ECONOMIC ASPECTS OF THE BIOLOGY AND CONTROL OF THE ORIENTAL FRUIT MOTH, *GRAPHOLITHA MOLESTA* BUSCK, IN THE UNITED STATES[1]

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ABSTRACT

The oriental fruit moth has caused considerable damage to fruit crops in the United States since its introduction from Japan about 1913. The greatest damage occurred during the period between 1930 and 1950, when fruit moth larvae damaged the tender shoots and fruit of peach and quince.

Biological control, in the form of widespread releases of fruit-moth parasites imported from Japan, Korea, Europe, and Australia, was unsuccessful since these parasites did not become permanently established. Indigenous parasites, however, notably *Macrocentrus ancylivorus*, were very effective, although no foreign colonization of this species has been successful.

Chemical control with DDT has been extremely effective in reducing populations of oriental fruit moth; however, populations of European red mite were greatly increased by such treatment. A better an safer insecticide now appears to be carbaryl, which is also effective against plum curculio, stink bugs, and plant bugs, although it does not control mites. An additional advantage of carbaryl is that it can be used closer to harvest than can DDT or other insecticides. It is suggested that chemical insecticides belonging to different chemical classes be alternated to avoid the development of chemical resistance in the species.

The oriental fruit moth has been present in the United States for about 55 years. In the 37 years following its introduction, the insect was a serious pest of peaches and quinces in the eastern and midwestern sections of the country. During the past 18 years, the species has apparently reached an ecological equilibrium, at least in Ohio, and is now regarded as a minor fruit pest.

This insect was first reported in the United States in 1916 by Quaintance and Wood (1916), but was presumably accidentally introduced into the United States from Japan about 1913. The initially discovered infestation was confined to Washington, D.C., and a few neighboring counties in the states of Virginia and Maryland. From this center, the species spread rapidly to the commercial peach areas in eastern United States and Canada. By 1928, it had become well distributed in Ohio and other parts of the midwest (Stearns, 1928). It required but 17 years more for the species to reach the commercial peach orchards in California, Oregon, and Washington.

The principal means of dispersal in the United States was by the shipment of infested fruit and nursery stock bearing overwintering larvae in cocoons. Secondary dispersal was accomplished through flights of moths from orchard to orchard. Flight-behavior studies have shown that moths frequently fly for distances of at least a mile and sometimes for nearly two miles (Steiner and Yetter, 1933).

HOST PLANTS AND DAMAGE

The larvae of the first and second generations feed primarily in the tender shoots of peach, plum, cherry, quince, and apple. Each larva requires three or more shoots for the completion of its developmental period. While this is of little consequence in established peach orchards, it may become a serious problem to the nurseryman. Frequently as many as 90 percent of the terminal and lateral

[1]Manuscript received February 24, 1969.

shoots of nursery peach trees may be attacked by fruit-moth larvae. The end result of such an infestation is a much-branched, bushy tree, which is of little value as stock.

Shoot-feeding may continue throughout the season, but as soon as the terminal growth begins to harden and the fruit becomes of suitable size and texture, a distinct preference is shown for the fruit. Quince is the fruit most severely damaged by larvae; it is not unusual to find from six to twelve larvae in a single quince fruit. This situation made it practically impossible to produce quinces commercially during the peak of fruit-moth activity, between 1930 and 1950.

Peach fruits are also severely attacked, particularly the later ripening varieties, such as Elberta and Lizzy. Although first- and second-generation larvae feed almost exclusively in the terminal and lateral shoots of peach trees, first-generation larvae sometimes also attack small fruits. Second-generation larvae occasionally cause superficial fruit injury during late June and early July. During this period, peaches exude considerable gum, which prevents actual entry of the larvae. The resultant injury appears as a gummy blemish.

The most severe damage is caused by third-generation larvae, which feed exclusively within the fruit. Sometimes third-generation larvae, when very small, enter the fruit at the stem end and no external signs of infestation are visible. These fruits, when cut open at harvest, quite frequently contain full-grown larvae.

In certain varieties of apples, such as Jonathan, Red Delicious, Stayman Winesap, and Rome Beauty, which are interplanted with, or adjoining to, early and midseason peaches, fruit-moth-larval damage to apples may be serious.

More detailed information on host damage and economic importance is contained in Agriculture Information Bulletin No. 182 (Allen, 1958).

BIOLOGICAL CONTROL

Nearly all attempts to control the oriental fruit moth with conventional insecticides from 1916 to 1940 were unsuccessful. The arsenicals, which controlled codling moth and plum curculio, were ineffective, because larvae of the fruit moth discard the first few mouthfuls of tissue and ingest only the inner tissues of shoots and fruits. For this reason the United States Department of Agriculture, in cooperation with many states, developed a program for the importation of fruit-moth parasites from Japan, Korea, Europe, and Australia (Allen, 1962). Although numerous exotic species were propagated and released in peach orchards in the United States, only 10 species were recovered in field collections. Several of these species were obtained from field-collected fruit-moth larvae in the eastern states, but apparently the only two parasite species which had become at least temporarily established were *Agathis diversa* (Muesbeck) and *Agathis festiva* (Muesbeck). However, except in one or two localities, this establishment was effective only for one growing season.

Fortunately, wherever the fruit moth has become established in the United States, the various stages have soon been attacked by numerous species of native parasitic and predaceous insects. Studies by federal and state scientists indicate that, by 1940, about 130 species of indigenous parasites had adopted the fruit moth as a host (Allen, 1962). Most of these species which have been reported parasitizing the oriental fruit moth actually attack the fruit moth only infrequently. The exception to the preceding statement are pointed out as follows.

First- and second-generation fruit-moth larvae, which are shoot-infesting, are heavily attacked by the braconids *Macrocentrus ancylivorus* Rohwer, *M. delicatus* Cresson, *M. instabilis* Muesbeck, and by the ichneumonids *Glypta rufiscutellaris* Cresson, *Pristomerus euryptychiae* Ashmead, and *Temelucha (Cremastus) minor* (Cushman). These six species of parasites account for more than 80 percent of the total parasitism of shoot-infesting larvae in eastern United States (Allen, 1962).

When it was discovered that *Macrocentrus ancylivorus* was a valuable parasite of both the fruit moth and the strawberry leaf roller, *Ancylis comptana fragariae*, and that it could be easily reared, federal and state laboratories propagated and released this parasite on a large scale. As a result of this endeavor, *M. ancylivorus* was widely dispersed and in a few years became the dominant parasite of the fruit moth in almost every locality (Allen, 1962).

Probably the most logical explanation of the success of *Macrocentrus ancylivorus* in parasitizing the oriental fruit moth is the widespread distribution of its alternate hosts. Both the ragweed borer, *Epiblema strenuana* Walker, and the strawberry leaf roller are alternate hosts of *M. ancylivorus* and serve as parasite reservoirs in the vicinity of peach orchards.

So far as is known, no foreign colonization of *Macrocentrus ancylivorus* has been permanently successful. Efforts to establish *M. ancylivorus* on the oriental fruit moth in countries outside North America have been reported by Allen and Haeussler (1932) for France, by Grandi (1933) for Italy, by Ishii (1940) for Japan, by Lopez-Cristobal (1941) for Argentina, and by Helson (1947) for Australia.

MASS LIBERATIONS

Allen (1948) reported an average reduction of 50 percent in fruit injury after mass liberations of *Macrocentrus ancylivorus* in 100 to 140 acres of peach trees each year for 10 years. A mass liberation may be defined as the release of approximately 1 or more female parasites per tree during the first- and second-generation fruit-moth larval period. Research in Ohio indicated that, although an average of 43.4 percent reduction in fruit injury could be obtained with mass releases of from 0.75 to 1.60 females per tree, the variation between orchards was so great that it was impossible to predict the results of such liberations (Rings, 1947, unpublished data). Brunson and Allen (1954) showed that mass liberations of *M. ancylivorus*, in combination with a reduced number of spray applications, were as effective as a larger number of spray applications without the parasites.

CHEMICAL CONTROL

The first insecticide to show real effectiveness against the oriental fruit moth was DDT. At the close of World War II, DDT became available as an agricultural chemical. Experimental results in Ohio (Rings, 1948) and other states proved that two applications of DDT at 35-day intervals would reduce fruit--moth injury by 97 percent. Although DDT was the first really effective control for oriental fruit moth, it soon became evident that the DDT was contributing to tremendous increases of the European red mite. These increases in mite populations were presumed to be due to the lethal effects of DDT on mite predators, though this has not been clearly demonstrated by any investigator. In fact, European red mite was not recognized as a major peach pest until DDT had been used for fruit-moth control. In attempting to develop an effective chemical control program for both the red mite and the fruit moth, the organic phosphates, parathion and EPN, were found to be very useful (Rings, 1949).

Chemical control investigations conducted in Ohio in 1958 showed that carbaryl (1 naphtyl-N-methyl carbamate = Trade name Sevin) gave better control of the fruit moth than did either DDT or parathion (Rings, 1959). In addition to giving excellent control of fruit moth, carbaryl was effective against plum curculio, stink bugs, and plant bugs. However, it was not effective in controlling mites. United States registration laws prohibit the application of DDT within 30 days of peach harvest and of parathion within 14 days of harvest, but allow the application of carbaryl the day before harvest. Carbaryl is not only safer to use for fruit moths than are other chemicals, but it is also the most effective material which can be used close to harvest time to prevent stem entrances by fruit-moth larvae.

AVOIDANCE OF CHEMICAL RESISTANCE

The oriental fruit moth in the United States is probably the peach insect most likely to become resistant to chemicals. This insect has three or four broods each year and, because chemicals have been widely used for fruit-moth control since 1947, a total of from sixty to eighty generations have been exposed to organic chemicals, at least in some orchards. While chemical resistance has not been proved in the case of the fruit moth, there have been reports of failure to control this pest with chemicals in Michigan, Virginia, and Canada. In these cases, chemical resistance has been strongly suspected, but remains to be verified.

Fortunately, several classes of insecticides are available for controlling oriental fruit moth and are adaptable to the peach-insect control program. These chemicals make possible a rotational spraying program for oriental fruit-moth control to prevent the development of resistance. The rotational spray schedule is based upon changing the class of insecticide from year to year. For example, in a rotational spray program on peaches, a grower may use one of the organophosphates (represented by parathion, EPN, or Guthion) the first year, and a carbamate (represented by carbaryl) the second year, all being insecticides registered for this use by the United States Department of Agriculture and the Federal Food and Drug Administration (Rings, 1961). A rotational spray program should prevent or greatly retard the development of resistance, because different classes of insecticides are believed to have different physiological effects on fruit-moth larvae. At one time DDT was included in the rotational spray schedule, but the persistence of the chemical in the environment is its greatest disadvantage.

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