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Effect of Age, Size, and Mating Combinations in *Trichomalopsis Uziae*, A Pteromalid Ecto-Pupal Parasitoid of the Tachinid Fly, *Exorista Bombycis*, Onits Reproductive Performance

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Abstract- Preliminary laboratory studies have indicated that the pteromalid ecto-pupal parasitoid, *Trichomalopsis uziae* Sureshan & Narendra Kumar, has been reported to possess immense potential to serve as a biological control agent of the tachinid fly, *Exorista bombycis* (Louis), which inflicts a cocoon yield reduction of 10-20% in the southern states of India. The present laboratory investigations aims at generating information on the impact of age (0-10 days at 1 day apart in age) and size (big and small) of the parasitoid in addition to mating combinations (sib, conspecific, and random) on its reproductive performance when the pupae of *E. bombycis* were parasitized.

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Abstract- Preliminary laboratory studies have indicated that the pteromalid ecto-pupal parasitoid, *Trichomalopsis uziae* Sureshan & Narendra Kumar, has been reported to possess immense potential to serve as a biological control agent of the tachinid fly, *Exorista bombycis* (Louis), which inflicts a cocoon yield reduction of 10-20% in the southern states of India. The present laboratory investigations aims at generating information on the impact of age (0-10 days at 1 day apart in age) and size (big and small) of the parasitoid in addition to mating combinations (sib, conspecific, and random) on its reproductive performance when the pupae of *E. bombycis* were parasitized.

The results revealed that age of *T. uziae* had an influence on rate of parasitism, brood allocation, progeny production, and sex ratio that decreased significantly with the parasitoid age. With regard to parasitoid size, big females showed significantly superior reproductive efficiency when compared with their small counterparts. In size-related mating combinations, all the reproductive parameters were significantly higher with big females irrespective of size of males they mated with. Among sib, conspecific, and random mating combinations, the latter led to substantially superior reproductive performance. The findings of the investigation have been discussed to explore the possibilities of undertaking mass production of *T. uziae* on *E. bombycis.*

Keywords: brood allocation; developmental duration; hymenoptera; parasitism; progeny production; pteromalidae; sex ratio.

I. Introduction

Contraryto the general thinking that tachinid flies have been relentless in their attack of in sectpests of various crops, thus lending a helping hand in man's relentless fight against such pests, there are a few tachinid flies reported to be causing problem in the raising of silkworm larvae by sericulture farmers as they parasitize these larvae which results in considerable reduction in the production of cocoons/raw silk. These include (i) the Japanese uzi fly, *Crossocosmia sericariae* (Randani) (ii) the hime or black uzi fly, *Ctenophorocera pavida* (Meigen) (iii) the tasar uzi fly, *Blepharipa zebina* Walker, and (iv) the Indian uzi fly, *Exorista bombycis* (Louis) (Sengupta et al. 1990).The parasitism of larvae of the mulberry silkworm, *Bombyx mori* L. (Lepidoptera: Bombycidae), by *E. bombycis*is estimated to cause a cocoon yield reduction of 10-20%in the premier silk producing states of the Indian sub-continent namely Karnataka, Andhra Pradesh, and Tamil Nadu (Narayanaswamy and Devaiah 1998). It is an accidentally introduced pest from the State of West Bengal (India), where it existed for centuries, in to the state of Karnataka way back in 1980.Since then, the fly pest menace has continued unabated in these south-Indian states warranting the sericulture entomologists to make concerted efforts to develop strategies, chiefly non-chemical, to obviate the economic loss. Such strategies also include an IPM package comprising an adult exclusion to render silkworms inaccessible to the fly by confining silkworms to a nylon net/wire mesh enclosure, a chemotrap (uzitrap) to attract and kill both sexes of fly, an ovicide (uzicide) to kill eggs laid by the fly on silkworms, an eulophid ecto-parasitoid (*Nesolynx thymus* Girault) to parasitize pupae of the fly, and killing of the fly maggots and pupae by packing silkworm rearing residue in polythene bags (Dandin and Giridhar 2010; Narendra Kumar et al. 2017).

E. bombycis is reported to have long list of parasitoids (as many as 21) (larval, larvi-pupal, and pupal) which also includes the newly reported ecto-pupal parasitoid namely *Trichomalopsis uziae* Sureshan & Narendra Kumar (Hymenoptera: Pteromalidae). (Narayanaswamy and Devaiah 1998; Narendra Kumar and Manjunath 2018). Of these, only a few, *viz. N. thymus* (Aruna 2007), *Trichopria* sp. (Veena 2008), and *Tetrastichus howardi* (Olliff) (Gangadhar 2009) have been studied for various biological aspects. Preliminary laboratory investigations have indicated that *T. uziae* possess immense potential to serve as a biocontrol agent of *E. bombycis.* However, in-depth studies are yet to be undertaken on various biological aspects of the parasitoid in order to understand whether the parasitoid could be used alongside *N. thymus* as a biocontrol agent. The contemplation of such an idea assumes great significance in the backdrop of the statement of

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Bellows and Fisher (1999) and Gordh et al.(1999) that increased dependence on a single biological control agent for containing any pest is not a good proposition. In addition, keeping in view the increased sensitivity of *B. mori* to most chemical agents, exploitation of biocontrol agent(s), especially parasitoids and predators (if any), would undoubtedly assume great significance and go a long way in the management of *E. bombycis*.

When the use of a biocontrol agent, such as a parasitoid, is contemplated in a pest control program, what becomes the pre-requisite is its mass production. Such an effort is invariably preceded by investigations on the factors influencing the parasitoid performance subsequent to its release in the field. Such factors include (a) host-associated factors (age, size, quality, density, etc.), (b) parasitoid-associated factors (age, size, density, mating status, super-parasitism, multiple parasitism, etc.), and(c) environment-governed factors (chiefly physical) (temperature, relative humidity, solar radiation, etc.) (Singh and Thangavelu 1996; Traynor and Mayhew 2005; He and Wang 2006; Aruna 2007; Veena 2008; Hu et al.2012; Iqbalet al. 2016; Broski and King 2017; Narendra Kumar and Manjunath 2018; Narendra Kumar et al. 2018). Further, the interplay of some or all of these factors would decide the fitness of the progeny individuals and their efficiency in containing the pest problem. Fitness is exclusively associated with parasitoid size which assumes great significance, especially when it relates to female. Therefore, what one needs to understand is 'bigger the female better would be its fitness' by way of possessing the desirable traits of a biocontrol agent, such as being more fecund, long lived, efficient in host searching and parasitism, higher temperature tolerance and so on (Godfray 1994; Petersen and Hardy 1996; West et al. 1996; Gao et al. 2016). It is, therefore, necessary to undertake detailed investigations on these aspects so that information generated thereof would be useful for developing protocol(s) for mass production of parasitoids. In the backdrop of this, an attempt has been made in the current investigation to record the impact of age, size, and mating combinations on the reproductive performance of *T. uziae* that could be of considerable value in the direction of working out a protocol for mass production of the parasitoid.

II. Material and Methods

a) Procurement of parasitoid adults and host pupae

The investigations were undertaken in the laboratory at 23-28° C and 70-80% RH. The adult females of the parasitoid (*T. uziae*) (0-10 day-old) were chosen from the laboratory culture maintained on the pupae of *E. bombycis*. The pupae of *E. bombycis* (3 day-old) were procured by collecting the post-parasitic maggots that were emerging from the cocoons of *B. mori* subjected to transaction (sale by open auction) by the sericulture farmers in the Cocoon Markets located in Karnataka and allowing them to pupate in the laboratory. For parasitoid size-related studies, the size of parasitoid adults (males and females) was decided based on measurement of the cold-exposed (at 4° C for 2-3 min) individuals using a stage micrometer under a light microscope at 50 X and ensuring that there was a significant difference in size of the adults of the respective sexes.

b) Effect of female age on the reproductive performance of T. uziae

The impact of *T. uziae* female age on reproductive performanceof the parasitoid was recorded by allowing 1 to 10 day-old females to parasitize 3 day-old pupae of *E. bombycis* for a period of 5 days at a parasitoid-host ratio of 1:5 in glass test tubes the mouth of which plugged with cotton. Aqueous honey 30% smeared with a camel hairbrush on an elongated stripe of paraffin wax-coated paper hung from top in test tube served as the parasitoid adult diet. After the stipulated duration of parasitism, the parasitoid females were removed from test tubes. The host pupae in test tubes were observed and data were recorded on rate of parasitism (%), parasitoid developmental duration (days), brood allocation (numbers of parasitoid adults emerging/host), progeny production (total numbers of parasitoid adults emerging from parasitized hosts), and progeny sex ratio (females/male).

c) Effect of female size on the reproductive performance of T. uziae

Size-related reproductive ability of *T. uziae* was studied by exposing 3 day-old *E. Bombycis* pupae to big and small females of the parasitoid at a parasitoid-host ratio of 1:5 for 5 days. Aqueous honey 30% was provided as parasitoid adult diet during the period of oviposition. Observations on rate parasitism, developmental duration, brood allocation, progeny production, and sex ratio were recorded. Data on these parameters were also collected to understand the reproductive performance of the progeny individuals, as influenced by female size in parent generation, by allowing the randomly chosen females to oviposit on the pupae of *E. bombycis*(3 day-old) at a parasitoid-host ratio of 1:5 for 5 days.

d) Effect of size-related mating combinations on the reproductive performance of T. uziae

To understand the impact of mating among the big and small sized parasitoid adults, the following mating combinations were set up: a) big female x big male, b) big female x small male, c) small female x big male, and d) small female x small male. Each of the mated females was offered 5*E. bombycis* pupae (3 day-old) for parasitism for 5 days. Aqueous honey 30% was provided as parasitoid adult diet during the period of oviposition. Results on rate parasitism, developmental duration, brood allocation, progeny production, and progeny sex ratio were recorded.

e) Effect of sib, conspecific, and random mating on the reproductive performance of T. uziae

With regardto studies on these aspects, the following mating combinations were set up: a) sib mating (mating between brothers and sisters), b) conspecific mating (mating between sons and daughters of two mothers) c) random mating (mating between sons and daughters of several mothers). In each mating combination, each of the mated females was offered 5 pupae of *E. bombycis*(3 day-old)for parasitism for 5 days. Aqueous honey 30% was provided as parasitoid adult diet during the period of oviposition. Results on rate of parasitism, developmental duration, brood allocation, progeny production, and progeny sex ratio were documented.

The observations on all the experiments were based on 10 replications. The accrued data were analyzed by one-way ANOVA (Version 21) followed by DMRT for understanding whether or not the results were significantly different from each other at 1 or 5% among the treatments as per the methods outlined by Snedecor and Cochran (1979).

III. Results

a) Effect of female age on the reproductive performance of T. uziae

When the parasitoid females of 0-10 day-old, at a space of 1 day in their age, were allowed to parasitize *E. bombycis* (3 day-old), the rate of parasitism was highest by 1 day-old female (96.00± 4.00%) and least by 7 and 8 day-old females (48.00± 4.90%) with variation in the mean values among the treatments being highly significant. The parasitoid developmental duration was longest for the progenies of 8 day-old female (12.80±0.20 days) and shortest for those of 1, 2, 5, and 6 day-old females (12.20±0.20 days) with mean results being comparable. While the 10 day-old female allocated a minimum brood of 9.00±1.00 numbers, the zero day-old one (newly emerged and mated) allocated a maximum brood of 37.33±0.59 numbers. The comparison of mean data among the treatments revealed a significant variation. With regard to progeny production, the mean value was greatest for zero day-old female (164.40 ±15.66numbers) and least for 10 day-old female (22.60 ±1.60 numbers) with mean results among the treatments revealing highly significant variation. Looking at the progeny sex ratio, it was highest for zero day-old female (5.42±0.48 females/male) and least for 10 day-old female (1.90±0.25 females/male) with mean values differing significantly (Table 1).

b) Effect of female size on the reproductive performance of T. uziae

The mean results for rate of parasitism by small and big parasitoid females were 60.00±5.96 and 72.00±6.80%, respectively with a highly significant variation ($P \leq 0.01$).The time spent for completion of parasitoid progeny development was almost identical from small(12.70±0.21 days) and big (12.50±0.17days) parent females. While the small female allocated a brood of 25.12±1.79 numbers, the big one did so with 33.36±2.09 broods that were significantly higher in number. Insofar as the progeny production was concerned, it was significantly greater in numbers for big female (120.50±14.17) as compared to small female (77.10±10.19) with progenies sex ratios being 6.08±0.51 and 3.60±0.21, respectively (Table 2).

c) Effect of size-related mating combinations on the reproductive performance of T. uziae

Of the 4 mating combinations, the rate of parasitism was highest with big female x big male (88.00±8.00%) which was *at par* with big female x small male (84.00±7.48%). The mean results scored for these mating combinations were significantly higher ($P \leq 0.01$) than those obtained for mating combinations of small female x big male (68.00±10.20%) and small female x small male (64.00±4.00%) with the mean values for these mating combinations being comparable with each other. The time taken by the parasitoid for completion of its development was nearly identical for mating combinations of small female x big male(12.00±0.00 days) as well as big female x big male and small female x small male (12.60±0.24 days). With regard to brood allocation, it was least with small female x small male (22.48±0.88numbers) and highest and significantly superior with big female x small male (33.56±3.11numbers) which was no different from mating combination involving big female x big male (32.72±2.85numbers). The parasitoid produced a progeny which was maximum and significantly higher with big female x big male (154.40±25.80numbers), which was *at par* with mating between big female x small male (145.40±24.50numbers), when compared with small female x small male (71.80±4.60numbers). The mean sex ratio(females/male) for progenies produced by the above mating combinations was significantly superior with big female x big male (6.09±0.20)when compared with rest of the mating combinations where the mean sex ratio scored for big female x small male (4.23±0.62) was significantly higher than that for small female x big male (2.88±0.17) and small female x small male (2.81±0.22) with the results for the latter mating combinations being comparable (Table 3).

d) Effect of sib, conspecific, and random matings on the reproductive performance of T. uziae

The results onimpact of mating among the progenies of a single mother (sib mating), of two

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mothers (say A & B) (conspecific mating), and of several mothers (random mating) were documented by setting up the mating combinations as follows: a) sib mating, b) female progeny of mother A x male progeny of mother B, c) female progeny of mother B x male progeny of mother A, and d) random mating. It was observed that mean values registered for rate of parasitism for the treatments a, b, c, and d were 72.00±7.42, 84.00±5.81, 82.00±6.29, and 90.00±4.47, respectively, with the values differing significantly except the mating involving conspecifics that had nearly identical performance. With regard to parasitoid developmental duration, the mean data for the treatments were 12.50±0.17, 12.20±0.13, 12.50±0.17, and 12.50±0.17days and the values were comparable. Considering brood allocation, the results scored for the above treatments except sib mating (29.24±1.11) were significantly greater and comparable (33.75±1.74 for Fem A x Male B; 34.09±1.21 for Fem B x Male A; 37.81±1.39 numbers for random mating). Taking in to consideration of the progeny production, the mean results for the above treatments stood at 105.50±12.06, 148.70±11.44, 142.00±13.99, and 171.70±12.35 with conspecifics being comparable in performance and sibs to be inferior and random ones to be significantly superior. The corresponding sex ratios for progenies of these mating combinations were 3.33±0.21, 4.17±0.31, 4.47±0.35, and 5.50±0.34 with the latter (random mating) being significantly superior (Table 4).

IV. Discussion

When a constant number of *E. bombycis* pupae (5 in number) was offered to*T. uziae* females of varying ages from zero to 10 days, at a space of 1 day in their age, brood allocation, progeny production, and sex ratio decreased with parasitoid parent female age. The mean values for these parameters declined sharply at an age of 5 days where the decrease amounts to nearly 1.70-folds for brood allocation and 2-folds for progeny production as well as sex ratio when compared with corresponding results at a parasitoid age of zero day. The further decrease in mean results for these parameters at a parasitoid age of 10 days *vis-à-vis* zero day was of the order of nearly 4, 7, and 3-folds, all of which were appreciably inferior even when compared with those at a parasitoid age of 5 days. It's also worth mentioning that rate of parasitism at a parasitoid age of 10 days too was found diminished by 1.70-folds. The above findings, therefore, clearly demonstrated that parasitoid female age had a substantial impact on the reproductive parameters, except developmental duration. The substantial decrease in brood allocation, progeny production, and sex ratio, at least at parasitoid female ages of 5 and 10 days in comparison with zero day, as has been considered for discussion here, could be attributed to oosorption/ovisorption, a phenomenon/condition where matured eggs in ovary getting absorbed whenever there is a longer time lag between egg production and availability of host for oviposition (Flanders 1942; Doutt 1959; King 1963). The reason for substantial reduction in progeny sex ratio was due to production of more numbers of male progenies relative to female progenies as parasitoid females in general allocate more numbers of male brood to a host when they are older and less numbers when they are younger and *vice-versa* for female brood (Broski and King 2017).

The information available with regard to impact of parasitoid age on biological parameters of pteromalid parasitoids, more so of *Trichomalopsis* spp., is rather scanty. Nonetheless, Singh and Thangavelu (1996) studied the age-specific survival and fecundity, intrinsicrate of population increase, and sex ratio in the case of *Trichomalopsis apanteloctena* Crawford, a pupal parasitoid of the tachinid fly, *B. zebina*, parasitizing the tropical tasar silkworm, *Antheraea mylitta* Drury, underlaboratory conditions. It was revealed that the numbers of progeny produced by the parasitoid and the sex ratio did not vary significantly with maternal age when the parasitoid developed on the pupae of *B. zebina*. Hu et al. (2012) working with *Pachycrepoideus vindemmiae* (Rondani) recorded a decrease in off spring male percentage with female age. Likewise, parasitoid female age-related reproductive strategy has been observed in *Anisopteromalus calandrae* (Howard) (Choi et al. 2001; Choi and Ryoo 2002; Ji et al. 2004; Zilch et al. 2017). In a recent study, Broski and King (2017) noticed the impact of female age on reproductive performance in *Spalangia endius* (Walker).

It is a well-known fact that a parasitoid female exhibits a great deal of fluctuation in egg production and egg deposition during her life time. Considerably fewer eggs are laid on the first day of life than on the following days, showing a peak of egg deposition on a couple of days; the number diminishing gradually towards the end of her life. With the egg number varying greatly, often the number of eggs laid would be more than that of progeny emerging as a large number of young larvae on most occasions dying as a consequence of competition for food (resources), especially under the conditions of super parasitism (Merwe 1943; van Dijken and Waage 1987; van Alphen and Jervis 1996; Aruna 2007; Gonzalez et al. 2007; Kraft and Nouhuys 2013). Enhanced fecundity was realized in younger female parasitoids than older ones (Guang and Oloo 1990; Iqbalet al. 2016). As far as sex ratio is concerned, in younger parasitoids female-biased sex ratio and in older ones male-biased sex ratio has been realized (Simser and Coppel 1980; Laetemia et al. 1995). With increasing age, an ovipositing female may receive depleted sperm numbers and hence produce more male progeny towards the end of her reproductive period (King 2000; Santolamazza-carbone et al. 2007).

Ininsects, including parasitoids, bodysize is found positively correlated with fitness of their life-history traits (Leather 1988; Odeet al. 1996; Cloutier et al. 2000; Ji et al. 2004; He and Wang 2006). Larger females may have greater longevity (Visser 1994; Ueno 1999; He and Wang 2006; Aruna 2007; Veena 2008), higher fecundity (Visser 1994; He and Wang 2006; Aruna 2007; Veena 2008), superiordispersal and host searching ability (Visser 1994; Ellers et al. 1998; He and Wang 2006), greater oviposition success (Ueno 1999; Gao et al. 2016), and an innate capacity for increase (Cloutier et al. 2000), thus clearly supporting our understanding that 'bigger the better'. Especially, in hymenopteran parasitoids, "adult size-fitness hypothesis" shows that large sized individuals (especially females) possess more physiological and behavioral advantages, such as ability to search and attack large and high quality hosts, lifetime fecundity, longevity and mating success, even the outcome of numerous parasitoid-host interactions, than small sized congeners (Wylie 1966; Godfray 1994; Petersen and Hardy 1996; West et al. 1996; Ji et al. 2004; Gao et al. 2016).Therefore, it is a foregone conclusion that adult size is known to have effect even on some of the behavioral traits, such as mating, host searching, host acceptance, sex allocation and other parameters, viz. longevity, fecundity, progeny production, offspring adult size and so on.

Our attempts to document the reproductive efficiency of *T. uziae*as influenced by its sizeled us to understand that rate of parasitism, brood allocation, progeny production, and sex ratio to befargreater for mating combinations involving big female irrespective of size of male she mated with as against small female of the parasitoid. When the effect of parasitoid size based on mean data for females of both sizes were quantified and compared, the superiority of big female was to the tune of nearly 1.20, 1.30, 1.60, and 1.70 times, respectively for the above parameters. For superior performance of big parasitoid female, the female progeny numbers proved instrumental and males had no role whatsoever as their numbers remained almost similar for mating combinations comprising females of both the sizes. From these observations, what one could conceive is that parasitoid female gained advantage in terms of reproductive capability by virtue of being bigger, irrespective of size of the male it mated with, thus falling in line with the glorifying statement that 'bigger the better' to indicate that bigger parasitoid females are bestowed with superiority in terms of longevity, temperature tolerance, dispersal, parasitism rate, progeny production and so on (Cloutier et al. 2000; King 2002; Eliopoulos et al.2005; He and Wang 2006; Sagarra et al.2002). Therefore, production of parasitoid females of bigger size undoubtedly assumes supreme importance when one contemplates the idea of undertaking their mass production for inundative release of parasitoids in field under biological control programs of crop pests. Nevertheless, the role of host-related factors, especially host size and host quality, need to be coupled with parasitoid female size while undertaking mass production program.

The findings on reproductive efficiency of *T. uziae* based on whether mating was between brothers and sisters (sib mating), sons and daughters of two mothers (conspecific mating), or sons and daughters of several mothers (random mating), were on following lines: random mating > conspecific mating > sib mating. Be it an insect or any other animal, including human beings, it's a universal phenomenon that mating among sibs leads to reduction in vigor among progenies and expression of certain genetic defects. As against this, in the case of random mating the progenies would be vigorous and almost devoid of defective gene expression. In the case of mating among progenies of two different mothers, the progenies are likely to be 'mediocre' in vigor and expression of defective genes. In keeping fine tune with the fundamental principle governing the breeding in plants or animals, the parasitoid in question(*T. uziae*) followed this principle with utmost discipline. Interestingly, it was evident to note at this juncture that random breeding provided an opportunity not only to enhance the progeny production but also to boost the production of female progenies that would directly contribute to the efficiency of mass production of the parasitoid. Further, the relatively reduced numbers of males in random mating in comparison to the remaining two types of breeding (sib and conspecific) wouldn't be a constraint in view of the fact that the males oftener sort to multiple mating (polygamy) so that even a few of them would be adequate enough to inseminate several females.

Based on our awareness of literature on the above aspect pertaining to parasitoids belonging to the genus *Trichomalopsis* in particular and family Pteromalidae in general, it appears that efforts by researchers are yet to be spared. However, just to quote some instances where the parasitoids from other families too followed the fundamental principles governing mating among individuals of close or distant relatives have been drawn from the reports of Aruna (2007) and Veena and Manjunath (2015) working on *N. thymus*(Eulophidae) and *Trichopria* sp. (Diapriidae), respectively.

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Table 1: Reproductive performance of *Trichomalopsis uziae* as influenced by its age when *Exorista bombycis* was parasitized

Age of parasitoid female (Days)	Per cent parasitism@	Dev. duration (days)	Progeny production (No.)			Brood allocation (No.)			Sex ratio (♀♀/♂)
			Male	Female	Total	Male	Female	Total	
0	88.00 ±8.00^{a}	12.40 ±0.24	26.80 ±4.09^{a}	137.60 ±11.83^{a}	164.40 ±15.66^{a}	5.95 ±0.48^{ab}	31.37 ±0.55^{a}	37.33 ±0.59^{a}	5.42 ±0.48^{a}
1	96.00 ±4.00^{a}	12.20 ±0.20	23.20 ±2.75^{abc}	119.80 ±5.88^{ab}	143.00 ±8.19^{a}	4.79 ±0.45^{bc}	24.93 ±0.33^{b}	29.72 ±0.68^{bc}	5.36 ±0.43^{a}
2	84.00 ±9.80^{a}	12.20 ±0.20	28.00 ±6.47^{a}	123.60 ±20.76^{ab}	149.60 ±26.27^{a}	6.27 ±0.92^{ab}	28.75 ±2.64^{ab}	35.01 ±3.40^{ab}	4.83 ±0.49^{ab}
3	80.00 ±8.94^{ab}	12.60 ±0.24	28.00 ±4.01^{a}	113.40 ±20.51^{ab}	141.40 ±24.24^{a}	6.67 ±0.50^{ab}	26.36 ±2.36^{ab}	33.03 ±2.67^{abc}	3.98 ±0.30^{b}
4	80.00 ±8.94^{ab}	12.40 ±0.24	24.60 ±1.81^{ab}	101.40 ±10.08^{b}	125.60 ±10.88^{a}	6.27 ±0.33^{ab}	27.30 ±2.16^{ab}	32.21 ±3.05^{abc}	4.18 ±0.43^{b}
5	76.00 ±4.00^{ab}	12.20 ±0.20	22.80 ±2.67^{abc}	60.80 ±3.29^{c}	83.60 ±5.79^{b}	6.40 ±0.72^{ab}	16.12 ±0.92^{c}	22.52 ±1.40^{de}	2.75 ±0.17^{c}
6	60.00 ±6.32^{bc}	12.20 ±0.20	14.20 ±1.66^{cd}	38.20 ±3.92^{cd}	52.40 ±5.35^{bc}	4.78 ±0.45^{bc}	12.90 ±0.94^{c}	17.68 ±1.29^{e}	2.74 ±0.19^{c}
7	48.00 ±10.20^{c}	12.40 ±0.24	18.00 ±3.15^{abcd}	37.40 ±6.05^{cd}	55.40 ±8.64^{bc}	8.02 ±1.03^{a}	17.78 ±3.59^{c}	25.80 ±4.57^{cd}	2.16 ±0.22^{c}
8	48.00 ±4.90^{c}	12.80 ±0.20	15.40 ±1.69^{bcd}	35.00 ±4.72^{cd}	50.40 ±5.82^{bc}	6.90 ±0.61^{a}	14.10 ±1.73^{c}	21.00 ±2.15^{de}	2.05 ±0.23^{c}
9	52.00 ±4.90^{c}	12.40 ±0.24	9.20 ±1.07^{d}	18.00 ±1.76^{d}	27.20 ±2.52^{c}	3.73 ±0.66^{c}	7.17 ±1.09^{d}	10.90 ±1.68^{f}	2.03 ±0.26^{c}
10	52.00 ±4.90^{c}	12.80 ±0.20	8.20 ±1.24^{d}	14.40 ±0.40^{d}	22.60 ±1.60^{c}	3.23 ±0.49^{c}	5.77 ±0.62^{d}	9.00 ±1.00^{f}	1.90 ±0.25^{c}
F value	6.090 **	NS	5.238 **	19.804 **	16.573 **	5.053 **	23.661 **	16.416 **	17.315 **

@ - Based on 5 host pupae provided for parasitism; values given in the Table are the means of 10 replications (Mean ± SE)
Mean values followed by the same superscript in columns are not significantly different from each other
*** P≤0.01; NS-Non-significant.*

Table 2: Reproductive performance of *Trichomalopsis uziae* as impacted by its size when *Exorista bombycis* was parasitized

Parasitoid size[#]	Per cent parasitism[@]	Dev. duration (days)	Progeny production (No.)			Brood allocation (No.)			Sex ratio (♀♀:♂)
			Male	Female	Total	Male	Female	Total	
Small	60.00 ±5.96	12.70 ±0.21	16.70 ±1.99	60.40 ±8.44	77.10 ±10.19	5.53 ±0.44	19.58 ±1.46	25.12 ±1.79	3.60 ±0.21
Big	72.00 ±6.80	12.50 ±0.17	17.10 ±1.72	103.10 ±12.91	120.50 ±14.17	4.98 ±0.53	28.38 ±1.72	33.36 ±2.09	6.08 ±0.51
t value	3.78**	NS	NS	7.665**	6.13**	NS	15.27**	8.970**	20.008**

 # - Body length: 0.67±0.02 mm (small) and 0.82±0.01 mm (big) with measurements differing significantly
@ - Based on 5 host pupae provided for parasitism
Values given in the Table are the means of 10 replications (Mean ± SE)
Mean values followed by the same superscript in columns are not significantly different from each other
*** P≤0.01; NS- Non-significant.*

Table 3: Effect of size-related mating combinations on the reproductive efficiency of *Trichomalopsis uziae* on *Exorista bombycis*

Mating combination	Per cent parasitism @	Dev. duration (days)	Progeny production (No.)			Brood allocation (No.)			Sex ratio (♀♀:♂)
			Male	Female	Total	Male	Female	Total	
Big F x Big M	88.00 ±8.00[a]	12.60 ±0.24	21.60 ±3.47	132.80 ±22.37[a]	154.40 ±25.80[a]	4.78 ±0.45[b]	29.19 ±3.05[a]	32.72 ± 2.85[a]	6.09 ± 0.20[a]
Big F x Small M	84.00 ±7.48[a]	12.40 ±0.24	28.40 ±5.07	117.00 ±20.71[a]	145.40 ±24.50[a]	6.66 ±0.82[a]	26.89 ±2.76[a]	33.56 ± 3.11[a]	4.23 ± 0.62[b]
Small F x Big M	68.00 ±10.20[b]	12.00 ±0.00	19.80 ±2.31	57.00 ±7.55[b]	76.80 ±9.71[b]	5.95 ±0.22[ab]	17.17 ±1.35[b]	23.12 ± 1.50[b]	2.88 ± 0.17[c]
Small F x Small M	64.00 ±4.00[b]	12.60 ±0.24	19.20 ±1.88	52.60 ±3.01[b]	71.80 ±4.60[b]	6.00 ±0.48[ab]	16.48 ±0.54[b]	22.48 ± 0.88[b]	2.81 ± 0.22[c]
F value	3.98**	NS	NS	6.763**	5.568**	2.127 *	8.996 **	6.896**	18.912**

@ - Based on 5 host pupae provided for parasitism; values given in the Table are the means of 10 replications (Mean ± SE)
Mean values followed by the same superscript in columns are not significantly different from each other
*** P≤0.01; * P≤0.05; NS- Non-significant.*

Table 4: Impact of sib, conspecific, and random mating on the reproductive efficiency of *Trichomalopsis uziae* on *Exorista bombycis*

Mating combination	Per cent parasitism@	Dev. duration	Progeny production (No.)			Brood allocation (No.)			Sex ratio (♀♀/♂)
			Male	Female	Total	Male	Female	Total	
Sib mating	**72.00 ±7.42[c]**	**12.50 ±0.17**	**24.30 ±2.50**	**81.20 ±9.83[c]**	**105.50 ±12.06[c]**	**6.89 ±0.43**	**22.35 ±0.91[c]**	**29.24 ±1.11[b]**	**3.33 ±0.21[c]**
Conspecific mating Fem-A x Male-B	84.00 ±5.81[b]	12.20 ±0.13	29.20 ±2.45	119.50 ±9.72[b]	148.70 ±11.44[b]	6.63 ±0.37	27.12 ±1.59[b]	33.75 ±1.74[a]	4.17 ±0.31[bc]
Fem-B x Male-A	82.00 ±6.29[b]	12.50 ±0.17	26.30 ±2.53	115.70 ±12.15[b]	142.00 ±13.99[b]	6.43 ±0.42	27.66 ±1.10[b]	34.09 ±1.21[a]	4.47 ±0.35[b]
Random mating	90.00 ±4.47[a]	12.50 ±0.17	26.90 ±2.29	144.80 ±10.67[a]	171.70 ±12.35[a]	6.06 ±0.39	31.85 ±1.17[a]	37.81 ±1.39[a]	5.50 ±0.34[a]
F value	3.943*	NS	NS	6.041**	4.822**	NS	10.176**	6.431**	8.362**
df	2, 27	2, 27	2, 27	2, 27	2, 27	2, 27	2, 27	2, 27	2, 27

@ - Based on 5 host pupae provided for parasitism
Fem-A x Male B: female of mother A x male of mother B; fem B x male A: female of mother B x male of mother A
Values given in the Table are the means of 10 replications (Mean ± SE)
Mean values followed by the same superscript in columns are not significantly different from each other
*** $P \leq 0.01$; * $P \leq 0.05$; NS- Non-significant.*