

DEVELOPMENT RATES OF *TRICHOGRAMMA MINUTUM* (HYMENOPTERA: TRICHOGRAMMATIDAE) AND IMPLICATIONS FOR TIMING AUGMENTATIVE RELEASES FOR SUPPRESSION OF EGG POPULATIONS OF *CHORISTONEURA FUMIFERANA* (LEPIDOPTERA: TORTRICIDAE)¹

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Abstract

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Development rates of the parasitoid, *Trichogramma minutum* Riley, were studied to provide information required in timing field releases of *T. minutum* for suppression of egg populations of the spruce budworm, *Choristoneura fumiferana* (Clemens). Development was observed in eggs of 2 host species, *C. fumiferana* and *Sitotroga cerealella* (Olivier), at constant temperatures of 14, 21, and 27°C. Parasitoid development varied directly with temperature. Parasitoids developed more rapidly in eggs of *S. cerealella* than in those of *C. fumiferana*. Parasitoid males developed faster than females in some host-temperature treatments. Development of *T. minutum* is apparently rapid enough to allow progeny of parasitoids released early in the spruce budworm's oviposition period to mature and be available to oviposit in budworm eggs deposited later in the budworm oviposition period. Potential release strategies are discussed.

Résumé

On a étudié les taux de développement du parasitoïde *Trichogramma minutum* Riley afin d'obtenir l'information requise pour le relâchement au bon moment de *T. minutum* en vue de la suppression des populations d'oeufs de la tordeuse des bourgeons de l'épinette, *Choristoneura fumiferana* (Clemens). On a suivi le développement dans des oeufs de 2 espèces d'hôtes, *C. fumiferana* et *Sitotroga cerealella* (Olivier), aux températures constantes de 14, 21 et 27°C. Le développement du parasitoïde a varié directement en fonction de la température. Les parasitoïdes se sont développés plus rapidement dans les oeufs de *S. cerealella* que dans ceux de *C. fumiferana*. Les parasitoïdes mâles se sont développés plus rapidement que les femelles à certaines températures. Le développement de *T. minutum* est apparemment suffisamment rapide pour permettre aux progénitures de parasitoïdes relâchés tôt au cours de la période de ponte de la tordeuse de mûrir pour pondre dans les oeufs de tordeuse déposés plus tard au cours de sa période de ponte. On discute de stratégies possibles de relâchement.

Introduction

Trichogramma minutum Riley is a native egg parasitoid of the spruce budworm, *Choristoneura fumiferana* (Clemens). Spruce-budworm eggs are subject to parasitization by this multivoltine chalcid soon after the eggs are deposited on coniferous-tree foliage in late-June to mid-July. Parasitism of budworm eggs by *Trichogramma* is usually less than

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15%, although levels greater than 70% have been observed (Anderson 1976). The effectiveness of *Trichogramma* in parasitizing budworm egg populations appears to be dependent on the density of alternative host populations (Miller 1953, 1963; Neilson 1963).

It may be possible to increase parasitism of spruce-budworm eggs by *T. minutum* by mass rearing and augmentative releases of the parasitoid. However, much basic information is needed before *T. minutum* can be practicably used to suppress spruce-budworm populations. Knowledge of the period of host availability (Houseweart *et al.* 1982), and an understanding of progeny production (Houseweart *et al.* 1983) and development rates of the parasitoid are prerequisites for proper timing of augmentative releases of *T. minutum*.

Development data have been reported for several strains of *T. minutum* reared in eggs of various orchard and stored-grain pests (Flanders 1931a; Lund 1934; Peterson 1930; van Steenburgh 1934); however, development studies have not been reported for *T. minutum* strains that parasitize spruce-budworm eggs. This report describes development rates of a Maine (USA) strain of *T. minutum* in spruce-budworm eggs and in eggs of *Sitotroga cerealella* (Olivier) (Lepidoptera: Gelichiidae), a common laboratory host for mass production of *Trichogramma*. The objectives of our study were (1) to determine and compare development rates of *T. minutum* reared in eggs of *C. fumiferana* and *S. cerealella*, and (2) to evaluate the possibility that the progeny of released parasitoids could mature soon enough to be available to oviposit in budworm eggs deposited later in the budworm oviposition period.

Materials and Methods

Parasitoid colony. A colony of *T. minutum* was established from parasitized eggs of *C. fumiferana* collected in 1980 near Columbia Falls, Greenville, Jonesboro, Orono, and Wesley, Maine. The colony was maintained in eggs of *S. cerealella* at 27°C and 75–90% RH with 24-h illumination following procedures adapted from Morrison (1970). The colony cage consisted of a glass tube (28 × 300 mm) stoppered at both ends.

Host colonies. Second-stage larvae of *C. fumiferana* were obtained from a colony at the Forest Pest Management Institute, Canadian Forestry Service, Sault Ste. Marie, Ontario and reared to pupation on artificial diet (Grisdale 1970). Pupae were sexed and held in petri plates until adult emergence. Daily, ca. 30 adults (2 males:1 female) were placed into mesh-covered, 3-L ice-cream containers with twigs of balsam fir (*Abies balsamea* (L.) Mill.) as oviposition substrate. Each container was lined with a plastic bag to facilitate removal of dead moths. The colony was maintained at room temperature (ca. 20°C). Foliage in the oviposition cages was replaced daily. Needles bearing egg masses were collected from the foliage and stored at 27°C until used (<24 h) in tests.

Eggs of *S. cerealella* were obtained from a colony maintained at the USDA Cotton Insects Research Laboratory, College Station, Texas. Weekly shipments of these eggs were stored at 4°C prior to use.

Tests of parasitoid development. Development of *T. minutum* was studied using eggs of both *C. fumiferana* and *S. cerealella* as hosts. Balsam-fir needles bearing 2-day-old egg masses of *C. fumiferana* (4–34 eggs/egg mass) were placed in rows on adhesive labels (16 × 32 mm). Loose eggs of *S. cerealella* were sprinkled onto a thin line of dilute white glue on 3 × 20-mm paper cards (ca. 50–80 eggs/card). Eggs of both host species were then exposed to adult *T. minutum* in the parasitoid colony tube for 1 h at 27°C. The tube was then held at room temperature (ca. 20°C), and a sleeve of black paper was placed around the end of the tube containing the host eggs to induce the positively phototactic parasitoids to leave the host eggs. After 30 min, host eggs were removed from the tube and examined under a microscope to remove all adult parasitoids. Needles with eggs of *C. fumiferana* were then removed from the labels, pinned individually to corks, and placed in glass vials (10 × 75 mm). The same procedure was followed for the *S. cerealella* egg cards. Equal

numbers of vials containing parasitized eggs were placed in environmental chambers at 1 of 3 constant temperatures (14, 21, and 27°C) and maintained at 75–90% RH and 24-h illumination.

One replicate was established for each host on 3 consecutive days. Ten *C. fumiferana* egg masses and 16 cards of *S. cerealella* eggs were stung for each temperature treatment within each replicate. Egg sample size varied, however, due to differences in numbers of eggs exposed to parasitoids and incomplete parasitism.

All vials were examined daily for emergence of adult progeny from host eggs. If emergence was observed, host eggs were transferred to a clean vial. The number of emerged parasitoids in the original vial and the time of each examination were recorded. Daily examination of test vials continued until no adult emergence had been recorded for several days.

Results and Discussion

Parasitoid development. The developmental rate of *T. minutum* expressed as percentage development per day ($(1/d) \times 100$, where d = number of days from oviposition to adult emergence) was computed for each emerged parasitoid. Developmental rate increased as temperature increased (Fig. 1). *Trichogramma minutum* reared in eggs of *S. cerealella* developed faster than those reared in eggs of *C. fumiferana*. Regression models that best describe these relationships (Fig. 1) are $Y = -7.901 + 0.743X$ with *S. cerealella* as host (Y = percentage development per day, X = temperature (°C), $n = 1835$, $R^2 = 0.982$), and $Y = -6.985 + 0.657X$ with *C. fumiferana* as host ($n = 1745$, $R^2 = 0.934$).

Based on the regression models, a minimum developmental threshold for *T. minutum* was estimated at 10.6°C for each host group. The true developmental threshold may be slightly lower than an estimated threshold determined from linear models, because of the sigmoid shape of temperature – developmental rate curves (Davidson 1944; Sharpe and DeMichele 1977). However, any development that might occur below the estimated threshold is likely to be extremely slow. Development of other strains of *T. minutum* has been observed to be slow and continuous at 10°C, but discontinuous or non-existent below that temperature (Flanders 1931a, 1931b; Peterson 1930).

The length of the developmental period of *T. minutum* (elapsed degree-days computed for each emerged parasitoid) was significantly affected by host, temperature, and parasitoid sex (Table 1). *Trichogramma minutum* reared in eggs of *S. cerealella* developed with significantly fewer degree-days than did those reared in eggs of *C. fumiferana*. *Trichogramma minutum* reared at 14°C required the fewest degree-days for development; *T. minutum* reared at 21°C required the most. Males of *T. minutum* developed with significantly fewer degree-days than females when reared at 21 and 27°C in eggs of *C. fumiferana* and at 14°C in eggs of *S. cerealella*.

One possible cause of host effects on parasitoid development rates is simply differences in nutritive quality of host eggs. Salt (1940) also suggested that differences in developmental rates of *T. evanescens* might be related to thickness of host-egg chorions or quantity of food contained in the host egg. In his study, *T. evanescens* had the slowest developmental rates in eggs of *S. cerealella*, the smallest of 3 host species tested. However, we found that *T. minutum* developed more rapidly in eggs of *S. cerealella*, which are less than half the size of eggs of *C. fumiferana*. *Trichogramma minutum* reared in eggs of *S. cerealella* also have significantly smaller body dimensions than those reared in *C. fumiferana* (Southard *et al.* 1982).

Superparasitism and the resulting smaller quantity of available food per parasitoid is another possible explanation for the significantly slower developmental rate we observed for *T. minutum* in eggs of *C. fumiferana*. Miller (1953) reported that an average of 3.7 adults of *T. minutum* emerged per budworm egg in New Brunswick. Southard *et al.* (1982) noted that as many as 11 pupae of *T. minutum* were present within a single egg of

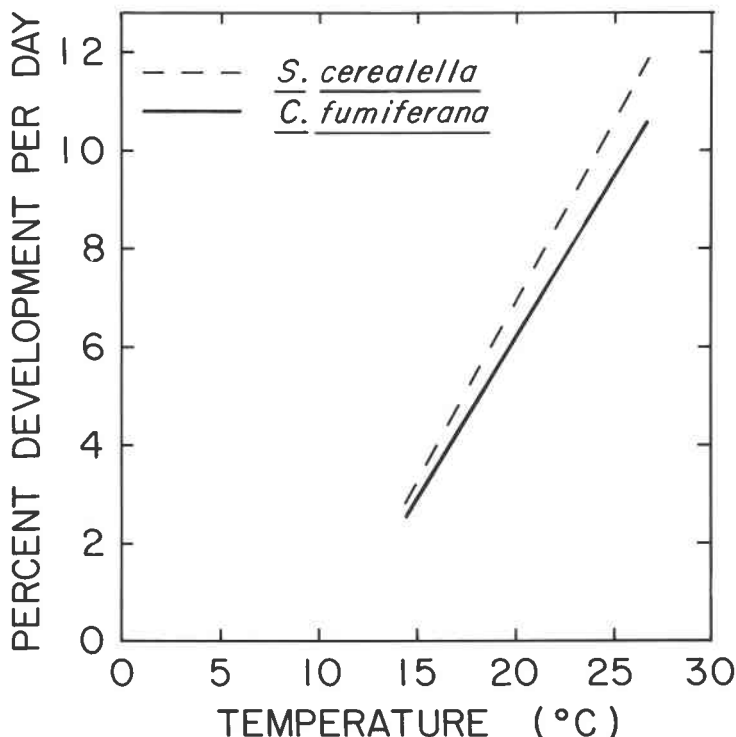


FIG. 1. Percentage development per day of *Trichogramma minutum* reared in eggs of *Sitotroga cerealella* and *Choristoneura fumiferana*.

C. fumiferana in laboratory studies, but rarely did more than 1 individual *T. minutum* develop within a single egg of *S. cerealella*.

Availability of progeny of field-released *T. minutum* for ovipositing in spruce-budworm eggs. Eggs of the spruce budworm are available for parasitization by *T. minutum* only during a brief period in mid-summer. An understanding of the timing and

Table 1. Mean degree-days at emergence of adult *Trichogramma minutum* reared from 2 host species at 3 constant temperatures

Host	Parasitoid sex	Temp (°C)	n	Mean degree-days at emergence*
<i>Choristoneura fumiferana</i>	Female	14	385	143.6 e
		21	509	166.5 a
		27	318	150.6 c
	Male	14	160	141.6 e
		21	213	159.6 b
		27	160	147.2 d
<i>Sitotroga cerealella</i>	Female	14	472	130.5 f
		21	444	144.0 e
		27	437	132.7 f
	Male	14	173	127.6 g
		21	144	142.5 e
		27	165	132.0 f

*Means followed by different letters are significantly different (Duncan's multiple-range test, $P < 0.05$).

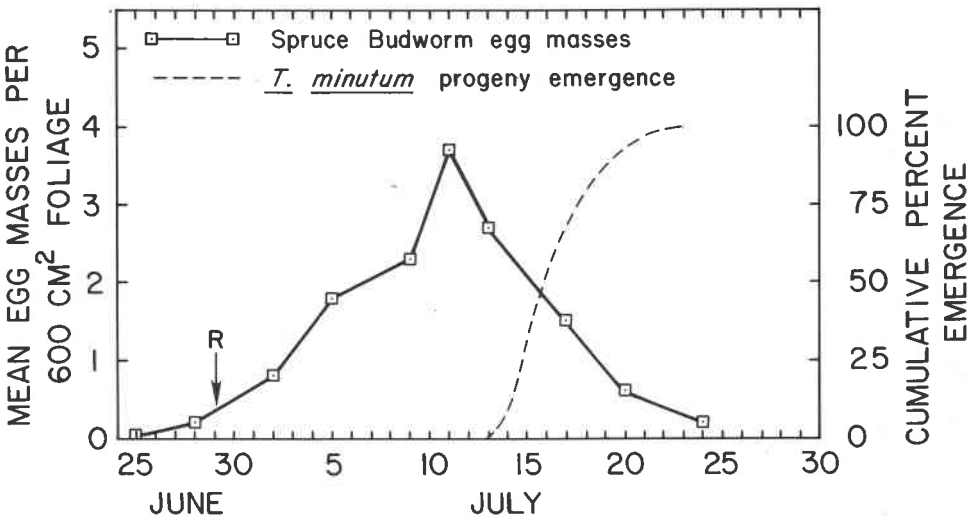


FIG. 2. Temporal pattern of oviposition by spruce budworm during 1979 near Parkman, Maine (from Houseweart *et al.* 1982) and predicted adult emergence of female progeny of *Trichogramma minutum* following a hypothetical field release (R) of the parasitoid.

duration of budworm oviposition is therefore necessary to time augmentative releases of the parasitoid accurately. Spruce-budworm oviposition in Maine starts in late-June or early-July; freshly deposited eggs are present for about 27 days; egg-mass density approximates a normal distribution during that period (Houseweart *et al.* 1982).

Releasing *T. minutum* early in the budworm's oviposition period might allow sufficient time for progeny of the released parasitoids to complete development, emerge, and oviposit in budworm eggs deposited later in the budworm's oviposition period. Comparison of our laboratory development data for *T. minutum* with field temperature data and the duration of the budworm's egg stage indicates that this is a viable release strategy. Figure 2 illustrates the spruce-budworm oviposition curve observed in a previous study near Parkman, Maine in 1979 (Houseweart *et al.* 1982), and a predicted emergence curve of female progeny of *T. minutum*, based on the results of the current parasitoid development tests. To construct the predicted emergence curve, a hypothetical release of the parasitoid was assumed to have occurred 1 day following the first observation of budworm egg masses (28 June 1979) on balsam-fir branch samples. Degree-day accumulations were estimated for the field study site using 1979 temperature data (US Dept. of Commerce 1979) for Dover-Foxcroft, Maine (nearest reporting station to Parkman). Degree-days were computed using a modified sine-wave method (Allen 1976). Cumulative percentage emergence and corresponding degree-day values for females of *T. minutum* reared in spruce-budworm eggs in the laboratory tests were compared with estimated field degree-day accumulations to determine the emergence curve of *T. minutum* progeny (Fig. 2).

Our data indicate that 50% emergence of female *T. minutum* progeny would have been expected on 16 July 1979 at Parkman, i.e. 17 days after release of the parasitoids. This occurs 5 days after the peak of the budworm egg-mass curve, and 8–9 days prior to the end of the budworm oviposition period. Seventy-five and 100% female-progeny emergence would have been expected on 18 and 23 July. Although *T. minutum* progeny emerge after the peak of the egg-mass curve, their emergence should be early enough to allow them to oviposit in spruce-budworm eggs.

Results from this and other studies suggest potential strategies for timing releases of *T. minutum* for suppression of spruce-budworm egg populations. Houseweart *et al.* (1983) reported that progeny production of *T. minutum* declines quickly following the first 2 days of oviposition. Therefore, closely timed multiple releases of the parasitoid may be more effective than single or widely spaced releases. Hsiao (1981) reported that a multiple-release technique was used with *T. dendrolimi* Mats. to reduce greatly (80–96%) populations of a pine-defoliating lepidopteran (*Dendrolimus punctatus* Wlk.) in China. Four or 5 releases were made during the first of 3 host oviposition periods per year with 70% of the parasitoids being released during peak host oviposition.

Releases of *T. minutum* should be concentrated during the first 2 weeks of spruce-budworm oviposition. For example, releases could be made immediately after the start of spruce-budworm oviposition and about 1 week later, immediately preceding the peak of budworm oviposition.

Timing of such releases is important; accurate determination of the beginning of the budworm's oviposition period is especially important. Further studies are needed to determine parasitoid release densities (parasitoids/hectare) and the timing and number of releases that will provide the most effective and economical suppression of spruce-budworm egg populations.

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