

Biological Control of Tephritid Fruit Flies in Hawaii with Special Reference to the Newly Discovered Egg-Larval Parasitoid, *Fopius ceratitivorus* (Wharton)

Aimé H. Bokonon-Ganta, Xin-geng Wang, and Russell H. Messing¹

Department of Plant and Environmental Protection Sciences,
College of Tropical Agriculture and Human Resources, University of Hawaii at Manoa,
Honolulu, HI 96822, USA. ¹E-mail: messing@hawaii.edu

Abstract. *Fopius ceratitivorus* Wharton is the most recently imported parasitoid for biological control of tephritid fruit flies in Hawaii. In this paper we summarize current progress on studies of this parasitoid under quarantine conditions in Hawaii. Tests on its potential target host range reveal that *F. ceratitivorus* attacks and completes its development only in the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann). The three other extant fruit fly pests in Hawaii, *Bactrocera cucurbitae* (Coquillett), *Bactrocera dorsalis* (Hendel) and *Bactrocera latifrons* (Hendel) are unsuitable for *F. ceratitivorus* development. Competition studies with the well-established and dominant fruit fly parasitoid, *Fopius arisanus* (Sonan), showed that either species can win in intrinsic competition with each other, depending on which one occupies the host first. In both choice and no-choice tests, *F. ceratitivorus* was found to cause no parasitism nor mortality to eggs or larvae of the non-target tephritid *Procecidochares alani* Steyskal on infested pamakani weed, *Ageratina riparia* (Regel); nor the native Hawaiian tephritid *Trupanea dubautia* (Bryan) infesting flower heads of the endemic Asteraceae shrub, *Dubautia raillardiodes* Hillebrand. These findings suggest that release of this parasitoid as a biological control agent in Hawaii will pose minimal non-target risk and may contribute to overall fruit fly biological control in the islands. The delays due to the regulatory bureaucracy in removing the wasp from quarantine following host range testing are also discussed.

Introduction

Four accidentally introduced tephritid fruit flies (Diptera: Tephritidae) are serious pests affecting fruit and vegetable production on all major islands in Hawaii. Besides the loss of production due to high infestation levels, infestation by these insects poses a serious risk of invasion into other states of the mainland USA. The melon fly, *Bactrocera cucurbitae* (Coquillett) and the Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann) invaded Hawaii in 1895 and 1907, respectively (Back and Pemberton 1918); the oriental fruit fly, *Bactrocera dorsalis* (Hendel) was first reported in 1945 (van Zwaluwenburg 1947); and the solanaceous fruit fly, *Bactrocera latifrons* (Hendel) in 1983 (Vargas and Nishida 1985). Attempts to manage the flies have included bait-spray applications, sanitation, sterile insect techniques, and releases of numerous hymenopteran parasitoids over the years. Over 30 parasitoids introduced from Asia, Africa and Australia have been released in Hawaii to control these pests, resulting in some of the more successful examples of classical biological control of fruit flies in the world (Bess et al. 1961, Clausen et al. 1965, Haramoto and Bess 1970, Wong and Ramadan 1987, Wharton 1989, Vargas et al. 1995).

The history of classical biological control of invasive pest fruit flies in Hawaii can be summarized in three different periods. The first period covers a large biological control program undertaken in 1912 following the invasion of medfly and melon fly (Wharton

1989). A number of fruit fly parasitoids were discovered in West Africa and Australia (Gilstrap and Hart 1987, Wharton 1989) and introduced, a few of which established. The second period covers the large program undertaken in the 1950s following the invasion of *B. dorsalis* (Wharton 1989). More than 20 parasitoid species were introduced to Hawaii from southern Asia and other regions (Wharton 1989). Of these, one egg-larval parasitoid [*Fopius arisanus* (Sonan)], five larval parasitoids [*Fopius vandenboschi* (Fullaway), *Diachasmimorpha longicaudata* (Ashmead), *Psytalia flecheri* Silvestri, *Psytalia incisi* (Silvestri), *Tetrastichus giffardianus* Silvestri], and two pupal parasitoids (*Dirhinus anthracia* Silvestri, *Pachycrepoideus vindimiae* Rondani) become established (Bess et al. 1961, Wong and Ramadan 1987, Vargas et al. 1993, Purcell 1998). Successful establishment of *F. arisanus* resulted in significant suppression of *C. capitata* and *B. dorsalis* (Purcell 1998, Wharton 1989). Since the 1950s, biological control in Hawaii has gone through a third period with only a few new fruit fly parasitoid introductions. Because of the importance of biological control in integrated pest management programs, and based on the positive impact of previous biological control in Hawaii, several scientists have renewed efforts to search for new biological control agents. These efforts have been delayed by several bottlenecks including (1) lack of resources for sustained exploration and rearing; (2) difficulties in obtaining release permits as a result of long bureaucratic delays (which increase the cost and turn-around time for agent evaluation); and (3) a tightening of regulations against the introduction of exotic species, due to rising concerns about non-target impacts on both endemic and beneficial species (Messing 1995, 1999). During this period, many entomologists emphasized the importance and potential economic benefits of improving biological control of tephritid flies (Steck et al. 1986, Gilstrap and Hart 1987, Wharton 1989, Messing 1995). Biological control is increasingly viewed as a safe and economically effective means of fruit fly control, and its importance continues to grow as pesticide use becomes more restricted. Consequently, recent studies were conducted using different approaches for better selection of biological control agents that are safe and effective prior to any introduction decision.

In this paper we address recent parasitoid introductions into Hawaii within this last period, with special reference to the most recent introduction, the egg-larval parasitoid, *F. ceratitivorus*.

Materials and Methods

Parasitoid selection. Search for new parasitoids was oriented towards species co-evolved with the invasive fruit fly pests, as well as new associations not having co-evolutionary histories with them prior to introduction. It also takes into account the global pattern of competitive superiority of early-attacking species in fruit fly parasitoids (Wang et al. 2003), a finding consistent with predictions of theoretical models of multi-species competition (Briggs 1993).

Parasitoid introduction and handling. Potential new biological control candidates were shipped to the State Quarantine Facility within the Hawaii Department of Agriculture. *F. ceratitivorus* was originally collected in Central Kenya from coffee berries infested by *C. capitata* (Wharton et al. 2000), and shipped to the USDA-APHIS / MOSCAMED quarantine facility at San Miguel Petapa, Guatemala, Central America where the parasitoid was propagated on *C. capitata*-infested coffee berries (Lopez et al. 2003). After transshipment to Hawaii, the parasitoid colony was maintained in the laboratory using papaya fruit infested with *C. capitata* eggs.

Target and non-target host range tests. Host preference and host suitability testing were performed using all four extant tephritid fly species in Hawaii (Bokonon-Ganta et

al. 2005). The potential risk to the environment was tested in both choice and no-choice experiments, using the non-target pamakani gall fly, *P. alani* (an introduced weed biological control agent); and the non-target native Hawaiian tephritid *Trupanea dubautia* (Bryan), infesting flower heads of the endemic Asteraceae shrub, *Dubautia raillardioides* Hillebrand (Wang et al. 2004, Bokonon-Ganta et al. 2005). In choice tests, infested papaya fruits and pamakani plants or flower heads were exposed in screen cages to female *F. ceratitivorus*. In no-choice tests, female wasps were exposed only to infested pamakani or flower-head test units. Data were collected on the behavior of the wasps, and on the results of rearing or dissection of exposed fly eggs and larvae.

In addition, competition between *F. ceratitivorus* and *F. arisanus* within *C. capitata* was studied following the procedures described by Wang and Messing (2002). Bionomics of the wasp were also studied to better understand its biology and to facilitate mass rearing, which is useful both for research and for applied biological control releases. All studies were conducted under quarantine conditions at $28 \pm 2^\circ\text{C}$, 60–80% RH, and a 12 L: 12D regime.

Parasitoid release from quarantine and field evaluation. Data on host range and efficacy of *F. ceratitivorus* were presented in appropriate dossiers to the Entomology Subcommittee, the Plants and Animals Advisory Committee, the Board of Agriculture, and several reviewers in order to obtain release permits. Identities of specimens of *F. ceratitivorus* were re-confirmed by Dr. Robert Wharton of Texas A&M University. Voucher specimens were deposited in the insect collections of the State of Hawaii Department of Agriculture, Division of Plant Industry, Plant Pest Control Branch, and also the Insect Museum of the Department of Plant and Environmental Protection Sciences, University of Hawaii at Manoa, both in Honolulu, Hawaii.

Results and Discussion

Parasitoid selection. From February 1996 to December 2004, nine species in seven genera from three different families that attack tephritid flies were introduced into Hawaii (Table 1). These species originated from Africa, Asia, Australia and Southern Europe. An important factor influencing the focus of searches for new parasitoids is the well-documented success and oviposition attributes of the egg-larval parasitoid *F. arisanus*. *F. arisanus* is the only extant species in Hawaii that attacks host eggs at the very beginning of fruit infestation, while all other extant species attack host larvae or puparia. Arriving in the host fruit earlier, *F. arisanus* has an intrinsic competitive superiority against the larval fruit fly parasitoids (Wang et al., 2003) and has become the dominant parasitoid in most lowland areas of Hawaii. The success of *F. arisanus* in the Hawaiian Islands has stimulated exploration for similar egg- attacking parasitoids, which could enhance overall fruit fly control. The egg-larval parasitoid, *F. ceratitivorus* Wharton was discovered during the search for new candidates for biological control in east Africa, the putative area of origin of the medfly (Wharton 1999).

Parasitoid introduction and handling. An initial cohort of 1,200 adults of *F. ceratitivorus* was shipped to the Hawaii Department of Agriculture Quarantine Facility in May 2002. At this point a laboratory rearing colony was established for studies on host range, competition and non-target impacts.

Host range tests. The parasitoid was found to have a very narrow host range, and successfully reproduced only in *C. capitata*. All parasitoid eggs laid in *Bactrocera cucurbitae*, *B. dorsalis*, and *B. latifrons* were killed through encapsulation. Similar observations have been reported with other opiine parasitoids of *C. capitata* encapsulated in *Bactrocera* species (Mohamed et al. 2003, Pemberton and Willard 1918, Ramadan et al. 1994). Failure of the

parasitoid to develop in *Bactrocera* spp is probably due to lack of physiological compatibility with these hosts. *F. ceratitivorus*, which is of African origin, has no evolutionary history with the three *Bactrocera* species of Asian origin.

The great majority of opiine parasitoids that attack tephritids are larval endoparasitoids (Wharton 1989). *F. arisanus* is currently reported as the only species attacking host eggs in Hawaii, and is by far the dominant parasitoid (Purcell et al. 1998; Wong and Ramadan 1987), partly due to its intrinsic competitive superiority against all larval fruit fly parasitoids (Wang and Messing 2002, 2003, Wang et al. 2003). Parasitoids attacking hosts early are generally better competitors than those attacking the hosts at a later developmental stage (Bokonon-Ganta et al. 1996, Wang and Messing 2002, Wang et al. 2003). *F. arisanus* physiologically suppresses egg development of larval parasitoids when competition occurs (van den Bosch and Haramoto 1953, Wang and Messing 2002, Wang et al. 2003).

Interspecific competition. We conducted competition studies between *F. arisanus* and *F. ceratitivorus* in the laboratory, with various fixed schedules of the order of oviposition, and found after dissections of multi-parasitized host eggs and adult emergence that either species can win the competition against the other, depending on which one occupies the host first. The outcome of this competition needs to be studied in the field, where *F. arisanus* is widely established.

Non-target impact. In addition to host range studies with target hosts, we studied the impact of *F. ceratitivorus* on non-target hosts. In Hawaii, there are 33 non-target tephritid flies, including 26 endemic species, and five deliberately introduced and two inadvertently introduced weed control agents (Hardy and Delfinado 1980). The potential environmental impacts of new parasitoid species introduced against tephritid pests in Hawaii have been pointed out by several authors (Duan et al. 1996, 1998, Howarth 1991). Gall-forming tephritids such as *P. alani*, *Procecidochares utilis* Stone, and *E. xanthochaeta* are already attacked by the extant opiine larval parasitoids *D. longicaudata* and *D. tryoni* in the field (Clancy et al. 1952). However, not a single case of an egg-larval parasitoid attacking non-target tephritid flies has been reported to date, despite several intensive field surveys (Duan et al. 1996).

Hapai (1977) studied the oviposition behavior of the gall-forming tephritid, *P. alani* and found that the fly lays eggs on the tips of growing shoots of its host plants; hatching larvae then bore into stem tissues and eventually induce spheroid galls on the apical region of plant stems. *F. ceratitivorus* deposits its eggs inside host eggs that have been inserted into fruit tissues, and it does not recognize nor attack fly eggs on leaf tips. Results from our laboratory experiments demonstrate that *F. ceratitivorus*, exposed to pamakani plants infested with a wide range of fly stages (including eggs, early and late larval instars) completely lacks oviposition responses to the non-target fly, *P. alani*. Therefore, utilization of *F. ceratitivorus* in biological control programs targeted against the frugivorous pest *C. capitata* would likely have no harmful impact on these gall-forming tephritids.

Because native flower-head feeders on endemic plants in Hawaii should also be protected from attack by introduced biological control agents, we investigated the impact of *F. ceratitivorus* on *Trupanea dubautiae* (Bryan), which is an abundant species infesting flower heads of the native Asteraceae shrub *Dubautia raillardioides* Hillebrand that grows in mesic forests of Kauai island (Duan et al. 1996). In both choice and no-choice experiments, none of the *F. ceratitivorus* female parasitoids was observed searching terminal shoots or probing on stems or growing points of the flower heads.

These laboratory results concur with previous findings showing that no flower head-feeding tephritids were attacked by larval fruit fly parasitoids, because of the lack of a positive behavioral response to flower microhabitats (Duan et al. 1997, 1998). In addition, to date, field surveys have not discovered any deliberately introduced fruit fly parasitoids emerging

from endemic flower head-feeding tephritids (Duan et al. 1996).

Parasitoid release from quarantine and field evaluation. The reproductive behavior of *F. ceratitivorus*, its potential coexistence with *F. arisanus*, and the demonstrated absence of harmful impacts on non-target (non-frugivorous) fly species are positive attributes for a tephritid biological control agent and warrant its introduction for Mediterranean fruit fly control in Hawaii and other regional *C. capitata* integrated pest management programs. We believe that *F. ceratitivorus* may be complementary to *F. arisanus* in areas of high elevation where the impact of *F. arisanus* is very low.

A request to remove *F. ceratitivorus* from quarantine was submitted to the State of Hawaii Department of Agriculture in late 2003 following host range testing and competition studies. The request remained under review by the State for two full years with repeated delays due to inordinate legal oversight, postponements of decision-making and, ultimately, a lack of sufficient voting members when substantial efforts were made to set a consensual date and time for a review committee meeting. In fact, the Plants and Animals Advisory Committee eventually voted 4 to 2 in favor of releasing *F. ceratitivorus* from quarantine, but the request was denied because a majority of the nine-member committee (i.e., five members) did not vote for the release.

In 2006, the application for *F. ceratitivorus* was resubmitted with additional data to state permit officials. This time, the application languished for a full year before comments from the first review level (Entomology Subcommittee) were finally collated and referred back to the applicant, who was then given one week to address subcommittee concerns and prepare voluminous paperwork for the next level of review. Given the lack of time, the application was temporarily withdrawn from consideration, and revisions to the dossier are underway to try to broach the state permit process one more time in early 2008.

Van Driesche and Hoddle (1997) noted that while increased regulations are a partial solution to invasions of exotic species, biological control introductions are a very minor source of exotic species in the U.S. across all taxonomic groups. The major sources of exotic species damaging to natural communities are: (1) releases of domestic animals in the wild, (2) the pet trade, (3) the deliberate spread of exotic fish, game, and fur-bearing species to regions beyond their native range, (4) invasions of rats and other predators that hitch-hike on ships and planes, (5) the world-wide movement of a vast number of ornamental, forage, and erosion control plants, and (6) poor regulation of movement of bulk materials in trade, such as ballast water and raw materials.

Although regulations controlling deliberate new species introductions are necessary, extensive unwarranted delays are detrimental to biological control because of loss of genetic diversity and increased handling costs for natural enemies in quarantine. The State of Hawaii needs improved regulations that are thorough, rational, streamlined, efficient, transparent, accountable, and ecologically meaningful.

Acknowledgments

We thank our collaborators for providing new introduced species. We also thank E. Jang, (USDA-ARS Pacific Basin Agricultural Research Center, Honolulu, and USDA-ARS Hilo, Hawaii) for providing insect rearing and test materials, K. Teramoto and M.M. Ramadan (Hawaii Department of Agriculture) for use of quarantine facilities and research support. This research was supported by USDA-ARS grant no. 5853208147 to R.H.M, X.G.W. and A.H.B.

Literature Cited

- Back, E.A., and C.E. Pemberton.** 1918. The Mediterranean fruit fly in Hawaii. US. Dept. Agri. Bull. 536, Washington D.C.
- Bess, H.A., R. van den Bosch and F.H. Haramoto.** 1961. Fruit fly parasites and their activities in Hawaii. Proc. Hawaii. Entomol. Soc. 17: 367–578.
- Bokonon-Ganta, A.H., J.J.M. van Alphen, and P. Neuenschwander.** 1996. Competition between *Gyranusoida tebygi* and *Anagyrus mangicola*, parasitoids of the mango mealybug, *Rastrococcus invadens*: interspecific host discrimination and larval competition. Entomol. Exp. Appl. 79: 179–185.
- Bokonon-Ganta, A. H, M.M. Ramadan, X.G. Wang, and R.H. Messing.** 2005. Biological performance and potential of *Fopius ceratitivorus* (Hymenoptera: Braconidae), an egg-larval parasitoid of tephritid fruit flies, newly imported to Hawaii. Biol. Control. 33:238–247.
- van den Bosch, R., and F.H. Haramoto.** 1953. Competition among parasitoids of the oriental fruit fly. Proc. Hawaii. Entomol. Soc. 15: 201–206.
- Briggs, C.J.** 1993. Competition among parasitoid species on a stage-structured host and its effect on host suppression. Am. Nat. 141: 372–396.
- Clancy, D.W., P.E. Marucci, and E. Dresner.** 1952. Importation of natural enemies to control the oriental fruit fly in Hawaii. J. Econ. Entomol. 45: 85–90.
- Clausen, C.P., D.W. Clancy, and Q.C. Chock.** 1965. Biological control of the oriental fruit fly (*Dacus dorsalis* Hendel) and other fruit flies in Hawaii. USDA Techn. Bull. 1322:1–102, Washington, D.C.
- van Drieseche, R.G., and M. Hoddle.** 1997. Should arthropod parasitoids and predators be subject to host range testing when used as biological control agents? Agri. Human Values 14: 211–226.
- Duan, J.J., M.E. Purcell, and R.H. Messing.** 1996. Parasitoids of non-target tephritid flies in Hawaii: implications for biological control of fruit fly pests. Entomophaga 41: 245–256.
- Duan, J.J., R.H. Messing, and M.F. Purcell.** 1998. Association of the opiine parasitoid *Diachasmimorpha tryoni* (Hymenoptera: Braconidae) with the lantana gall fly (Diptera: Tephritidae). Environ. Entomol. 27: 419–426.
- Gilstrap, F.E., and W.G. Hart.** 1987. Biological control of Mediterranean fruit fly in the United States and Central America. US Dept. Agri. ARS. 56: 1–64.
- Hapai, M.M.** 1977. The Biology and Ecology of the Hamakua Pamakani Gall Fly. Master's Thesis, University of Hawaii at Manoa, Honolulu, 77 p.
- Haramoto, F.H., and H.A Bess.** 1970. Recent studies on the abundance of the oriental and Mediterranean fruit flies and the status of their parasites. Proc. Hawaii. Entomol. Soc. 20: 551–566.
- Hardy, D.E., and M.D. Delfinado.** 1980. Insect of Hawaii. Vol. 13. Diptera: Cyclorrhapha III. Honolulu, HI: University of Hawaii Press, 122–135.
- Howarth, F.G.** 1991. Environmental impact of classical biological control. Annu. Rev. Entomol. 36: 485–509.
- Lopez, M., J. Sivinski, P. Rendon, T. Holler, K. Bloem, R. Copeland, M. Trostle, and M. Aluja.** 2003. Colonization of *Fopius ceratitivorus*, a newly discovered African egg-pupal parasitoid (Hymenoptera: Braconidae) of *Ceratitidis capitata* (Diptera: Tephritidae). Fla. Entomol. 86: 53–60.
- Messing, R.H.** 1995. Status and needs of biological control research for tephritid flies. In B.A. McPherson, and G. Steck. (eds), Economic Fruit Flies: A World Assessment of Their Biology and Management. St. Lucie Press, FL, pp.365–367.
- Messing, R.H.** 1999: The impact of nontarget control on the practice of biological control. In P.A. Follett, and J.J. Duan. (eds.), Non-target Impact of Biological Control. Norwell, MA: Kluwer Academic Publishers, pp.45–55.
- Mohamed, S.A., W.A Overholt, R.A. Wharton, S.A. Lux, and E.M. Eltoum.** 2003. Host specificity of *Psytalia cosyrae* (Hymenoptera: Braconidae) and the effect of different host species on parasitoid fitness. Biol. Control 28:155–163.
- Pemberton, C.E., and H.F. Willard.** 1918. Interrelations of fruit fly parasites in Hawaii. J. Agri. Res. 12: 285–303.
- Purcell, M.F.** 1998. Contribution of biological control to integrated pest management of tephritid fruit flies in the tropic and subtropics. Integrated Pest Manage. Rev. 3: 63–83.
- Purcell, M.F., J.C. Herr, R.H. Messing, and T.T.Y. Wong.** 1998. Interactions between augmentatively released *Diachasmimorpha longicaudata* and a complex of opiine parasitoids in a commercial

- guava orchard. *Biocontrol Sci. Tech.* 8: 139–151.
- Ramadan, M.M., T.T.Y. Wong, and J.C. Herr.** 1994. Is the oriental fruit fly (Diptera: Tephritidae) a natural host for the opiine parasitoids *Diachasmimorpha tryoni* (Hymenoptera: Braconidae)? *Environ. Entomol.* 23: 761–769.
- Steck, G.J., F. Gilstrap, R.A. Wharton, and W.G. Hart.** 1986. Braconid parasitoids of Tephritidae infesting coffee and other fruits in west-central Africa. *Entomophaga* 31: 59–67.
- Vargas, R.I., and T. Nishida.** 1985. Survey for *Dacus latifrons* (Diptera: Tephritidae). *J. Econ. Entomol.* 78: 1311–1314.
- Vargas, R.I., T. Nishida, and J.W. Beardsley.** 1993. Opiine parasitoids (Hymenoptera: Braconidae) of oriental fruit fly (Diptera: Tephritidae) on Kauai island, Hawaii: islandwide relative abundance and parasitism rates in wild and orchard guava habitats. *Environ. Entomol.* 22: 246–253.
- Vargas, R.I., W.A. Walsh, and T. Nishida.** 1995. Colonization of newly planted coffee fields: dominance of Mediterranean fruit fly over oriental fruit fly (Diptera: Tephritidae). *J. Econ. Entomol.* 88: 620–627.
- Wang, X.G., and R.H. Messing.** 2002. Newly imported larval parasitoids pose minor competitive risk to the extant egg-larval parasitoid of fruit flies in Hawaii. *Bull. Entomol. Res.* 92: 423–429.
- Wang, X.G., and R.H. Messing.** 2003. Intra- and interspecific competition by *Fopius arisanus* and *Diachasmimorpha tryoni* (Hymenoptera: Braconidae), parasitoids of Mediterranean fruit fly *Ceratitis capitata* (Diptera: Tephritidae). *Biol. Control* 27: 251–259.
- Wang, X.G., R.H. Messing, and R. C. Bautista** 2003. Competitive superiority of early acting species: a case study of opiine fruit fly parasitoids. *Biocontrol Sci. Techn.* 16: 391–402.
- Wang, X.G., A.H. Bokonon-Ganta, M.M. Ramadan, and R.H. Messing.** 2004. Egg-larval opiine parasitoids (Hym., Braconidae) of tephritid fruit fly pests do not attack the flowerhead-feeder *Trupanea dubautiae* (Dip., Tephritidae). *J. App. Entomol.* 128: 716–722.
- Wharton, R.A.** 1989. Classical biological control of fruit infesting Tephritidae. In A., Robinson, G. Harper (eds), *World Crop Pests. Fruit Flies: Their Biology, Natural Enemies, and Control*, Vol. 3b, Elsevier, Amsterdam, pp. 303–313.
- Wharton, R.A.** 1999. A review of the old world genus *Fopius*, with description of two new species reared from fruit-infesting Tephritidae. *J. Hymen. Res.* 8: 48–64.
- Wharton, R.A., M.K. Trostle, R.H. Messing, R.S. Copeland, S.W. Kimani-Njogu, S. Lux, W.A. Overholt, S. Mohamed, and J. Sivinski.** 2000. Parasitoids of medfly, *Ceratitis capitata*, and related tephritids in Kenyan coffee: a predominantly koinobiont assemblage. *Bull. Entomol. Res.* 90: 517–526.
- Wong, T.T.Y., and M.M. Ramadan.** 1987. Parasitization of the Mediterranean and oriental fruit flies (Diptera:Tephritidae) in the Kula area of Maui, Hawaii. *J. Econ. Entomol.* 80: 77–80.
- van Zwaluwenburg, R.H.** 1947. Notes and exhibitions. *Proc. Hawaii. Entomol. Soc.* 13:8.

Table 1. Recent introductions of tephritid fruit fly parasitoids in Hawaii (February 1996–December 2004).

Species	Family	Origin	Mode of action	Primary target host	Status
<i>Aceratoneuromya</i> sp	Eulophidae	Thailand	Larval-pupal parasitoid	<i>Bactrocera cucurbitae</i>	Lost in quarantine
<i>Aganaspis dacti</i> *	Eucolidae	Greece	Larval-pupal parasitoid	<i>Ceratitidis capitata</i>	Still in quarantine
<i>Diachasmimorpha kraussii</i>	Braconidae	Australia	Larval-pupal parasitoid	<i>Ceratitidis capitata</i> , <i>Bactrocera latifrons</i>	On-going field releases
<i>Fopius ceratitivorius</i>	Braconidae	Kenya	Egg-larval parasitoid	<i>Ceratitidis capitata</i>	Still in quarantine
<i>Fopius caudatus</i>	Braconidae	Kenya	Egg-larval parasitoid	<i>Ceratitidis capitata</i>	Lost in quarantine
<i>Psytthalia concolor</i>	Braconidae	Kenya	Larval-pupal parasitoid	<i>Ceratitidis capitata</i>	Lab holding **
<i>Psytthalia phaeostigma</i>	Braconidae	Kenya	Larval-pupal parasitoid	<i>Ceratitidis capitata</i>	Lost in quarantine
<i>Psytthalia lounsburyi</i>	Braconidae	Kenya	Larval-pupal parasitoid	<i>Bactrocera cucurbitae</i>	Lost in quarantine
<i>Utetes africanus</i>	Braconidae	Kenya	Larval-pupal parasitoid	<i>Bactrocera olea</i>	Lost in quarantine

* Introduced by Mohsen Ramadan for the USDA Area Wide Fruit Fly Project.

** Released from quarantine but not released in the field yet.