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Development and reproductive capacity of the predatory mite *Parasitus consanguineus* (Acari: Parasitidae) reared on the larval stages of *Megaselia halterata* and *Lycoriella ingenua*

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Abstract Development and reproduction of the predatory mite *Parasitus consanguineus* Oudemans et Voigts (Acari: Parasitidae) reared on a diet of first and second instars of *Megaselia halterata* (Diptera: Phoridae) or *Lycoriella ingenua* (Diptera: Sciaridae) were studied. Mites were allowed to feed on these diets until death. The developmental time of immature stages of *P. consanguineus* was significantly longer when reared on *L. ingenua* than on *M. halterata* larvae (8.3 vs. 7.9 days, respectively). Survival to adulthood of *P. consanguineus* reared on *L. ingenua* or *M. halterata* larvae was 63 and 49%, and mite fecundity was 17.8 and 12.3 eggs/female, respectively. Adult females reared on *L. ingenua* lived on average 6.9 days, whereas those reared on *M. halterata* lived for 5.7 days. Mite survival, female longevity and fecundity were significantly different among the two diet types.

Keywords *Parasitus consanguineus* · Biological control · Mushroom cultivation · Phoridae · Sciaridae · Dipteran pests

Introduction

Chemical control of dipteran pests associated with the cultivation of mushrooms (*Agaricus bisporus*) is unsatisfactory, and this has led to increasing interest in biological control (Al-Amidi and Downes 1990). Several mite species have been found to be effective predators of mushroom pests, especially dipteran larvae (Gillespie and Quiring 1990; Al-Amidi et al. 1991; Wright and Chambers 1994; Enkegaard et al. 1997; Rudzińska 1998; Rudzińska-Sajdak 1998; Jess and Bingham 2004). Al-Amidi and Downes (1990) found that *Parasitus bituberosus* (Karg) preys on sciarid larvae and eggs, cecid larvae, nematodes and springtails. In trials conducted by Al-Amidi et al. (1991) in commercial mushroom houses, *P. bituberosus* was able to suppress *Lycoriella ingenua* (Diptera: Sciaridae) adult

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pest numbers by 50–66%, and to reduce the numbers of another dipteran pest species, *Heteropeza pygmaea* (Diptera: Cecidomyiidae), leading to an 18% increase in crop yield.

Another predatory *Parasitus* species, *P. consanguineus* Oudemans et Voigts, was found in Poland by Haitlinger in 1993. *P. consanguineus* occurs in places where an abundance of organic matter is accumulated, including mushroom houses (Evans and Till 1979; Hyatt 1980; Gill et al. 1988; Trivedi 1988; Gresham 1990; Szlendak and Lewandowski 2000, 2002). Its habitats are mainly compost, dung and decaying vegetable matter. This species was first recorded in the British Isles, and was later found to be indigenous to other European countries as well as Russia and Israel (Hyatt 1980). Information available on the biology of *P. consanguineus* is scarce, but this mite species has been shown to feed on small arthropods, nematodes, and their eggs (Fox et al. 1989). Gill et al. (1988) reported that *P. consanguineus* can develop in mushroom houses by feeding on eggs and larvae of the sciarid fly *Bradysia tritici*, on larvae of the phorid *Megaselia sandhui*, and on eggs of the collembolan *Seira iricolor*.

The aim of this study was to determine whether *P. consanguineus* could complete its development and reproduce after feeding exclusively on larvae of the phorid *Megaselia halterata* or the sciarid *L. ingenua*, both major pests of Polish mushroom houses. In addition, we provide insights into the potential of using this predatory mite to control the dipteran pests.

Materials and methods

Mite sampling and rearing

Samples of *P. consanguineus* deutonymphs and adult *L. ingenua* and *M. halterata* flies were collected from a Polish mushroom house located in Widzew-Łódź. Adult flies were collected using an aspirator and then reared in the laboratory as described by Szlendak and Lewandowski (2002). Mites were sampled from the casing and frames of mushroom beds using a fine camel-hair brush, and placed in conical 130 ml polyethylene containers partially filled with heat-sterilized moist peat. In the laboratory, *P. consanguineus* mites were reared in 10–20 uncovered plastic containers (48 × 34 × 26 cm) in incubators maintained at 24 ± 1°C. Bedding in these containers comprised half of a commercially produced block of compost, inoculated for mushroom production with *A. bisporus* mycelium and covered by a layer of casing. On to this bedding approximately 20 *P. consanguineus* deutonymphs and 300 specimens of flies (equal numbers of both fly species) were released. Adequate humidity was maintained by daily watering of the bedding in the containers. Under these conditions, the numbers of *P. consanguineus* increased during the next 4 weeks, and mites were plentiful for several more weeks. When new containers with fresh bedding were placed in the incubator the mites would quickly colonize a new block of compost and start to develop and lay eggs there (Szlendak and Lewandowski 2002).

During the tests mites were reared in two types of rearing cages. Small cages were used for monitoring developmental time and mortality of eggs, larvae and protonymphs, and for determining the fecundity of separate pairs of mites. Large rearing cages were used for assessing longevity and mortality of *P. consanguineus* deutonymphs. Mites from all mobile developmental stages were allowed to feed on the same diet (larvae of either *M. halterata* or *L. ingenua*).

In our experiments deutonymphs that were reared separately in small cages had sufficient food but insufficient space to move freely, and rarely emerged into adults (4%); most of them (96%) died within ca. 3 weeks, still at the deutonymph stage. However, when newly emerged deutonymphs were transferred into large rearing cages, ca. 95% emerged into adults.

Small rearing cages were made of 0.5 cm thick glass cut into 4 × 3 cm rectangles. In each piece of glass a conical cavity of 12–17 mm upper diameter and 8–11 mm lower diameter was drilled. The upper side of the cavity was covered with a microscope slide cover slip (20 × 20 mm) attached to the glass by strips of sticky tape, while the lower side was covered with a ca. 15 mm square piece of Whatman Qualitative No. 1 filter paper, using hot wax as adhesive.

Large rearing cages were adapted from sterilized containers used commercially for urine tests. These conical, plastic rearing containers were 6.5 cm high, with lower and upper diameters of 5 and 6 cm, respectively. Holes were made in the sides of these containers using a needle. A 3 cm diameter hole was drilled in the plastic lid and covered by mesh attached with glue.

Experimental conditions

Parasitus consanguineus mites were reared in small or large rearing cages partially filled with moist peat mixed with pieces of compost containing *A. bisporus* mycelium. High relative humidity was maintained by placing the rearing cages in plastic boxes (16 × 16 × 5 cm for the small rearing cages and 25 × 13 × 13 cm for the large rearing cages), covered by a plastic lid. The bottom of each box was filled to a depth of ca. 2–3 cm with permanently moist pasteurized peat, which was covered by metal mesh. Rearing cages with mites were placed on the metal mesh. In this way, high humidity was maintained, simulating the conditions typical in mushroom houses. The boxes were then placed in incubators at 21 ± 0.5°C.

Collecting data on mite development and reproductive biology

Adult *P. consanguineus* were transferred from mass culture to 40 small rearing cages as described above. One pair of *P. consanguineus* was placed in each cage, with a small amount of moist peat mixed with compost containing *A. bisporus* mycelium. Two types of diet were supplied in abundance to the mites: four larvae of *L. ingenua* or four larvae of *M. halterata* per mite. The mites were transferred daily to a new cage with fresh food, using a camel-hair brush; in this way, eggs were obtained for further experiments. Two hundred 1-day-old *P. consanguineus* eggs were divided into two groups of 100 for each food type. The viability of eggs, larvae and protonymphs, as well as the duration of their development, was established by recording daily the number of live and dead individuals. To determine mortality and longevity of *P. consanguineus* deutonymphs, they were reared in large rearing cages with the same bedding and diet as mentioned above. Mites were transferred daily to new cages containing fresh food. Mortality, longevity and fecundity of adults were also recorded by placing 20 1-day-old pairs of adult *P. consanguineus* separately in small rearing cages and transferring them daily to new ones with fresh food.

To obtain more information on fecundity and female longevity, an additional series of experiments was conducted with a further 20 pairs of adult *P. consanguineus* reared on the same types of diet. These additional 20 pairs of adults were reared on a diet containing larvae of *M. halterata* or *L. ingenua*, but their mortality or longevity during immature

stages was not recorded. Thus, a total of 40 pairs of adult mites fed on larvae of *M. halterata* or *L. ingenua* were observed.

Statistical analysis

Developmental times for immature male and female stages reared on both types of food were evaluated using analysis of variance (ANOVA), and by Fisher's least significant difference procedure ($\alpha = 0.05$) in all cases where ANOVA showed a significant difference. Data on survival rate, longevity of mature stages and fecundity, oviposition and post-oviposition periods of females reared on different diets were compared using the *t*-test ($\alpha = 0.05$).

Results

Survival of *P. consanguineus* to the adult stage was significantly different on *L. ingenua* and *M. halterata*, reaching 63 and 49%, respectively. High mortality in the larval (16 and 20%) and protonymphal (10 and 19%) stages fed on sciarid and phorid larvae was mainly responsible for low overall survival of juvenile forms of *P. consanguineus*. On these diets mortality was 6 and 8% (egg) and 5 and 4% (deutonymph), respectively. The developmental time of immature stages of *P. consanguineus* was significantly longer when mites were reared on *L. ingenua* (8.3 days) than on *M. halterata* larvae (7.9 days).

Most *P. consanguineus* eggs hatched the day after oviposition, the remainder during the next 2 days (average developmental time was 1.3–1.5 days, irrespective of diet and sex) (Fig. 1a, b). The developmental time for female larvae was similar on diets containing larvae of either fly species (ca. 2 days) (Fig. 1a). Female protonymph developmental time was similar on both tested diets (ca. 1.9 days), and the deutonymph stage lasted similarly long on diet containing larvae of either species (Fig. 1a). Male larvae of *P. consanguineus* developed significantly more quickly on phorid larvae (1.8 days) than on sciarid larvae (2.6 days) (Fig. 1b); for protonymphal males, the developmental time was significantly shorter on sciarid larvae (1.6 days) than on phorid larvae (2.3 days) (Fig. 1b). Male deutonymph developmental time was similar (ca. 2.5 and 2.7 days) on the two diets (Fig. 1b).

Female *P. consanguineus* lifespan averaged 5.7 days when the mites were fed on phorid larvae and 6.9 days on sciarid larvae (Table 1). Male lifespan was shorter, averaging 4.6 days on phorid larvae and 5.6 days on sciarid larvae (Table 1). The average oviposition period was not significantly different when females were reared on sciarid or phorid flies and lasted 5.0 and 4.8 days, respectively, whereas the post-oviposition period lasted 1.9 days on diet with sciarid larvae and 0.9 days on diet with phorid larvae (Table 1).

Parasitus consanguineus females first laid eggs the day after pairing; then, during the next 2 or 3 days, they laid most of their eggs and continued to oviposit for several more days (Fig. 2). Fecundity was significantly higher for females reared on *L. ingenua* than on *M. halterata* (Table 1). The total average fecundity of *P. consanguineus* females was 17.8 and 12.3 eggs/female on *L. ingenua* and *M. halterata,* respectively (Table 1). Maximum fecundity for individual females reached 41 and 22 eggs/female on the two diets, respectively.

The data collectively show that *P. consanguineus* can complete its development on diet comprising larvae of the phorid *M. halterata* and the sciarid *L. ingenua*, indicating that it has potential as a predatory mite for controlling both pest species.

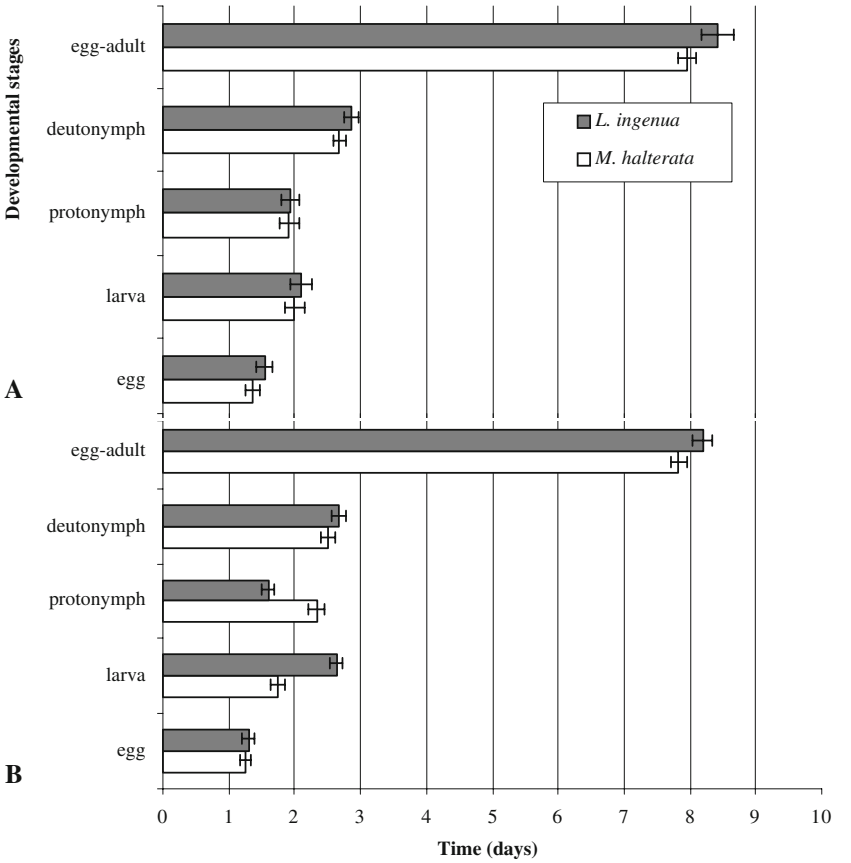

Fig. 1 Developmental times (days) of immature stages of females (**a**) and males (**b**) of *Parasitus consanguineus* fed on *Lycoriella ingenua* or *Megaselia halterata* larvae

Table 1 Longevity of mature stages of *Parasitus consanguineus* as well as fecundity, oviposition and post-oviposition periods of females reared on larvae of the phorid fly *Megaselia halterata* or the sciarid fly *Lycoriella ingenua*

Parameters evaluated	Prey	
	M. halterata	*L. ingenua*
Longevity of females (days)	5.7 ± 2.0 (2–10) a	6.9 ± 2.0 (2–10) b
Longevity of males (days)	4.6 ± 2.0 (2–10) a	5.6 ± 2.0 (2–9) b
Fecundity (no. of eggs/female)	12.3 ± 4.7 (2–22) a	17.8 ± 7.6 (6–41) b
Oviposition period (days)	4.8 ± 1.8 (1–9) a	5.0 ± 1.1 (2–7) a
Post-oviposition period (days)	0.9 ± 0.9 (0–4) a	1.9 ± 1.5 (0–5) b

Shown are mean values ± SD, ranges in brackets, sample sizes: $n = 40$ for tests with each prey species
Means within a row followed by a different letter are significantly different (t-test, $P < 0.05$)

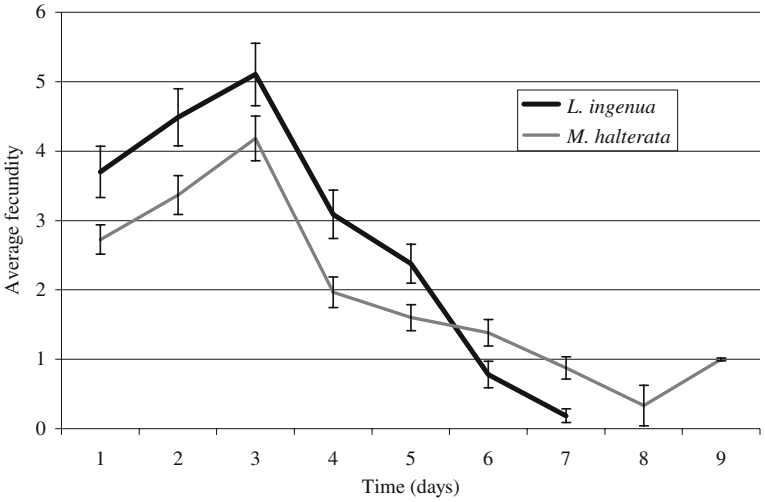

Fig. 2 Fecundity of *Parasitus consanguineus* fed on *Lycoriella ingenua* and *Megaselia halterata* larvae

Discussion

Since literature data on the developmental biology of *P. consanguineus* and its potential suitability as pest control agent in mushroom houses are scarce, our results can only be compared with those for other predators of the Gamasida. Rudzińska (1998) and Rudzińska-Sajdak (1998) found 32% mortality among all immature stages of the predatory mite *Arctoseius semiscissus* (Berlese) reared on eggs of the sciarid *L. auripila* (=*L. castanescens*). In her experiments, most of this mortality occurred in the egg stage (21%). Completely different results were obtained by Enkegaard et al. (1997), in tests with *Hypoaspis miles* (Berlese) fed on *L. solani* (=*L. ingenua*) larvae or on the stored product mite *Tyrophagus putrescentiae* (Schrank). Low mortality (3.5%) was found on the diet of sciarid larvae, but higher mortality (20%) was recorded on the diet of mould mites, where as many as 16% of the immature individuals died in the protonymph stage. Mortality was much higher (41.5%) in the juvenile stages of *H. aculeifer* (Canestrini) fed on mould mites (Barker 1969) or on the collembolan *Onychiurus fimatus* (48%) (Chi 1981). In our tests, mortality of the immature stages of *P. consanguineus* was also high, reaching 37% on a diet of *L. ingenua* and 51% on *M. halterata*.

Developmental times of *P. consanguineus* were similar to those observed for *Proctolaelaps deleoni* Nawar, Childers et Abou-Setta and *A. semiscissus* (6.2–8.9 and 7.9 days, respectively) (Nawar 1992; Rudzińska 1998; Rudzińska-Sajdak 1998). Immature stages of *Pergamasus crassipes* Berlese and *Amblygamasus septentrionalis* (Oudemans), on the other hand, completed their development during the longer period of 3 weeks after oviposition (Hartenstein 1962).

In our experiments the highest proportion of the developmental time was taken by the deutonymph stage (32–34%), whereas in experiments with *A. semiscissus* conducted by Rudzińska (1998) and Rudzińska-Sajdak (1998), the largest part of the developmental time was for egg development (41%).

The developmental time of *P. consanguineus* eggs is very short in comparison with data for *P. deleoni* (Nawar 1992), for *A. semiscissus* (Rudzińska 1998; Rudzińska-Sajdak 1998),

or for *Arctoseius cetratus* (Sellnick) (Binns 1974). In these experiments, eggs developed during 2.8–2.9, 3–3.3, or 5–6 days, respectively. Similar to our observations are those of Hartenstein (1962), who reported that larvae of *P. crassipes* and *A. septentrionalis* hatched 24–36 h after oviposition. The average developmental time for female protonymphs and deutonymphs of *P. consanguineus* on a diet containing *L. ingenua* or *M. halterata* was longer than that reported by Rudzińska (1998) and Rudzińska-Sajdak (1998) for the same juvenile stages of *A. semiscissus* (1.4 and 1.2 days).

Mean longevity and total fecundity of *P. consanguineus* were also much lower than those observed for *A. semiscissus, P. deleoni* and *H. miles* (Rudzińska 1998; Rudzińska-Sajdak 1998; Nawar 1992; Enkegaard et al. 1997). For example, the average number of eggs laid by *A. semiscissus* fed on sciarid eggs was 58.5 (range: 22–93 eggs per female) (Rudzińska 1998; Rudzińska-Sajdak 1998), and the mean longevity of *P. deleoni was* almost three times longer than that of *P. consanguineus* females (Nawar 1992).

The shorter developmental time of *P. consanguineus* compared to that of other species of predatory mites is potentially advantageous for control of dipteran pests, leading to a rapid increase in the number of mites under optimal conditions. The low fecundity observed in our study was probably the result of unfavorable conditions, since the mites were reared in small cages. In a laboratory colony of *P. consanguineus* established in large containers, the mites could move freely and they became numerous within a few weeks, suggesting a higher fecundity (Szlendak and Lewandowski 2002).

Observations of *P. consanguineus* revealed its voraciousness and its effectiveness in attacking and killing prey that is up to several times bigger than itself. This species kills more sciarid or phorid larvae than it can eat, and has a preference for live prey (Szlendak and Lewandowski 2000). Data obtained during this study and from unpublished preliminary experiments indicate that *P. consanguineus* is effective in the control of sciarid and phorid flies under laboratory conditions. When introduced into the substrate during laboratory trials, this mite reduced the number of *L. ingenua* by as much as 86%, and *M. halterata* by 65% (Szlendak and Lewandowski, unpublished data). *Parasitus consanguineus* thus appears to have considerable potential as a predator for the control of species of pest flies commonly occurring in Polish mushroom houses.

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