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J. Amer. Soc. Hort. Sci. 107(5):849–852. 1982.

The Role of Nitidulid Beetles in Natural Pollination of Annona in Israel[1]

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Additional index words. cherimoya, sugar apple, atemoya, fruit-set, *Annona* sp.

Abstract. **Four species of beetles of the family Nitidulidae were the most common arthropod visitors to flowers of annona (*Annona* sp.) in Israel throughout the flowering season and a significant relationship was demonstrated between these beetles and fruit-set. The beetles carry annona pollen on their dense cover of hairs. No difference in the efficiency of the 4 species was detected. The number of beetles per flower affected the fruit quality and shape.**

Sugar apple (*Annona squamosa* L.) and cherimoya (*A. cherimola* Mill.) were introduced into Israel early in the present century. The 2 species were frequently grown in close proximity to each other, and as a result seedlings with intermediate characteristics appeared in various places about 40–50 years ago. These seedlings were identified by Oppenheimer (11) as atemoyas (21), i.e., natural hybrids between the 2 species.

Commercial annona orchards are now planted with grafted trees mainly of locally selected atemoya cultivars. In addition, 2 cherimoya cultivars ('Jete' and 'Campa') introduced from Spain were planted on a limited scale. A great resemblance exists between atemoya and cherimoya fruits. The term "annona," is used in Israel for both. This term also will be used in the same way throughout the present and following reports.

The relatively low yields of atemoya in Israel and in other locations around the world (1, 2, 10, 12, 18, 19, 20, 21) is related to a low rate of natural pollination (1, 9, 10, 13, 16, 21). Cultivars of atemoya were therefore selected toward higher yield. However, fruit production even in these selected cultivars is often low and sometimes negligible. To overcome low yield, growers sometimes employ hand-pollination, a technique which improves fruit-set and increases yield in both *A. cherimola* and atemoya, but is not widespread because it requires as many as 40 working days per acre (1, 17).

Annona has a hermaphroditic protogynous flower, so that self-pollination is rare under normal conditions (1, 2, 10, 12, 16, 18). The biology and phenology of the flowering sequence in atemoya in Israel already have been reported (14). The flower opens in its female stage in early afternoon, between 1400 and 1600 HR and remains at this stage overnight. The next day it passes into the male stage, and between 1500 and 1700 HR it releases its pollen. After this stage, the petals usually fall off the tree. In areas with a relatively cold and humid climate, the stigma may remain receptive until the flower converts from the female to the male stage and releases its pollen (6, 7, 15). This phenomenon might explain the reported high rate of fruit-set of *A. cherimola* in Spain (4, 15). In most places, such conditions apparently do not occur, and therefore pollen transfer from flowers in the male stage to those in the female stage must be carried out by a pollinator. Observations by various authors have provided a long list of insect species on annona flowers (1, 3, 5, 13, 16, 20, 21).

The direct correlation between the presence of insects, especially beetles of the family Nitidulidae, and the percentage of fruit-set was first detected 10 years ago by Reiss (1971) in Israel (14). The present study was initiated to elucidate the factors responsible for natural pollination of annona in commercial orchards in Israel.

Materials and Methods

This study took place in 14 commercial annona orchards throughout the coastal plain of Israel during the blossoming

[1]Received for publication Dec. 14, 1981. Contribution from the Agricultural Research Organization, The Volcani Center, P.O.B. 6, Bet Dagan, Israel. No. 305-E, 1981 series.

The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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[3]The authors would like to thank W. A. Connel (Newark, Del., USA), J. Jelinek (Narod. Muzeum V. Praze, CCSR), and R. D. Pope (Natural History, The British Museum, London, England) for identifying the beetles. We are also grateful to M. (Shlem) Galon for her technical assistance and to D. Rosen (Dept. of Entomology, Faculty of Agriculture, The Hebrew University of Jerusalem, Rehovoth, Israel) for reading and criticizing the manuscript.

seasons of 1977 and 1978. Both atemoya and cherimoya orchards were examined. The weather during the blossoming season in the coastal plain of Israel is warm (maximum temperature 30 to 35°C, minimum 18 to 22°), relatively dry by day [relative humidity (RH) between 45 and 70%], and more humid during the night (RH = 85–95%).

Sampling arthropods in annona flowers. Sampling was done between 1600 and 1800 HR in the evening and between 0600 and 0800 HR the following morning, by carefully separating the petals without disturbing the insects or removing the flowers from the trees. Insects present inside flowers were identified, counted, and, when necessary, collected for identification in the laboratory. Unless otherwise specified, sampling took place in female-stage flowers.

The role of nitidulid beetles in the process of fruit-set. During the peak of the blossoming season (July), annona branches on the tree were confined within sleeves made of insect-proof 40-mesh plastic net, 1.4 m long and 0.6 m in diameter. Only branches with an estimated potential for producing ca. 100 flowers for the next period of 3 weeks were used. All fruitlets were removed from these branches before observations were initiated. The method of randomized complete blocks was applied in designing these experiments. A tree, or 2 adjacent trees, served as a block and each experiment was conducted in 5 replicates (blocks).

Results

Arthropod population in annona flowers. A total of 2044 arthropod individuals, mostly insects, were found in about 30,000 female-stage flowers that were examined; 96% of the insects were beetles of the Nitidulidae (Table 1).

The nitidulid beetles were collected and identified. They were found to belong to 4 species of 3 different genera, in the following proportions: *Uroporus humeralis* (F.), 47.6%; *Carpophilus hemipterus* (L.), 27.6%; *Haptoncus luteolus* (Er.), 16.1%; and *Carpophilus mutilatus* (Er.), 8.7%.

Observations were also carried out in flowers during the male stage. Again, most of the arthropods discovered visiting these flowers were nitidulid beetles. Although bees were also observed collecting pollen, they cannot be considered potential pollinators, since their bodies are too large to enter female-stage flowers. During this stage the petals are very close together.

Because most of the arthropods visiting annona were nitidulid beetles, these insects were used in the experiments and observations to study their potential as pollinating agents of annona in Israel.

Adaptability of nitidulid beetles to transfer annona pollen. The outer surface of the nitidulid beetles is densely covered with hairs (Fig. 1). This cover, differing in density on the various parts of the body, is suitable for holding pollen collected when visiting male-stage flowers and carrying it to other flowers at the female stage. Pollen tetrads were detected within the hairy cover of beetles which had visited annona flowers (Fig. 2).

Table 1. Arthropods detected inside annona flowers during the 1977–78 blossoming seasons.

Arthropod grouping	No. of individuals
Insecta	
Anthocoridae	5
Formicoidea	43
Lygaeidae	7
Nitidulidae	1938
Tenebrionidae	7
Other Arthropoda	
Arachnida	44
Total	2044

Effect of nitidulid beetles on fruit-set and fruit quality in annona. During the 1977 blossoming season, flowers were examined for nitidulid beetles, and those containing them were marked. This procedure was carried out during the morning hours and repeated in 4 commercial orchards (totaling ca. 400 flowers) located in the northern and central parts of the coastal plain. Nitidulid beetles were detected in 84 flowers (21%), which were re-examined 24 days later. Fruit-set from flowers which had contained insects varied between 43% and 67%, whereas it did not exceed 8% from those flowers from which insects were absent when the flowers were examined (Table 2).

In the following experiment, carried out in the Nordia orchard during the peak of the 1978 blossoming season, ca. 16,000 flowers were examined for nitidulid beetles. The flowers were first examined during the afternoon hours (shortly after they had opened) and again the next morning. Those flowers (totaling 407) in which nitidulid beetles were detected were marked and the number of beetles per flower was counted. Three weeks later these marked flowers were re-examined for fruit-set and 3 months later for fruit shape and quality. The results are presented in Fig. 3.

The proportion of fruit-set from flowers in which beetles were observed in the afternoon was higher than in those where beetles were detected in the morning (67.5% vs. 48%, respectively) and so was the percent of fruits which completed their development (48% vs. 39%, respectively). There was also a clear relationship between the number of beetles observed in each flower and fruit shape and quality. All flowers in which at least 4 beetles were observed completed their development on the trees and produced high-quality, symmetrical fruits, whereas some of those in which fewer beetles were detected (1–3) yielded low-quality, asymetrical fruits, if any at all. The tendency of the fruitlets to drop or to develop into small asymmetrical fruits decreased with the increase in the number of beetles found in the flower.

In addition to the observations described above, an experiment was conducted in which groups of 10 nitidulid beetles were

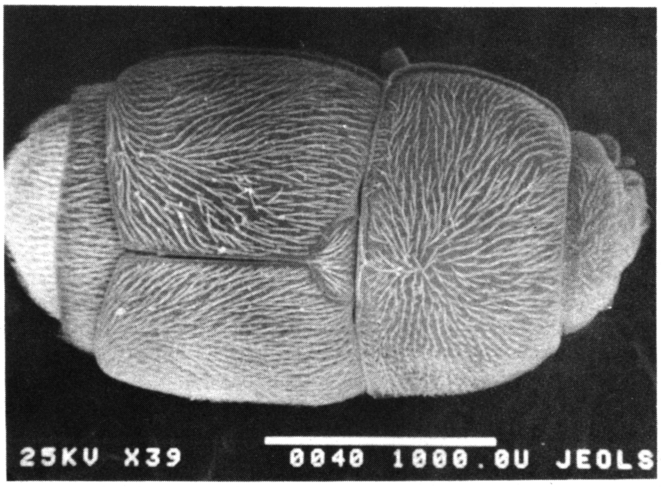

Fig. 1. Scanning electron microscope photograph of *Carpophilus hemipterus* (Nitidulidae: Coleoptera). Note the dense cover of hairs.

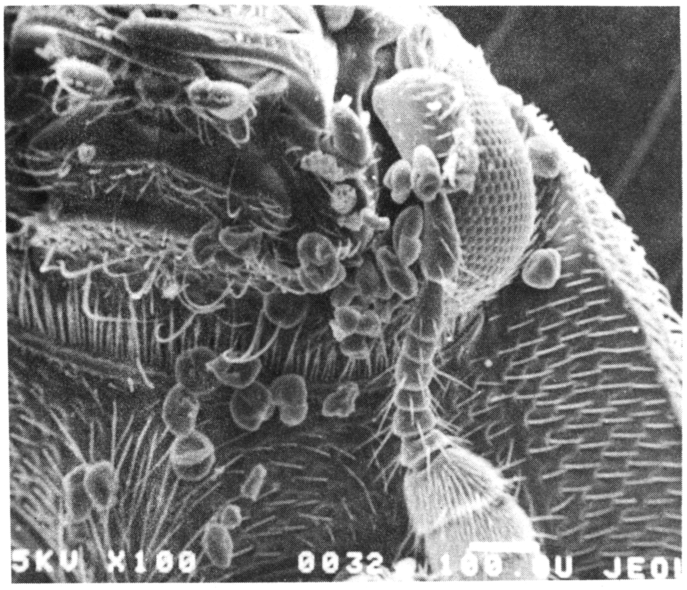

Fig. 2. Scanning electron microscope photograph of *Carpophilus hemipterus* after leaving annona flower. Note the pollen particles among the hairs.

confined in sleeves made of insect-proof plastic net on flowering twigs of atemoya trees. The effect on fruit-set of 4 different species of beetles was compared; in addition, natural fruit-set was recorded in control cages, in which no beetles were introduced. The results indicate clearly that while there was no difference in the efficiency of the 4 species, fruit-set occured only in the presence of beetles (Table 3).

A similar experiment, conducted on *A. cherimola* 'Campa', demonstrated the importance of the nitidulid beetles in this cultivar as well (Table 4).

The initial fruit-set observed in the last 2 experiments when the sleeves were removed was 2 to 3 times higher than that observed 3 months later. According to our practical experience, the twigs could not carry such a large number of fruitlets, and therefore half to one-third dropped during the above-mentioned period. A similar phenomenon was observed in cases of excessive hand-pollination. However, the number of fruits remaining still exceeded that which is common under natural pollination (Fig. 4).

Discussion

The blossoming season in Israel takes place when the temperature is high and relative humidity is low. Under such conditions, we found that no self-pollination occurs within the individual flower (Tables 3, 4), and the annona require pollinators to set fruit.

Table 2. Relation between the presence of nitidulid beetles in annona flowers in the morning and fruit set (July 1977).

Orchard	No. of flowers		Fruit set (%) 24 days later	
	With beetles	Without beetles	Flowers with beetles	Flowers without beetles
Nordia	7	93	57.1	3.2
Bené Deror	50	100	58.0	8.0
Gan Hashomron	6	20	66.7	5.0
Yehiam	21	100	42.9	4.0

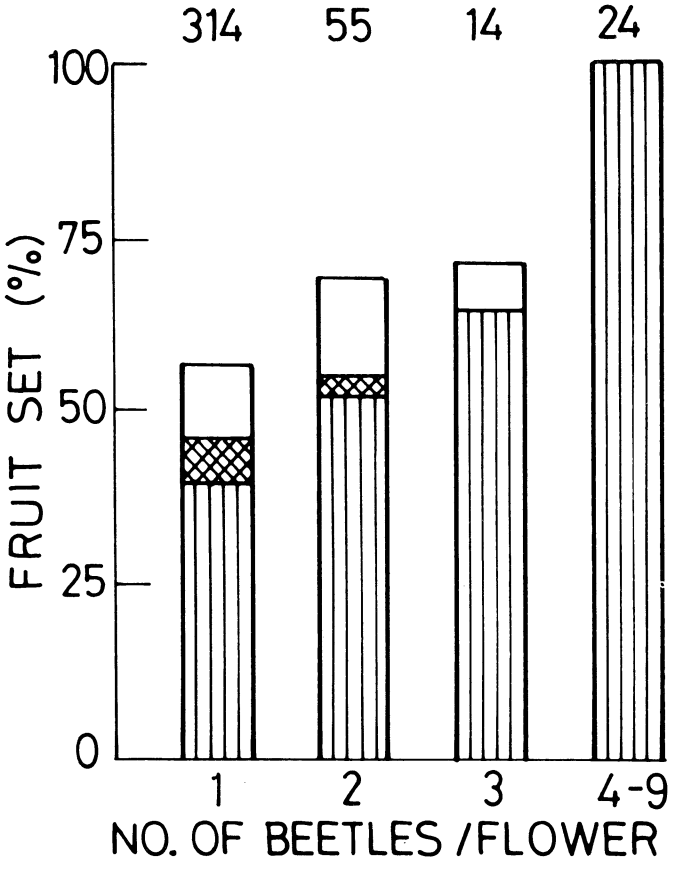

Fig. 3. Relationship between the number of nitidulid beetles observed in annona flowers and the percentage of: fruit-set (height of histograms); fruitlets which dropped off the trees (▭); asymmetrical fruits (▨); and high-quality symmetrical fruits (▥). The figures above the histograms represent the number of flowers in the group.

Annona flowers attract a wide range of arthropods, of which only nitidulid beetles seem to have any importance as potential pollinators. The nitidulid beetles observed in the annona flowers are well-suited to carry pollen on their dense cover of hairs.

The conversion of the atemoya flower to the male stage takes place in Israel during late afternoon (12, 14). Our observations showed that pollen release by *A. cherimola* also occurs in late afternoon, and at that time both species have female-stage flowers with receptive stigmas. Beetles can therefore move, loaded with pollen, from male-stage flowers to flowers in the young female stage and pollinate them.

Beetles carrying pollen also may enter flowers during the night and morning hours and pollinate them. The longevity of annona

Table 3. The relative efficiency of 4 species of nitidulid beetles in pollinating annona flowers when confined in net sleeves on twigs.

Species	No. of flowers per branch (mean ± SD)	Fruits after 3 months (%)
None	90 ± 11	0 b[z]
C. hemipterus	82 ± 15	10.7 a
C. mutilatus	82 ± 14	5.0 a
H. luteolus	62 ± 11	6.5 a
U. humeralis	120 ± 29	7.8 a

[z]Analysis was carried out after angular transformation of the data. Mean separation by Duncan's multiple range test, 5% level.

Table 4. Effect of nitidulid beetles confined in sleeves on twigs on the fruit-set of *Annona cherimola* 'Campa'.

Treatment	No. of flowers on branch (mean ± SD)	Fruits after 3 months (%)
Without beetles	29 ± 3	0
C. hemipterus & *U. humeralis* beetles combined	40 ± 7	3.5 ± 1.4

pollen ensures succesful pollination even in cases when pollen transfer occurs after 24 hr (14).

The results obtained in the present study lead us to conclude that fruit-set in annona orchards in Israel depends strictly on the presence of nitidulid beetles. This conclusion is in agreement with results of pollination studies carried out in the Annonaceae, and especially in the genus *Annona,* where pollination was reported to be carried out by beetles (8, 9). It might be important to study the factors responsible for pollinating annona in Central America (Peru and Equador), where the tree is believed to have originated (13).

The present study shows great variability in the percentage of flowers containing beetles in different orchards, and at different periods of the season in the same orchard. We suggest that the density of beetle populations and the activity of the beetles are the key factors responsible for these variations. This problem of annona fruit production might be solved either by selecting cultivars more suited for self-pollination, or by developing methods to encourage visits by the nitidulid beetles to the annona flowers at times that will produce maximum yields in shorter harvest periods.

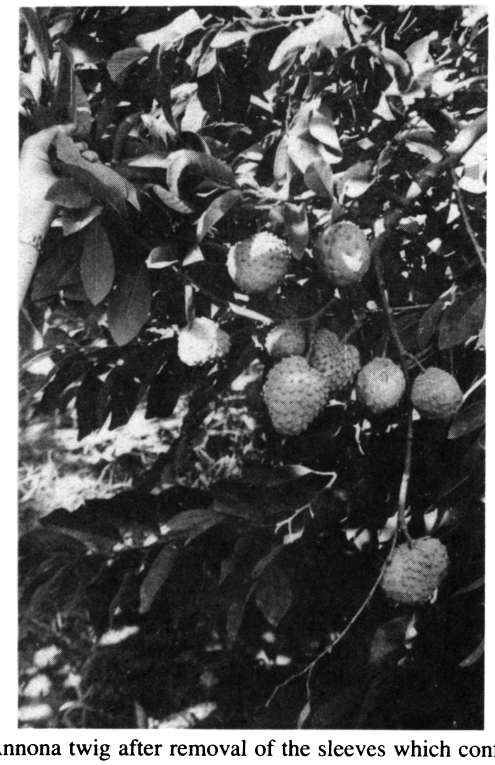

Fig. 4. Annona twig after removal of the sleeves which confined the nitidulid beetles. Note the large number of fruits.

Our present knowledge is insufficient for regulating the activity of the nitidulid beetles in pollinating annona flowers for the purpose of increasing fruit production or quality, or to concentrate fruit-set into a shorter period.

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