophilus hemipterus larvae in Ohio. The infected larvae fluoresce when
11 examined under a black light. Larvae of Carpophilus hemeralis, Carpophilus
12 lugubrus, and Stelidota glischochilus sp. became infected after feeding on
13 diet containing Mattesia spores. Spores from infected C. hemipterus larvae
14 held in a freezer were still viable after one year. However, spore powder
15 prepared with cellulose powder, as has been done with other Mattesia species,
16 was not infective.

17 C. hemipterus larvae became visibly infected before changing to pupae in
18 12-18 days when placed on contaminated diet and held at 27°C. Those held at
19 21°C became infected in 37-45 days after changing to pupae or adults. Although
20 infected pupae did fluoresce, infected adults did not. Infected adults were
21 also obtained by allowing beetles or late-instar larvae to feed on Mattesia-
22 contaminated diet.

Microscopic examination of the developmental stages of this Mattesia sp. indicate it is probably a new species. The presence of a new species is also supported by the fact that C. hemipterus larvae were not infected by spores

1 of Mattesia trogodermæ, and Trogoderma spp. larvae were not infected by spores
2 of Mattesia from C. hemipterus (Klein, unpublished data). This information
3 was presented at the annual meeting of the Society of Invertebrate Pathology
4 (Klein and Williams, 1982, papers presented at scientific meetings).

5 Dr. Klein is in contact with R. E. McLaughlin on the identification of
6 this disease. A manuscript is in preparation covering the infectivity of
7 Mattesia sp. to sap beetles (Klein and Williams - see Publications under BARD
8 in Preparation).

9 RESULTS AND DISCUSSION

10 The papers on the seasonal abundance of the pest species in Israel and
11 the U.S. were the first of their kind establishing benchmark population trends
12 for sap beetles. The most abundant species in date plantations during the
13 harvest season (Sept. - Nov.) were H. luteolus and C. humeralis and to a lesser
14 extent C. hemipterus and C. mutilatus. These results were unexpected and will
15 surely be influential in future control schemes.

16 It is known from parasite collections made in the U.S. that we have a
17 parasite (B. abruptus) that will attack all of the pest species on dates in
18 Israel. {B. abruptus attacks members of the Carpophilinae (Carpophilus spp.)
19 and Nitidulinae (Haptoncus and Stelidota), whereas Z. utilis is limited to
20 the genus Carpophilus and Z. insularis is limited to a single species, Lobiopa
21 insularis (Nitidulinae)}. B. abruptus is capable of high levels of parasitism
22 and is thought to be the most valuable biocontrol tool which we have in Israel
23 and in the U.S. However, we realize that in Ohio this parasite arrives on the
24 scene too late for natural control of Stelidota in strawberry fields. In this
25 case it will require manipulation. This would require mass rearing of B. abruptus

1 throughout the winter for liberation in early June rather than wait for its
2 normal appearance in mid-July. Obstacles in the rearing of this species have
3 been overcome. We now have the methods developed for rearing whereby it can
4 be cultured successful throughout the winter months.

5 It is still too early to know if B. abruptus is established in the Bet
6 She'an Valley where it was released. Additional shipments will be made to
7 enhance establishment and to increase the genetic base. Sap beetles attack
8 dates in the fall of the year when B. abruptus populations are normally at their
9 peak, thus timing of the parasite population should be ideal.

10 The Zeteticontus utilis studies in the U.S. and Israel have been most
11 fruitful. We have made great strides at better understanding the biology of
12 Z. utilis. At the time we began work on this grant, the species was unnamed.
13 We feel that we were partially responsible for getting it described (Noyes 1982).

14 Apparently there are two strains or biotypes of Z. utilis. The Israel
15 strain parasitizes C. hemipterus and C. mutilatus yet could not be reared on
16 C. humeralis. However, the Kenya strain does parasitize C. humeralis as well
17 as C. hemipterus and C. mutilatus. This is an important difference. We feel
18 that it would be desirable to introduce the Kenya strain into Israel. Especially
19 now that we know that C. humeralis is of considerable importance during
20 date harvest.

21 An important finding for the U.S. was that Z. utilis (Kenya strain) also
22 attacks C. lugubris. The Israeli strain did not parasitize this host. In Ohio
23 C. lugubris is a minor pest of corn and small fruits. However, in several sweet
24 corn growing areas of the eastern U.S. C. lugubris is a primary pest causing
25 considerable damage. Until now larval parasites of C. lugubris were unknown.

1 It is possible that some of the sweet corn growing areas will be interested
2 in establishing this parasite in the future. Unfortunately, Z. utilis does
3 not reproduce on our primary strawberry pest in Ohio, Stelidota geminata,
4 however, it does oviposit in the larvae and cause host mortality. In additon
5 it also kills larvae of Glischrochilus faciatus, the primary sap beetle pest
6 of raspberries in Ohio, but is not able to develop in this host.

7 The success with Microctonus nitidulidis has not been sensational. We
8 had great hopes for this species at the onset since it attacked the adults of
9 a wide variety of sap beetle species. However, we have had difficulty in
10 rearing it in Israel. This problem could stem from a number of causes. Per-
11 haps there are differences in the host since rearing conditions in the two
12 laboratories were quite similar. If it could be established in Israel we feel
13 that it would be a useful additon to the natural enemy complex of sap beetles
14 there.

15 Studies in the U.S. allowed us to expand the distribution of M. nitidulidis
16 from Ohio to Florida. Collections of Stelidota geminata larvae from the citrus
17 region of southern Texas did not yield this parasite. For the first time we
18 collected the parasite from Carpophilus adults in Ohio. The Carpophilus adults
19 were attracted to sweet corn cobs which had been stripped for processing.

20 The egg predator Atheta coriaria consumes large numbers of sap beetle eggs.
21 Its preference for the eggs of C. hemipterus over other sap beetles was unexpected
22 since predators are usually general feeders. The aggressiveness of this tiny
23 rove beetle is spectacular. It was such a dominate factor in our rearing rooms
24 that we had to put excluders (fine mesh cloth) on all of our sap beetle cultures.
25 Otherwise, sap beetle populations in the containers would decline rapidly due
26 to Atheta coriaria.

1 We realize that A. coriaria and perhaps other rove beetles play an im-
2 portant role in regulating sap beetle populations in Ohio. This would perhaps
3 be a good candidate for introduction as a biological control agent; however,
4 before this is done it would be important to conduct additional studies on its
5 arthropod host range and to make sure its not phytophagous. Since our publications
6 on this insect have appeared in scientific journals, we have had many requests
7 for reprints from various parts of the world.

8 The results from studies with the protozoan disease (Mattesia sp.) have
9 been encouraging. This disease organism can be carried by any stage of sap beetle.
10 Therefore, it would seem ideal to infect adults so that they can in turn dis-
11 seminate it through flight activities. Infection of adults can be accomplished
12 by feeding them viable spores in their diet and releasing them or by attracting
13 them to infective bait stations in the field. All indications are that this is
14 a new species. We know from our experience with the disease that it can be
15 devastating in laboratory cultures. Studies are needed to confirm field trans-
16 mission.

17 Two major hurdles which had to be crossed in order to proceed with our
18 research on sap beetles were the lack of a good literature reviews on Carpophilus
19 and the hymenopterous parasites of sap beetles. We are pleased to report that
20 we accomplished both. The bibliography of the genus Carpophilus was composed
21 of 1000 citations (Williams et al. 1983). The review of the literature on the
22 hymenopterous parasites of sap beetles was a major undertaking yielding all of
23 the known wasp parasites which attack nitidulids (Williams et al. 1984). We
24 believe that through information provided in these publications there will be a
25 renewed interest in the biological control of sap beetles on various crops.

EVALUATION OF RESEARCH ACHIEVEMENTS

In the proposal abstract we stated:

"The goal of this proposal is to develop a biological control program for the sap beetle complex utilizing several natural enemies. This is to be accomplished by first studying the specificity of the natural enemies to their nitidulid hosts focusing on host suitability for parasite development.

Natural enemies, composed of larval and adult insect parasites, nematodes and pathogens will be investigated under controlled environmental conditions. Rearing techniques and preliminary evaluation will be conducted in the U.S.A. As many parasites as possible will be evaluated in order to strive toward a goal of introducing four natural enemies into Israel.

Release and recapture of natural enemies will be evaluated in Israel, as will be the ability of the parasites to withstand normal field climatic fluctuations during the course of a year. Finally, the degree of control of the pests by natural enemies will be determined."

In the research proposal we envisioned a complete biological control program which could be initiated and completed within three years. This was an ambitious goal. However, most of it was accomplished!

We studied and evaluated four species of hymenopterous parasites. Three of these are useful for the fruit crops in Israel and Ohio. The fourth is of interest in Mexico and Brazil. The only predator studied was found to be quite useful as a sap beetle egg predator. The protozoan disease has potential according to laboratory studies.

Rearing techniques have been developed for all of the natural enemies studied.

1 We did not attain the final goal of getting the natural enemies
2 established and evaluated in the field before the grant ended. However,
3 the laboratory phase of testing has provided us with the necessary tools to
4 complete the job. Since the contract ended additional shipments of the most
5 promising species, B. abruptus have been field released in the Bet She'aan
6 Valley. Several future shipments are planned for field release in the spring
7 of 1984. We know that this is the best of all natural enemies of sap beetles
8 and we certainly anticipate its establishment.

9 DESCRIPTION AND RESULTS OF COOPERATION

10 The cooperation between the entomologists at OARDC and ARO has been
11 a most rewarding experience. In my opinion, the value of the trip to Israel
12 and to be able to see problems first hand was extremely valuable. I could
13 not imagine having sap beetles in the field all year round. This sort of
14 information was vital to the complete understanding of our joint project.
15 Also when M. Kehat and D. Blumberg visited the U.S. this gave us great
16 opportunities to sit down and exchange ideas and discuss problems and successes
17 of our sap beetle research as well as other entomological activities.

18 As scientists, of course, research publications are regarded as important
19 indicators of accomplishment. In this case a high degree of cooperation was
20 also necessary in order to conduct studies of mutual interest on separate
21 continents. Thus far, four publications are in print or been accepted for
22 publication along with one presentation at a scientific meeting. Two additional
23 publications with OARDC/ARO cooperation are in preparation.

24 One of the results of our cooperation has been to see the needs and benefits
25 of continuing to work jointly on sap beetles. The subject of our next research

1 project will be chemical attractants and repellents for sap beetles attacking
2 fruit crops.

3 BENEFIT TO AGRICULTURE

4 In Israel and in the U.S. sap beetles were fairly easily controlled with
5 malathion insecticide until about 10 to 15 years ago. Then it was noticed
6 that it took more insecticide to accomplish the same degree of control. The
7 sap beetles were becoming resistant to the insecticide. Additionally, in the
8 date plantations the use of chemicals was interfering with the biological control
9 of the date scale. In order to resolve the insecticide problem and keep control
10 of date scale, biological control seemed the most practical approach. The
11 solution is made easier by the fact that sap beetles do not attack fruit until
12 fall when fruit is ripe. By fall natural enemies would have a chance to
13 greatly reduce sap beetle populations.

14 In Ohio the problem is more complex because even though we have identified
15 the natural enemies that might be most useful the question still remains, can
16 we manipulate these natural enemies to be effective earlier in the season?
17 We need control in June rather than August.

18 It is difficult to estimate monetary benefits to agriculture. To put an
19 estimate on the savings on dates to Israel will require time to observe the
20 full effect of the establishment of the organisms. Benefits to fruit growers
21 in Ohio could be as much as 10% of the strawberry crop if the natural enemies
22 can be manipulated to interact with the sap beetles earlier in the season.

23 We have made some important breakthroughs during the course of the in-
24 vestigations. Other agricultural industries in the U.S. and elsewhere in the
25 world will benefit greatly from these studies. Examples are: (1) the fig industry

1 in California and elsewhere, (2) the date industry worldwide, (3) the pine-
2 apple industry worldwide, (4) the strawberry industry in Mexico and Brazil,
3 (5) the raisin industry in Australia, and (6) the sweet corn industry of the
4 eastern U.S. As soon as our publications on the parasites begin to appear,
5 we anticipate a great deal of activity by these agricultural industries to
6 obtain and utilize the natural enemies we have investigated.

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- 5 Miller, K. V. and R. N. Williams. The functional response of Atheta coriaria
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PUBLICATIONS IN PREPARATION UNDER BARD SPONSORSHIP

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