Trichogramma and Its Utilization for Crop Protection in the U.S.A.

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Major attention was given to *Trichogramma* in the United States in the taxonomic studies by Girault (1911, 1912, 1913). As a result, releases of sizable numbers of *Trichogramma* in the United States were made by Howard and Fiske (1911) in an attempt to control the browntail moth, *Euproctis chrysorrhoea* (L.); however, high levels of parasitism were not obtained. Subsequently, a considerable revival of interest in *Trichogramma* took place when methods of mass culture were developed by Flanders (1929, 1930a)—eggs of the Angoumois grain moth, *Sitotroga cerealella* (Oliver) were used as a host. As a result, experimental release of *Trichogramma* was made against the codling moth, *Cydia pomonella* (L.) (Flanders, 1930b; Alden and Webb, 1937); the oriental fruit moth, *Grapholitha molesta* (Busck) (Peterson, 1930; Schread, 1932; Allen and Warren, 1932); pecan nut casebearer, *Acrobasis nuxvorella* Neunzig (Spencer et al., 1949); European corn borer, *Ostrinia nubilalis* (Hübner) (Schread, 1935); and sugarcane borer, *Diatraea saccharalis* (F.) (Hinds and Spencer, 1928, 1930; Hinds et al., 1933).

These and other experimental tests and sporadic commercial efforts in the 1930's and 1940's to utilize releases of mass-reared *Trichogramma* did not achieve the extent of consistency of control desired (Clausen, 1958). Nevertheless, limited continuous commercialization of *Trichogramma* in the United States began in 1953 and has continued since that time (E. J. Detrick, personal communication, 1979). However, commercial sales of *Trichogramma* failed to gain wide acceptance during the 1950's and 1960's because: 1) control was not clearly demonstrated; 2) adequate numbers were not used; 3) adequate quantities of *Trichogramma* were not available; 4) adapted species or strains were not used; and 5) highly effective, relatively inexpensive, synthetic insecticides were readily available.

The significant expansion in research on *Trichogramma* that occurred in the United States in the late 1960's and the 1970's is the subject of this paper. Major topics to be considered include biosystematics, efficacy (including results of augmentative releases, a review of factors affecting efficacy, and interactions with natural predators), economic and social considerations and future prospects.

Biosystematics

Correct identification of *Trichogramma* is essential to the most effective use of this insect. Unfortunately, because of misidentification and inconsistent application of the nomenclature, the taxonomic literature is confused and much of the literature on *Trichogramma* biology cannot be assigned with confidence to a particular species. Species recognition was greatly improved when Nagarkatti and Nagaraja (1971) established the importance of the male genitalia as a diagnostic character. More recently, the taxonomy of the North American species was placed on a solid foundation with the designation of neotypes for *T. pretiosum* Riley and *T. minutum* Riley and the designation of lectotypes for several species often confused in past literature (Pinto et al., 1978).

Current literature documents the existence of 11 biparental species of *Trichogramma* in the continental United States (Table 1). The species that are listed are, with the exception of *T. platneri*, morphologically distinct and thus structurally identifiable. The type, sex and location of the type, the distribution and hosts that have been verified and the reference documenting the determinations are also provided. Some published sources have been excluded where inaccuracies are likely. Of the species listed, *T. minutum*, *T. pretiosum* and *T. exiguum* are most commonly collected and submitted for identification by agricultural workers in the United States.

Even though the 11 U.S. species of *Trichogramma* appear to be fairly well defined, the biosystematic relationships among them are not well understood. For example, host records in nature for *T. minutum* and *T. pretiosum* indicate a high degree of nonspecificity for these widely distributed species (Clausen, 1978), but marked host selectivity has been demonstrated experimentally for *T. nubilale* (Curl and Burbutis, 1978). Also, host specificity is inferred for *T. semblidis* since only appropriate eggs deposited in aquatic environments are parasitized (Burks, 1979). However, several species may share as hosts the eggs of a single lepidopteran species on the same plant and may occur synchronously, or in succession, in eggs of the same host species (Oatman and Platner, 1973; E. R. Oatman, personal communication, 1979; Goodpasture and J. D. Lopez, unpublished data).

In addition to the complications in biosystematics produced by complex ecological requirements related to distribution, habitat preference and host range, the biosystematics of *Trichogramma* are further complicated by the occurrence of sibling species; i.e., there are many apparently morphologically indistinguishable but biologically distinct entities. Populations of most of the originally described and more common species seem to include entities that exhibit different biological characteristics. For example, the morphological taxon *T. minutum* includes the morphologically indistinguishable *T. platneri* (Pinto et al., 1978), and according to Nagaraja and Nagarkatti (1973), *T. californicum* includes an undescribed European sibling species. Other sibling or near-sibling species are represented by populations that are morphologically intermediate between pairs of morphological species such as *T. pretiosum* × *T. minutum* and *T. minutum* × *T. exiguum* (Goodpasture, unpublished data). In fact, hybridization tests reveal the existence of infraspecific forms that are only partially isolated reproductively (Nagarkatti and Nagaraja, 1977). For example, these authors noted that *T. pretiosum* and *T. minutum* exhibit incomplete genetic isolation and thus bear semispecies status with respect to each other. *Trichogramma* workers are therefore confronted with a morass of intraspecific categories.

The solution for those attempting practical biological control with *Trichogramma* is to consider intraspecific entities such as semispecies, biological races or genetic strains as equivalent to distinct species. Then, as additional entities are discovered and characterized, the resource pool of these natural enemies available to biological control workers can be expanded. Indeed, the apparent success of *Trichogramma* in biological control in the Soviet Union may be attributable, at least in part, to biosystematic studies that revealed 15 intraspecific forms of three *Trichogramma*

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