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THE BIOLOGY OF THE CAROB MOTH ECTOMYELOIS CERATONIAE (ZELL.) IN ISRAEL.

III. PHENOLOGY ON VARIOUS HOSTS.

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ABSTRACT

The phenology and population density of the carob moth were studied in carob, acacia and grape- fruit. This insect hibernates, in its larval stage in carob and acacia pods. In spring, from mid April and on, eggs are laid on carob pods infested by the carob midge, and as from late June oviposition occurs on cracked carob pods. The total number of larvae and pupae per 100 fruits, found on carob at the end of the season was 300 and the number of adults which had already emerged from the pods by that time exceeded 100.

Egg laying in citrus groves begins in July and lasts for as long as temperatures permit adult activity. About 15% of the fruits were found to be infested by the moth in groves which were known to be infested each year. Usually one larva was found per fruit. Although all larvae eventually died on citrus fruit, high economic losses were caused due to fruit drop.

In acacia, the only important generation is the one which develops in the autumn, significantly infests up to 30% of the pods (one individual per pod), and hibernates inside the pods.

Except for the almond in which the biology of the moth has not been studied, no other hosts of the carob moth were found.

Considering the consecutive host chain of the carob moth, same possible agrotechincal control measures are suggested.

Introduction

In some Mediterranean countries the carob moth is continually causing economic losses, by damaging citrus, carob and almond crops. Since very little was known of the life-history and other biological aspects of this insect, a thorough study of its biology in Israel was undertaken in the years 1959 - 1962. The results of this study were first reported in a publication of the Volcani Institute of Agricultural Research (Gothilf, 1964). Most of this material was later translated into English and published in a series of articles (Levinson and Gothilf, 1965; Gothilf, 1968, 1969, 1969a, 1969b). The present paper is the last of this series and summarizes field studies of the seasonal occurrence and population density of the carob moth on its various hosts.

Methods

In order to observe the course of adult emergence in carobs from autumn till spring, samples containing 120 to 600 fruits were picked in September from a number of trees at three locations: Ramat-Yohanan, Kiryat-Ono and Ayanot. The samples were kept in cloth cages mounted on a wooden frame, located outdoors in the shade. During the rainy season they were watered every 10 days to simulate outdoor conditions. Adult emergence was recorded daily.

Two factors affecting carob moth infestation - the rate of infestation by the carob midge, and the cracking of carob pods - were followed up every two weeks during two years in three plantations (Agur, Gan-Shlomo and Givat-Brenner). At every location 200 or 500 fruits were randomly examined on each of 5 - 10 trees which served for permanent inspection. The number of trees inspected and the size of the sample were determined according to the size of the plantation. Sporadic examinations of carob midge infestation and cracking of pods were also carried out in other plantations throughout the country. Samples consisted in this case of 1000 fruits randomly picked from 10 trees (100 fruits per tree).

In order to study carob moth infestation, samples of 200 fruits were picked randomly at two-week intervals while walking crosswise through each of the three plantations mentioned above. Sampling was during 3 years. Sporadic inspections were carried out at other locations using the same method of sampling. Infestation in each sample batch was determined by checking each fruit under a stereomicroscope. The numbers of carob moth eggs, larvae, pupae and pupal skins from which the adults had already emerged, were recorded.

Infestation of acacia pods was studied from samples containing 500 pods each, picked randomly at various locations every two weeks, while walking for 100 meters along an acacia hedge. Each pod was dissected and examined for the presence of the carob moth in its various stages, except for eggs which are difficult to detect in acacia pods.

Infestation of grapefruit was studied in three groves (Yagur, Petah-Tikva and Ramat-Yohanan). In each grove 20 dunams were assigned for sampling. Fruits were always picked from the same trees - one fruit from every second tree in every second row - and a total of 200 fruits were picked from each plot (usually 40 trees are planted per dunam). Samples were collected on the 15th of each month during two years. The fruits were brought to the laboratory and the stem and calyx of each fruit was removed and examined under a stereomicroscope for the presence of eggs, larvae and for signs of larval penetration.

The possible existence of other plant hosts, in addition to carob, citrus and almonds, was studied in monthly surveys at various locations throughout the Galilee, the Jordan Valley, the Jezreel Valley, the Coastal Plain and the Jerusalem Hills. Both wild and cultivated areas were inspected.

Results and Discussion

Infestation on carob trees

The carob tree Ceratonia siliqua L. is endemic to the Mediterranean basin, especially the Eastern Mediterranean countries. Apart from organized plantations, it grows widly in nature, has edible fruits and is harvested. Carob trees flower during September -

October and the growth of the newly formed pods are retarded during the winter. In the spring the growth of pods is rapid, and maximum size is reached by the end of May or the beginning of June. Pods ripen during July when their color changes from green to brown. The crop is usually harvested during early August.

Effect of the condition of carob fruit on egg laying: Observations made in various regions during the period of female activity revealed that eggs are seldom laid on healthy undamaged fruit. Oviposition is restricted almost solely to certain types of damaged pods.

One type of damaged pod preferred by ovipositing moths is that infected by the fungus Phomopsis sp. Phomopsis-infected fruits are found from late June onwards. Females are attracted to such fruit, although on the outside they look undamaged. The hatching larvae are unable to penetrate into the fruit and eventually die. This is true in all cases where eggs are laid on fruit with undamaged peel. This finding was confirmed not only by field observations, but also in a series of tests which included rearing of newly-hatched larvae on undamaged carob fruits of different varieties. No penetration of larvae into such fruits was noticed. The second type of fruits on which oviposition occurs is that infested by the carob midge Eumarchalia gennadii Marchal. Usually each infested pod harbors one midge. When the midge attains maturity it leaves the pod through a small emergence hole. Carob moth females subsequently lay eggs inside these holes and the hatching larvae develop inside the pod. The third type of fruits attacked by the moth are cracked pods. Cracking of fruit is common during the ripening season. The female moth lay their eggs inside the fisures formed. It was found that any type of damage to the peel, even artificially made, serves as oviposition site.

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Emergence and egg laying in spring. Patterns of emergence was very similar in the three samples collected at different locations and therefore, emergence from only one of the samples is illustrated in Fig. 1. Emergence stopped at the end of November and started again in the second half of April. Examination of the pods revealed that the insect passes the winter in larval stage. No pupation takes place till the following spring, this being due to the low temperature prevailing in winter. Should any infested pods collected in autumn or winter be kept at favorable temperatures, pupation would proceed as normal.

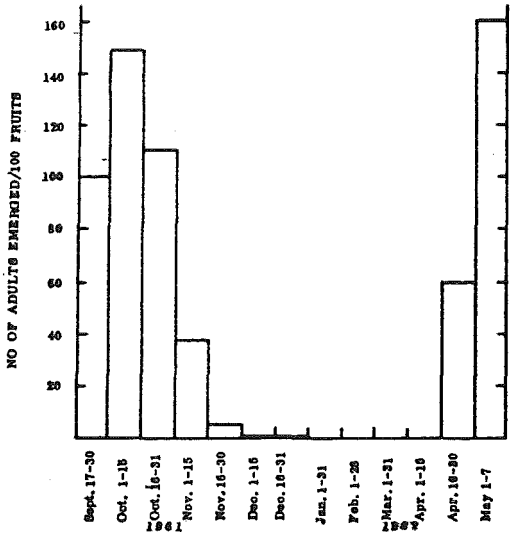

Fig. 1. Emergence from carob fruits kept outdoors (collected in September 1961 at Ramat Yochanan).

Concommitantly with the study of emergence during winter and spring the onset of egg laying in nature was checked. No eggs were laid on artificially infected wounds on carob pods during the winter, only in the second half of April, were large numbers of eggs found. This coincides with the first appearance of adults in nature.

Infestation of fruits infected by the carob midge. The carob midge lay their eggs into the flower or the newly-formed fruit (Di Martino 1956). From January on the afflicted fruits containing the midge larvae can be distinguished from healthy fruits (Fig. 2).

First emergence holes of the midge are observed in mid-February, and from then on their number increases. Egg laying on such fruits starts during the second half of April. The general course of infestation by the carob moth was similar in all locations and for every year studied. As shown in Table 1, infestation by larvae started in May and increased until August when midge-infected pods dried out and dropped. Adult emergence from such fruits started in July.

Infestation of cracked fruits. Carob pods start cracking around mid-June, reaching a peak a month later. Pods crack near the stem; the average fissure is 10 mm long, 0.25 mm wide and about 1 mm deep (Fig. 3). The factors which cause cracking are unknown. Its extent varies among carob varieties, even in the same plantation, and also from year to year (Table 2). It was observed, however, that cracking is considerably affected by irrigation and crop yield: well irrigated trees or trees with a low crop yield had a higher rate of cracked fruits. From mid-June on, when pods begin to crack, females are attracted to lay eggs inside the crevices, usually one or two eggs at a time. Oviposition into one crevice may occur several times during the season. Table 3 describes infestation of cracked fruits, during one year in the three experimental plantations, both at the beginning of July and before harvest at the beginning of August. It is evident from the Table that infestation increased considerably during the short period from the time cracking starts until harvest. At the beginning of August the harvested pods harbored about 120 larvae and pupae per 100 fruits, with a considerable number already emerged as judged from the number of empty exuviae. A similar trend and rate of infestation was recorded during two additional years. The numbers given in Table 3 include also dead stages. On the average, mortality was 14% among eggs, 4% among larvae and 5% among pupae. It should be noted that not every cracked fruit was affected by the carob moth, about 25% of them remain free of infestation at harvest time.

Infestation of carob pods during post harvest season. Carob fruits which for some reason are not harvested, continue to serve as host to the carob moth (Fig. 4) Eggs are laid as long as the temperature is favorable, i. e. till about the end of October. The number of larvae per fruit and the number of individuals reaching adulthood increases till the beginning of winter (Table 4). No pupation occurs during winter. The insects survive the winter as

larvae inside pods which usually drop off. The unharvested fruits serve therefore, as a reservoir for the moth population due to reach adulthood the following spring.

Carob moth on Acacia farnesiana (L.) Wild. A. farnesiana (commonly called acacia) is an ornamental tree widely distributed in Israel, where it is planted around orange groves to serve as a fence. Acacia trees are in blossom from October through April - May. The pods reach maximum size in August and then dry out. Similar to carob fruits, here too, the female moth prefers to lay eggs on pods already infested or injured. Egg laying on undamaged fruit is rare, and if it happens the newly hatched larvae are unable to penetrate the fruit. A few insect species cause damage to acacia fruits, thus clearing the way to secondary development of the carob moth on such fruits. Among the better known insects are Virachola livia Klug.(Lepidoptera) whose larval activity is noticeable in the autumn and early summer when the pods are still fresh, and Pseudopachymerus lallemanti (Mars.) (Bruchidae, Coleoptera) which infest almost every acacia pod from midsummer onwards. The occurrence of injured pods and their secondary infestation by the carob moth was typical at all locations. Counts taken at Yavneh are given in Table 5. Infestation of newly formed pods by V. livia in the autumn and their secondary infestation by the carob moth was not included in this table; both are sporadic and of a small extent at this time and an accurate sampling was impossible. During the winter the fresh fruits remain intact and only at the beginning of June infestation by V. livia is again noticed. Infestation by this pest is limited to a short period up to August when the pods begin to dry out. The extent of this infestation and the secondary infestation by the carob moth varies greatly from year to year and from place to place. Birds seem to constitute one factor for this fluctuation as they prey intensively on the larvae found in the fresh fruits. Mass emergence of Bruchids from acacia pods starting in August, creates a new oviposition site for the carob moth. The moth population in such fruits (usually a single moth per pod) increases until winter and emergence of the new adult moth occurs in April-May, concomitantly with emergence of this species from carob pods (see Fig. 1). During the following summer these pods gradually drop off. It is evident that during winter two kinds of acacia pods are found: fresh green pods free of pests and old dark pods heavily infested by the carob moth.

Carob moth in citrus. In Israel the carob moth has apparently been infesting citrus for many years, but it was not considered a citrus pest until the late fifties, when it was found that the insect causes considerable fruit drop in grapefruit (Avidov and Gothilf, 1960). Prior to this finding, fruit drop in citrus had been related erroneously to Cryptoblabes gnidiella Mill. (Phycitidae, Lepidoptera), which is more conspicuous in citrus than the carob moth but is mainly a scavanger (Avidov and Gothilf, 1960). The reason for the carob moth being unknown in citrus is evident from its life history and phenology.

On grapefruit, the moths lay eggs underneath the calyx, usually one egg per fruit. The newly hatched larvae bore into the fruit; as a result gum is exuded by the fruit killing the larvae. The infested fruit is recognizable by the gum appearing around the stem and by its early color change (Fig. 5) Such fruits drop off from October on. Occurrence of carob moth on grapefruits in one of the inspected groves is described in Table 6. It is evident that egg laying on citrus starts in August and lasts as long as the temperature is favorable. In November, with the drop in temperature, egg laying stops. As mentioned above, larvae are usually killed by the gum when trying to penetrate into the fruit, but later in the season, i.e. from late October, gum exudation is less intense, and a few larvae may survive. Theoretically, such larvae would reach pupation the following spring or summer, but actually infected fruits, if not picked, rot and disintegrate during the winter. Pupae were never found in citrus.

Citrus is the only carob moth host on which eggs are being laid on undamaged fruits. The question arises whether the moth is attracted to the fruit itself or to the mealy bugs which are commonly found under the calyx of grapefruit. Counts were made in two of the three tested groves of the fruits on which mealy bugs had settled, out of the monthly samples collected. Rate of infestation of such fruits was compared to that of fruits on which no mealy bugs were found. To eliminate errors due to secondary infestation of mealy bugs (after egg laying of the carob moth) we based our data only on samples picked in August and September, when carob moth infestation is fresh. The data showed that carob moth females oviposit on 1 to 2% of the mealy bug-free fruits, while up to 14% of the mealy bug-infected fruits are infested. These results, however, still leave the question of host selection unclear. To complicate the problem, carob moth was found

on grapefruit only in Israel, Cyprus and Turkey, whereas in the Western Mediterranean countries other citrus varieties are attacked.

Other hosts of the carob moth. Almond fruit nuts are infested by the carob moth to a certain extent each year. The larvae usually develop between the hull and the nut, so that direct damage to the seed is scarce. Almonds have only recently become an economically important crop in Israel, and the phenology of the moth on this host has not yet been studied. Carob moth was not found in Ziziphus spina-Christi, althouth this was reported by Bodenheimer (1930). Apparently such infestation is very rare. No other host of the carob moth was found in the course of surveys conducted throughout the country at various seasons.

Life cycle of the carob moth. The life cycle of the carob moth on its various hosts can be summarized as follows: During the winter the insect is found in its larval stages on acacia and carob pods. Growth proceeds slowly during this time but no pupation occurs before March. Adult emergence from acacia and carob occurs from mid-April through May. After that the only suitable host available to the adult moth are the carob midge-infested pods. Oviposition on such pods lasts until July, when these pods dry out and drop off. Pupation takes place at about the same time. Adults emerging during this period oviposit in crevices of the freshly cracked carob pods. Oviposition on these fruits will last until winter, if they are not harvested. Little oviposition, and not very successful development of one generation, may occur during June on acacia pods previously infected by V. livia. In August, when carobs are being harvested, oviposition starts on bruchid-infested acacia pods. The larvae feeding on such pods will not pupate until the following spring. These, together with the larvae found on unpicked carobs create the winter generation. Grapefruit is the only host of the carob moth on which not even one generation is completed, but damage is still caused.

Finally, it is evident that the carob moth depends at certain periods and for normal population build-up, on the availability of a certain type of host. Elimination of such host by taking measures such as uprooting acacia hedges, control of the carob midge, complete harvesting of the carob crop or planting of carob varieties which are resistant to cracking, would certainly reduce the insect population and would thus prevent damage caused by this pest.

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Table 1. Typical secondary infestation by the carob moth of carob midge infected fruits[1] in Agur during 1961

Date checked	% pods infested	No. per 100 fruits	
		larvae	pupae
April 25	0[2]	0	0
June 6	9	7	0
July 12	49	43	5
Aug. 8	96	83	23

1 Fruits of the Thillirya variety, from which the midge had already emerged.

2 Eggs were found but were not included in counts.

Table 2. Occurrnce of cracked carob fruits at the beginning of August in different varieties and locations

Variety	Location	% cracked fruit	
		1960	1961
Thillirya	Kfar-Hananya	10.0	11.4
	Kiriyat-Haroshet	56.8	17.0
	Agur	31.1	32.7
	Gan-Shlomo	17.3	30.4
Sandalawi	Acre	0.1	5.4
	Atlit	-	4.0
Algierian	Kfar-Hananya	0.3	0.0
	Kiriyat-Haroshet	76.5	8.3
Faradiya	Kfar-Hananya	60.7	17.7
Bolzer	Gan-Shlomo	46.8	49.2

Table 3. Carob moth infestation in cracked Thillirya fruits in 1961

Location	Number per 100 cracked fruit			
	Eggs	Larvae	Pupae	pupal exuviae
Agur				
July	19	45	0	0
Aug.	37	109	10	10
Gan-Shlomo				
July	17	29	0	0
Aug.	14	102	16	14
Givat-Brenner				
July	52	71	2	0
Aug.	-	98	28	17

Table 4. Infestation of carob pods during late season in Ayanot[1]

Date checked	Number per 100 fruits			
	eggs	Larvae	Pupae	Pupal exuviae
Aug. 20	49	64	19	19
Sept. 9	32	110	52	22
Sept. 19	19	188	61	61
Oct. 2	60	152	72	100
Oct. 31	54	345	14	111
Dec. 12	0	317	0	163
Jan. 22	0	315	0	-

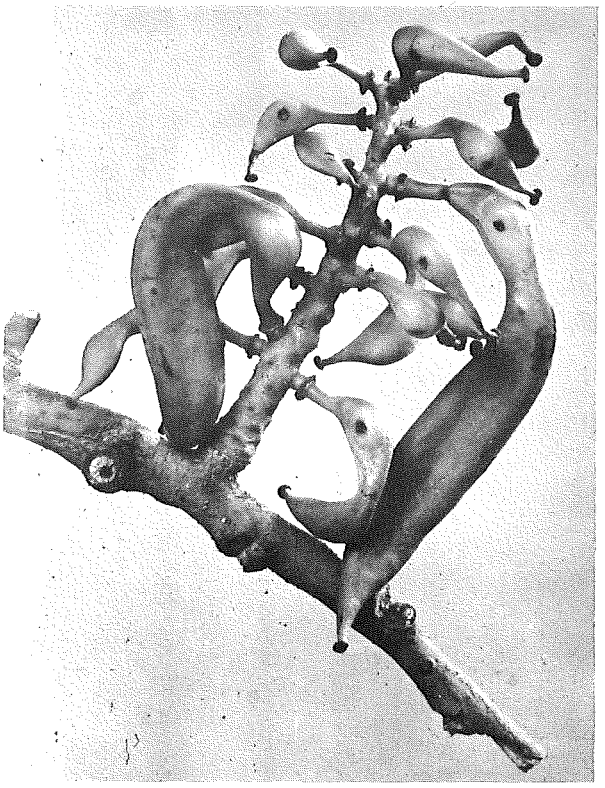
[1] Carobs of mixed varieties.

Table 5. Typical seasonal infestation of acacia pods by the carob moth in Yavneh

Date	Primary infestation		Secondary infestation by the carob moth No. per 100 pods		
	% pods infected	Insect	Larvae	Pupae	Pupal exuviae
April 16	0				
May 1	0				
May 15	0				
June 3	12	V. livia	8	0	0
June 17	9	"	0	0	0
July 7	8	"	25	0	0
July 17	7	"	0		
Aug. 2	19	"	16	0	0
Aug. 15	50	Bruchidae	0	0	0
Sept. 6	60	"	2	0	0
Sept. 18	83	"	0	0	0
Oct. 2	81	"	1	2	1
Oct. 30	91	"	7	1	1
Dec. 25	99	"	20	0	1
Jan. 28	100	"	32	0	8
March 3	100	"	24	3	5
April 3	100	"	13	9	3
April 30	100	"	1	5	24
June 2	100	"	1	0	30

Table 6. Carob moth occurrence on grapefruit in Yagur.

Date	% fruits infested	Eggs per 100 fruits		Larvae per 100 fruits	
		Alive	Dead	Alive	Dead
1960					
July	0.0	0.0	0.0	0.0	0.0
August	9.5	3.0	2.0	3.0	3.5
Sept.	13.5	1.0	2.5	0.0	12.5
Oct.	14.5	0.0	1.5	1.0	15.5
Nov.	15.5	0.0	0.0	0.5	15.0
1961					
July	0.0	0.0	0.0	0.0	0.0
Aug.	4.5	0.5	0.0	2.5	1.5
Sept.	13.5	1.0	1.0	1.0	12.0
Oct.	10.5	0.5	0.0	1.0	9.0
Nov.	16.0	1.0	1.0	1.0	12.0



ig. 2. Deformation of carob fruits as a result of infestion by the carob midge. Emergence holes of the midge are seen in some of the pods

Fig. 3. Carob pod cracked near the stem.

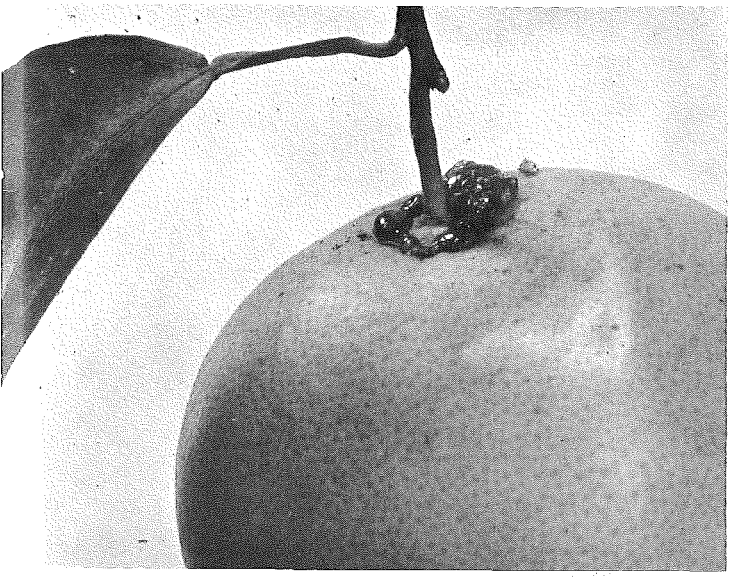


Fig. 4 Carob pod at the end of the season, after a prolonged infestation by the carob moth.

Fig. 5 Grapefruit infested by carob moth. Gum exuded from the larval penetration hole.