# Reproductive behaviour and fitness trade-offs in the aphid parasitoid *Diaeretiella rapae* (Hymenoptera: Aphidiidae)

A thesis presented in partial fulfilment of the requirements for the degree of

Doctor of Philosophy (PhD)
in

Plant Science (Entomology)
at

Massey University, Palmerston North,
New Zealand

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**2012**

**Abstract**

Parasitoids are fascinating insects that lay eggs in or on the body of their hosts where parasitic immatures grow and develop by exploiting the fixed resources available in a host. This study investigated host-parasitoid interaction between the cabbage aphid *Brevicoryne brassicae* and its parasitoid *Diaeretiella rapae.* The research explored the reproductive decisions made by *D. rapae*, and how these decisions affect its fitness and pest suppression ability.

The haplodiploid nature of reproduction in *D. rapae* imposes strongly contrasting outcomes of mating and oviposition decisions that directly affect population sex ratio. This study found that parasitoid fitness is the integral outcome of lifetime mating and oviposition behaviours. Poor host-parasitoid synchronisation was found in an uncontrolled/open system in spring in New Zealand; a low female/male ratio and a significant number of erroneous male-male mating pairs were detected in this *D. rapae* population. Adult emergence occurred only during the light period, with males emerging before females (protandry). Light triggered both mating and oviposition in *D. rapae*. Female *D. rapae* preferred to mate before oviposition, which allowed them to produce female-biased offspring. Females were found to allocate more time for choosing their mates whereas males were more active during mating and selected their mates quickly. Females mated once (monandrous), while males mated multiple times (polygamous) and became sperm depleted after their third mating. The monandrous and polygamous nature of *D. rapae* changed the female-biased sex ratio to a highly male-biased operational sex ratio, resulting in mating interference. Several factors including age, body size, mating status and previous mating experience affected mate selection behaviour in males and females. Female *D. rapae* emerged with developed eggs and did not require additional food to mature their eggs (autogenous), however, it took about two days for all their eggs to mature (weakly synovigenic). The nutrients acquired during the larval stage (by feeding on host resources) and during adult stage (by feeding on 10% honey solution) both affected individual fitness. Parasitoids lived longer after feeding on honey solution and this effect was more pronounced in females than in males. Female *D. rapae* fed on honey also carried their eggs longer without resorbing them. Females preferred to oviposit in larger hosts than in smaller ones, despite stronger defensive behaviour of the larger hosts. Females also preferred the larger hosts for ovipositing fertilised eggs that resulted in larger female offspring; the females that

emerged from larger hosts lived longer and produced more offspring than those emegered from smaller hosts. Female oviposited multiple eggs per host (superparasitism) after repeatedly attacking their hosts. This resulted in two to eight parasitoid larvae developing in a host, but only one adult emerged from each (solitary parasitoid). Female *D. rapae* produced more female offspring when hosts were limited, and the number of males only increased when host density was higher. Females oviposited more unfertilised eggs when competing with conspecifics, which allowed them to conserve their fertilised eggs for future oviposition.

Thus, the study suggests that strong intrasexual competition and intersexual selection exist during mating and oviposition in *D. rapae*. This study provides comprehensive information on interactions between cabbage aphid and *D. rapae* which can be used to develop effective biological control programmes for cabbage aphid and other aphid species using *D. rapae* or other parasitoids. Release of honey-fed, mated and 1-day old females in early morning and on sunny days would be most effective and result in quicker suppression of aphid populations. Raising females in low competition situations with large size hosts (5-7 day old) could help in producing efficient and female-biased broods in insectaries.

**Acknowledgements**

I express my sincere appreciation to my chief supervisor Masha Minor for her direction, guidance and encouragements during my study. She has always been readily available for consultations, and provided critical review of my work. Working with her has been a great learning experience.

I am very much grateful to my other two supervisors, Steve Trewick and Mano Sandanayaka for being supportive throughout my doctoral project. Mano has been involved in my project since its inception and provided fruitful suggestions on the experiments and manuscripts. Steve has played a great role in providing me with critical comments on my drafts and phylogenetic work on the parasitoid. His guidance helped me develop my thoughts from evolutionary perspective.

Thanks go to Mary-Morgan Richard and Alastair Robertson for suggestions and discussion at various points of the project. I would like to acknowledge the involvement of Qiao Wang early in the project. I thank my statistics teachers Greg Arnold, Jonathon Godfrey and Alasdair Noble for their advice during the project.

I am grateful to Peter Kemp, Jacqueline Rowarth, Ed Minot, Ian Henderson and Kerry Harrington, Institute of Natural Resources, for financial and logistic support. I express my gratitude to the INR technical staff – Paul, Tracy, Cleland, Shaun, Kay, James and Julia for support. I am also thankful to the INR secretaries, Sharon, Denise (S), Glenys and Denise (B) who extended all their support during my study.

I would also like to thank library staff, Centre for Teaching and Learning, IT Services, Student Association (MUSA), and International Student Office at Massey University for their advice and support. Thanks go to Prof Margaret Tennant and other staff of the Graduate Research School for technical support. I would also like to acknowledge Massey University for offering me various scholarships during my doctoral study including the Massey Doctoral Research Scholarship, Helen E Akers PhD Scholarship, John August PhD Scholarship and Hurley Fraser Scholarship. I am also thankful to ISM New Zealand for providing support. Thanks go to New Zealand Plant Protection and New Zealand Entomological societies for providing scholarships/grants for attending and presenting my research at different conferences. I also thank Solar Produce farm for providing access to their farm for insect collection. I also acknowledge the help I received from several scientists including Darren Ward from Landcare Research, John Early from Auckland Museum, Graham

Walker from Plant and Food Research and Paul Sunnucks from Monash University, in collecting and identifying insect samples. I thank Cilla Wehi, Marian Bulgarella, and Xiaojing Gan for their suggestions in improving the manuscripts. I also thank numerous anonymous reviewers and editors of journals I have submitted manuscripts to for their comments and suggestions.

I would like to thank all my friends and colleague in INR for their help and support and I will always remember the time we spent together. Despite being so far away from family we easily adjusted in New Zealand and never felt alone because of our Phoenix group and other friends including Santosh, Prashant, Rakesh, Prasad, Neha, Harmeek, Girish, Anand, Diwas and Casey, who shared traditional food and jokes to keep refreshing me during my studies.

I am also thankful to Terry McGrath, Jonathon Hannon, Dawn Patchett and Linda Gray for their personal and professional support during this period. I thank our kiwi friends Beth Hunt, Wilf Hunt, Jenny McGrath, Jenny Munro, Peter Munro, Hugh Badger, Margaret Badger, Ross Fountain, Tim Linton, Jeff, Neil, Faguali, Isaac and all other people from Kingston Street church for their support and prayer in completion of my PhD. I could not have accomplished this without thinking of my beloved mentors Professors Steven Foster and Marion Harris. I always remembered and got inspiration from my past teachers Professors Chirashree Ghosh, CR Babu, Inderjit, Mihir Dev, Lt. AVN Paul, TP Trivedi, RD Gautam, AK Garg, RK Seth, Pramila Gupta, Rita Bakshi, MS Mishra, SC Tiwari and SB Lall at some point of my studies.

I would like to thank my wife Neelam and our sons Tarang and Tapas for being so supportive throughout my research. I like to thank my father, mother, brothers and sisters who always been encouraging and provided emotional, technical and financial support during my study. I do appreciate my uncles, aunties and cousins whom I missed during this period. I miss my grandmother who passed away during my study, and I could not see her at the time when she left us forever.

**Preface**

A thesis is presented on reproductive behaviour and fitness trade-offs in aphid parasitoid *Diaeretiella rapae* (Hymenoptera: Aphidiidae). The thesis is comprised of four main parts – General Introduction, experimental chapters (Chapters 1-13), General Discussion and Conclusions, and an Appendix (Appendices 1-3). The experimental work was carried out at Massey University, Palmerston North, New Zealand.

I am the author of each section and chapter, and the first author on published papers from this research. The co-authors of the published papers are my PhD supervisors. I designed the initial experiments, executed the experiments, analysed the results and discussed findings of each chapter. The supervisors gave their inputs in finalising the experiments, helping with statistical analyses, providing comments on the results, and reviewing the drafts in terms of language and clarity.

Various aspects of reproductive, mating and oviposition behaviour of *D. rapae* are presented in **Chapters 1-13**. Each Chapter is presented as a standalone paper with its own Introduction, Methods, Results, Discussion and References, and as a result, there is some repetition between the Chapters. The numbering of figures and tables restarts at the beginning of each Chapter.

The thesis begins with a **General Introduction,** which covers the background information and literature relevant to the species used in the research, as well as theories related to reproductive fitness and rationale for this research. **Chapter 1** investigates parasitism and mating strategies of *D. rapae* in a wild population (uncontrolled conditions), identifying some problems in oviposition and mating in *D. rapae*, for example, erroneous male-male mating. All other studies in this thesis were carried out in the laboratory at controlled temperature, humidity and light period. **Chapter 2** looks at the emergence pattern and diurnal variations in mating and oviposition activities of *D. rapae*. Sexual receptivity, courtship and mating behaviour of emerged adults are reported in **Chapter 3**. Sexual selection in *D. rapae* is studied in **Chapter 4**. The effect of multiple matings on sperm transfer and on the fitness of males and females is investigated in **Chapter 5.**

I looked into general biology and the importance of adult food availability for longevity and reproductive potential of *D. rapae* in **Chapter 6.** Since *D. rapae* is a haplodiploid species, a newly emerged female has a valid choice between ovipositing unmated or after mating. I investigated the fitness consequences of this choice in

**Chapter 7**. Further, I examined the effects of age, and mating and oviposition delay on overall fitness of *D. rapae* in **Chapter 8**.

The general host searching, handling and oviposition behaviours of *D. rapae* are described in **Chapter 9**. **Chapters 10** and **11** investigate the preference–performance hypothesis in host selection, and the effect of host selection on reproductive fitness**.** Although *D. rapae* is a solitary parasitoid and only one adult emerges per host, the females can lay more than one egg per host (superparasitism). **Chapter 12** examines the consequences of superparasitism for fitness, and checks experimentally whether or not female *D. rapae* can discriminate between unparasitised and already parasitised hosts. The last **Chapter 13** deals with reproductive strategies of *D. rapae* females when they are competing for hosts and when more than one conspecific female are foraging together.

The findings from all the chapters are discussed in **General Discussion and Conclusions** in a broader context of reproductive fitness, biological control and evolution. The **Appendix 1** includes phylogenetic work on *D. rapae*. Some additional information on superparasitism that could not be included in published paper (**Chapter 12**) is reported in **Appendix 2**. Abstracts of the full papers published in journals, or abstracts published in conference proceedings which arose from this research are given in **Appendix 3**.

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