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Source: Florida Entomologist, 96(2) : 391-395
Published By: Florida Entomological Society
URL: https://doi.org/10.1653/024.096.0201

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Superparasitism of Ceratitis capitata and Anastrepha fraterculus (Diptera: Tephritidae) by Diachasmimorpha longicaudata (Hymenoptera: Braconidae)

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Abstract

Diachasmimorpha longicaudata is the most widely used braconid in biological control programs of fruit flies around the world. The objective of this study was to investigate the influence of different parasitoid-host ratios on D. longicaudata parasitism of Ceratitis capitata and Anastrepha fraterculus. Larvae of these fruit fly species were exposed to 5 different parasitoid-host ratios (4:1, 2:1, 1:1, 1:2 and 1:4). Subsequently, the numbers of oviposition scars and of parasitoid larvae per host were evaluated in the pupal stage. In both tephritid species, a larger number of scars and parasitoid larvae were observed at the 4:1 and 2:1 ratios. Results suggest that females of D. longicaudata can superparasitize both hosts. The differences between the tested parasitoid-host ratios suggest that there is an optimum parasitoid-host ratio for multiplying this natural enemy. These results are important for improving mass rearing programs of D. longicaudata.

Key Words: Anastrepha fraterculus, Ceratitis capitata, Diachasmimorpha longicaudata, superparasitism

Resumo

Diachasmimorpha longicaudata é o braconídeo mais utilizado em programas de controle biológico de moscas-das-frutas no mundo. O objetivo deste trabalho foi verificar a influência de coespecíficos no parasitismo sobre C. capitata e A. fraterculus, em diferentes razões de parasitoides e hospedeiros. Avaliamos o número de marcas de punctura e o de larvas do parasitoide no interior de pupários das duas espécies hospedeiras, após as larvas de moscas serem expostas nas razões (4:1, 2:1, 1:1, 1:2, 1:4) de parasitoide/hospedeiro. Para ambas as espécies de tefritídeos houve maior número de marcas e de larvas nos pupários nas razões 4:1 e 2:1, onde havia menor densidade de larvas por parasitoide. Os resultados mostram que fêmeas de D. longicaudata podem realizar superparasitismo em ambos hospedeiros. As diferenças entre as razões testadas sugerem uma proporção adequada para otimização dos métodos de multiplicação do inimigo natural. Os resultados tem importância como subsídio para a condução de criações massais em programas de liberação de D. longicaudata.

Palavras Chave: Anastrepha fraterculus, Ceratitis capitata, Diachasmimorpha longicaudata, superparasitismo

Understanding parasitoids-hosts interactions is essential for improving the management of pest populations in biological control programs. Most parasitoids are able to recognize hosts parasitized by conspecifics or by themselves (an ability known as “host discrimination”) and reject such hosts. However, they often lay a second clutch of eggs in or on them (an act called “superparasitism”) (van Dijken & Waage 1987; van Alphen & Visser 1990).

Superparasitism was initially believed to reflect parasitoid error, since there is no apparent benefit to laying eggs in a host already parasitized by the same species. It is now recognized, however, that superparasitism may promote natural selection through intraspecific competition (Bakker et al. 1985).

Diachasmimorpha longicaudata (Ashmead) (Hymenoptera: Braconidae) is a larval-prepupal endoparasitoid of tephritid fruit fly pests in tropical and subtropical countries (van Nieuwenhove et al. 2012). It was originally collected in the Indo-Philippine region attacking Bactrocera species (Sivinski et al. 2006). This parasitoid species is currently considered to be one of the most significant biological agents for augmentative release programs against fruit fly pests in Latin America (González et al. 2007).

Fruit flies (Diptera: Tephritidae) are the primary pests of fruit crops in Brazil (Nava et al.
Ceratitis capitata (Wiedemann) and Anastrepha fraterculus (Wiedemann) are especially important. The latter causes damage to temperate-zone fruit crops (Kovaleski & Ribeiro 2003) and native Myrtaeae (Gattelli et al. 2008).

The objective of this study was to investigate the influence of D. longicaudata conspecifics on parasitism of C. capitata and A. fraterculus tephritids, at different parasitoid-host ratios. These 2 host species are used in Brazil's Moscamed Biofactory for the multiplication of D. longicaudata for release in biological control programs.

**Materials and Methods**

The study was conducted in the Biology, Ecology and Biological Control of Insects Laboratory (BIOECOLAB), at the Universidade Federal do Rio Grande do Sul, Brazil. Laboratory conditions were maintained at 25 ± 2 °C, 65 ± 10% RH and 14:10 L:D.

*C. capitata* and *A. fraterculus* were bred using a modified version of the methodology proposed by Terán (1976). Adults were kept in 45 L × 30 W × 30 H cm wooden cages with the sides covered with voile mesh, provided distilled water, and fed *ad libitum* with a solid diet that consisted of sugar crystals, wheat germ, corn gluten, and brewer's yeast (3:1:1:1) (adapted from Jaldo et al. 2001). A 250 mL orange plastic tube was used as a substrate for *C. capitata* oviposition, following the methodology of FAO/IAEA/USDA (2003). The oviposition substrate for *A. fraterculus* was a 15 cm Ø plastic Petri dish with an 11 cm Ø opening protected with voile mesh covered by a thin layer of black silicone. This dish was filled with water and placed on the upper surface of the cage where *A. fraterculus* larvae were bred. Newly hatched larvae were placed onto blocks of artificial diet, based on carrot and corn flour, according to the BIOECOLAB protocol (Meirelles 2011).

Parasitoids were bred following Carvalho et al. (1998). Third instar larvae of *C. capitata* and *A. fraterculus* (approximately 12 days old) were used as hosts. Forty-five fruit fly larvae were exposed to parasitoids for a 1-h period, once a day, in parasitism chambers. However, *A. fraterculus* larvae contained more than one parasitoid larva. We analyzed a minimum of 120 pupae for each host and each parasitoid-host ratio.

Differences in the number of oviposition scars and parasitoid larvae per pupa for each fruit fly species were analyzed through the Kruskal-Wallis test (*P* < 0.05) and Dunn's paired comparisons (Ayres et al. 2007). The number of superparasitized pupae between species and parasitoid-host ratios were compared using the Mann-Whitney test (*P* = 0.05) (Ayres et al. 2007).

**Results**

Superparasitism by *D. longicaudata* was observed in both fruit fly hosts. There was a significant difference between the number of oviposition scars recorded at different parasitoid-host ratios in pupae of *C. capitata* (*H* = 170.1525; df = 4; *P* < 0.0001), and *A. fraterculus* (*H* = 123.4763; df = 4; *P* < 0.0001). The same pattern was observed for the number of *D. longicaudata* larvae in pupae of the 2 host species (*C. capitata: H* = 131.0551; df = 4; *P* < 0.0001; *A. fraterculus: H* = 139.7015; df = 4; *P* < 0.0001) (Table 1).

Superparasitism rates did not differ between the 2 hosts at the 4:1 (*U* = 6,405.5; *P* = 0.1143) and 2:1 (*U* = 6,642.0; *P* = 0.0983) parasitoid-host ratios. However, *A. fraterculus* showed a higher superparasitism rates at the 1:1 (*U* = 5,128.0; *P* < 0.0001), 1:2 (*U* = 5,564.0; *P* < 0.0001), and 1:4 (*U* = 5,550.5; *P* < 0.0001) parasitoid-host ratios (Table 2).

The number of superparasitized pupae did not differ between the 2 hosts at the 4:1 (*U* = 6,405.5; *P* = 0.1143) and 2:1 (*U* = 6,642.0; *P* = 0.0983) parasitoid-host ratios. However, *A. fraterculus* showed a higher superparasitism rates at the 1:1 (*U* = 5,128.0; *P* < 0.0001), 1:2 (*U* = 5,564.0; *P* < 0.0001), and 1:4 (*U* = 5,550.5; *P* < 0.0001) parasitoid-host ratios (Table 2).

The number of oviposition scars per pupa ranged from 1 to 66 in *C. capitata*, with a mean (± SD) of 6.67 ± 0.289. In *A. fraterculus*, this number ranged from 1 to 53 and the mean (± SD) was 11.72 ± 0.323. The mean number of *D. longicaudata* oviposition scars was higher in *A. fraterculus* than in *C. capitata* at the 4:1 (*H* = 38.3865; df = 1; *P* < 0.05), 1:1 (*H* = 79.5814; df = 1; *P* < 0.05), 1:2 (*H* = 131.7541; df = 1; *P* < 0.05), and 1:4 ratios (*H* = 48.8724; df = 1; *P* < 0.05). The number...
Table 1. Mean number (± SD) of oviposition scars in C. capitata and A. fraterculus pupae, and mean numbers of first-instar larvae of Diachasmimorpha longicaudata per host, 72 h after exposure, at different ratios of parasitoid females to host larvae (values in parentheses indicate the number of exposed host larvae).

<table>
<thead>
<tr>
<th>Parasitoid-host ratio</th>
<th>Oviposition scars</th>
<th>D. longicaudata larvae</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C. capitata</td>
<td>A. fraterculus</td>
</tr>
<tr>
<td>1:4 (120)</td>
<td>4:1 (121)</td>
<td>9.43 ± 0.89 b</td>
</tr>
<tr>
<td>2:1 (123)</td>
<td>2:1 (123)</td>
<td>13.20 ± 0.82 a</td>
</tr>
<tr>
<td>1:1 (127)</td>
<td>1:1 (120)</td>
<td>5.42 ± 0.33 b</td>
</tr>
<tr>
<td>1:2 (133)</td>
<td>1:2 (136)</td>
<td>3.19 ± 0.18 c</td>
</tr>
<tr>
<td>1:4 (143)</td>
<td>1:4 (124)</td>
<td>3.17 ± 0.28 c</td>
</tr>
</tbody>
</table>

Means with different letters within a column are significantly different (Kruskal-Wallis, $\alpha = 0.05$).

of oviposition scars in the 2 species did not differ significantly at the 2:1 ratio ($H = 0.3654$; df = 1; $P = 0.54$) (Table 1).

The mean number of D. longicaudata larvae was higher in A. fraterculus than in C. capitata at the 4:1 ($H = 12.3466$, df = 1, $P < 0.05$), 1:1 ($H = 71.9833$, df = 1, $P < 0.05$), 1:2 ($H = 95.744$, df = 1, $P < 0.05$), and 1:4 parasitoid-host ratios ($H = 37.9866$, df = 1, $P < 0.05$). There was no significant difference at the 2:1 ratio ($H = 0.0092$, df = 1, $P = 0.92$) (Table 1).

There was a positive correlation between the number of oviposition scars and the number of parasitoid larvae per pupa, in both C. capitata ($r = 0.8348$, $r^2 = 0.6969$, $P < 0.0001$) and A. fraterculus ($r = 0.8455$, $r^2 = 0.7149$, $P < 0.0001$).

DISCUSSION

Similar to our results with C. capitata and A. fraterculus, Montoya et al. (2003) had reported superparasitism of A. ludens by D. longicaudata. The higher superparasitism rates observed in A. fraterculus compared to C. capitata may have been influenced by the size of the host. Larger hosts (e.g., A. fraterculus) offer more resources to be exploited, allowing the development of larger and more competitive parasitoids with greater reproductive potential (Chau & Mackauer 2001). According to López et al. (2009), D. longicaudata superparasitizes more frequently (higher emergence, longevity, and search speed) when reared in larger hosts. Moreover, Ovruski et al. (2011) reported that D. longicaudata preferred A. fraterculus over C. capitata when given a choice.

In solitary parasitoids elimination of competition inside the pupae may occur by lethal combat between larvae or by physiological suppression (Godfray 1994). In our study combat between larvae was observed only once out of a total of 1,270 dissected pupae. Our observations are in accordance with Van Alphen & Visser (1990) and Montoya et al. (2000) who argued that D. longicaudata can efficiently remove excess conspecific larvae by physiological mechanisms.

The sex ratio of the offspring in our study was not determined because parasitoid pupae were dissected before emergence. However, González et al. (2007) and Montoya et al. (2011) reported a positive correlation between the number of oviposition scars and the percentage of females that emerged from A. ludens exposed to D. longicaudata. The positive correlation between the number of scars and the number of larvae in the pupae is similar to reports by Montoya et al. (2000) using A. ludens larvae as host.

Superparasitism is recognized as an adaptive feature of parasitoids (van Alphen & Visser 1990) and may be one of the factors that explain the success of D. longicaudata as a biological control agent of fruit flies. González et al. (2007) suggested that superparasitism in D. longicaudata selects for greater flying ability and a greater proportion of females, thereby increasing the reproductive success of the species. These authors also argued that the presence of more than one parasitoid larva can reduce the severity of the host's...
immune response and increase the survival rate of the parasitoid. Nevertheless, Van Nieuwenhove et al. (2012) demonstrated that increasing the ratio of *A. fraterculus* larvae to parasitoid above 4:1, and the exposure time of *D. longicaudata* to hosts to more than 30 min, did not significantly enhance overall parasitoid progeny yield.

The results of our study have applications for optimizing the mass rearing of *D. longicaudata* in both host species tested, which occur in Brazil and are used to rear the parasitoid at the Biofactory Moscamed. Specifically, our results indicate that using 1:1, 1:2, and 1:4 parasitoid/host ratios should lead to a more efficient multiplication of the parasitoid. However, other factors that affect parasitoid rearing merit additional study, including the age of females, their previous experience, and the densities in the rearing cages.

**ACKNOWLEDGMENTS**

We thank the National Council for Scientific and Technological Development (CNPq) for fellowships awarded to the first and second authors (proc. n. 305956/2010-8) and the financial support (proc. n. 475287/2010-0). We would like to thank Dr. Antonio Nascimento at Embrapa Mandioca e Fruticultura Tropical for providing the first individuals used to rear parasitoids in the laboratory.

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